

CALIFORNIA'S FIFTH
CLIMATE CHANGE
ASSESSMENT

Climate Impacts to the Economy Statewide Topical Report

A Statewide Topical Report for California's Fifth Climate Change Assessment

Coordinating Agency

CA Governor's Office of
Land Use and
Climate Innovation

About California's Fifth Climate Change Assessment

California's Climate Change Assessments are the state's scientific foundation for understanding future climate-related vulnerability across California's regions and systems. Senate Bill 1320 (Stern, 2020) requires the State to report the impacts and risks of climate change across California at least every five years, beginning with California's Fifth Climate Change Assessment (Fifth Assessment). Building on decades of climate research and previous Assessments, the Fifth Assessment presents new findings about California's climate future, with a dedicated focus on Tribal partnerships, public engagement, and communities most vulnerable to climate impacts.

The Fifth Assessment's research and tools are designed to fill knowledge gaps about California's climate future, inspire strategic climate actions, and shape planning, investments, and policies at the state, regional, and local scales. Guided by research priorities identified by state, Tribal, and local leaders, community representatives, and subject matter experts, its findings are designed to help illuminate potential climate futures, the challenges they may present, and the opportunities to build resilience through adaptation pathways.

For the full suite of Fifth Assessment research products, please visit: www.ClimateAssessment.ca.gov.

Purpose of the Statewide Topical Reports

The Fifth Assessment Statewide Topical Reports highlight issues of statewide significance and how the impacts and risks of climate change affect human and natural systems. These reports deepen our understanding of critical and cross-cutting topics in California, including racial equity and climate justice, climate impacts to tribal and indigenous communities, climate-induced human displacement and migration, and climate impacts to the economy. They also highlight opportunities to build adaptation capacity and resilience to climate impacts in ways that can inform state and local planning, policy, and action, vulnerability assessments, adaptation planning, and community resilience efforts.

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Map of California

Climate Change Assessment Regions

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Any references in this Assessment to the lingering and compounding effects of racism and discrimination are drawn from academic literature and are not factual findings of, or legal determinations by, the State of California or any agencies of the State, of prohibited discrimination in any particular instance. Similarly, any descriptions of potential future harms are not findings of or admissions by the State of California or any agencies of the State.

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The authors acknowledge the use of AI-enhanced search tools to support literature searches for relevant publications, R code troubleshooting, bibliographic assistance, and quality assurance. In all cases, the resulting content, analyses, figures, and code were reviewed and validated by the authors. Thus, the authors take full responsibility for the correctness of the contents of this report.

Executive Summary

- **Climate change is already imposing large and growing economic costs on California,** with the largest monetized damages arising from health and labor impacts (Borgschulte et al., 2024; Carleton et al., 2022a; CDI, 2024; EPA, 2024; Gould et al., 2025; Neidell et al., 2021; Qiu et al., 2025).
- **Economic damages increase nonlinearly with warming,** meaning each additional degree of warming causes larger increases in losses (Burke et al., 2015; Hsiang et al., 2023).
- **Impacts are highly unequal,** with inland regions, low-income households, outdoor climate-exposed industry, children, and older adults facing greater vulnerability (Cal-Adapt, n.d.; Jerrett et al., 2024).
- **Climate shocks cascade and compound across the whole economy.** Impacts don't stay in one sector; instead, they ripple outward with physical damages triggering indirect feedbacks that amplify losses across interconnected social, built, and natural systems.

California's economy is the fourth largest worldwide, ranking behind only China, Germany, and the United States as a whole (PPIC, 2026). Consequently, the economic impacts of climate change in California are of national and global importance. Research indicates that climate change will likely slow the rate of California's long-term economic growth, but the magnitude of the impact on the size of the overall economy is uncertain and remains an area of study (Kahn et al., 2021). The Fifth National Climate Assessment reports that annual gross domestic product (GDP) growth for the nation is projected to slow by around 0.13 percentage points for every 1°F (0.56°C) increase in global average surface temperature (Hsiang et al., 2023). For context, US real GDP growth averaged about 2.2% per year from 2000 to 2024, meaning this projected reduction is equivalent to roughly 6% of recent average annual growth for each additional 1°F of warming (BEA, 2026).

In California, economic vulnerability to climate change is highly uneven across regions, communities, and economic sectors (Carleton et al., 2022a; EPA, 2024). This variation arises from differences in exposure (e.g., baseline temperatures and frequency of extreme events) and in adaptive capacity (e.g., household income or the adoption of cooling technologies) (Carleton et al., 2022a; CDI, 2024).

Implications for California's Households

Climate change can impact household expenses substantially via increased costs for food, power, and water; inflation; home hardening; and increases in insurance premiums and personal expenses (An et al., 2023; Barreca et al., 2022; CPUC, 2024a; Hadachek et al., 2025; Kotz et al., 2024, 2025). Heat and wildfire smoke exposure increase heat-related mortality and morbidity, including emergency department visits, hospitalizations, and chronic cardiovascular and respiratory impacts, contributing to higher healthcare utilization and health insurance costs (CDI, 2024; Gould et al., 2025; Qiu et al., 2025). Energy costs are increasing; utilities are passing wildfire recovery and mitigation costs directly to ratepayers, which directly account for 7% to 12.8% of the average California residential electricity bill (CPUC, 2024). With growing wildfire and flood risks,

home insurance premiums in California increased by more than 23% between 2017 and 2022 and California's FAIR (Fair Access to Insurance Requirements) Plan coverage grew from $50 billion in 2018 to $750 billion as of March 2026 (Boomhower et al., 2024; CFP, 2026). Sea level rise adds the risk of floods to areas with coastal exposure: 20 inches of sea level rise, which could occur as soon as 2050, could inundate an estimated $17.9 billion worth of buildings across California (Grenier & Sencan, 2024). Projected climate-related costs for an American born in 2024 are estimated at $500,000 to $1 million over their lifetime, including higher housing, food, energy, healthcare, transportation, taxes, and lost income (ICF, 2024).

Implications for California's Businesses

Climate-related disruptions can impose significant operational costs on California businesses through foregone revenue from supply chain delays, worker displacement, and declines in worker health and productivity (Feo et al., 2020b; Roh & Alamo, 2022). Extreme heat events and other climate hazards can force businesses to temporarily close or curtail operations to protect worker safety, reducing daily output and increasing labor and operational costs. Power outages, both planned and unplanned, also pose significant costs to businesses; a 14-day heat wave in 2022 triggered power outages resulting in $230 million in lost productivity and foregone revenue for commercial and industrial businesses (CDI, 2024). Highway and road closures from wildfires, flooding, and debris flows create additional disruptions by severing supply chains, delaying the movement of goods and workers, and restricting access to markets and customers, costs that fall disproportionately on businesses in rural communities with fewer alternative routes or suppliers. Over the 2017–2021 period, wildfires were associated with an estimated $60.1 billion in average annual income losses statewide, while the 2025 Palisades and Eaton fires in Los Angeles County were estimated to cause approximately $300 million in wage losses for businesses and workers in affected areas (Paci et al., 2023; Li & Yu, 2025). Highly climate-exposed sectors such as agriculture, forestry, and construction already experience steeper losses than less climate-exposed industries such as information technology (Carleton et al., 2022a; Rode et al., 2022). However, climate adaptation, recovery, and decarbonization are also creating new areas of business activity. In 2024, California had the largest clean energy workforce in the nation, with clean energy employment growing by 1.3% compared with 0.4% growth across the rest of the state economy (E2, 2025).

Implications for California's Governments

Following climate-related disasters, local governments may experience reduced property and sales tax revenues due to declining property values, population loss from displacement, and reduced economic activity, while simultaneously facing higher public expenditures for recovery and service provision (Clark et al., 2025; Congressional Budget Office, 2024a). California's escalating disaster response costs are placing severe strain on state and local budgets. State General Fund costs for fire protection nearly quadrupled from roughly $750 million in 2005–06 to about $2.9 billion in 2020–21; debris removal for the 2018 Camp Fire alone cost an estimated $1.35 billion; and the state approved $2.5 billion in 2025 for Los Angeles fire response and recovery efforts (CDOF, 2025b; Cottom, 2019; Morales et al., 2022). After a disaster, Tribal nations

and smaller municipalities often face capacity constraints, including limited staff, technical expertise, and fiscal resources, which restrict their ability to plan, fund, and implement climate resilience projects and to successfully compete for external funding such as federal grants. Climate change intensifies these fiscal pressures by driving up demand for public services such as emergency health care, shelters, and infrastructure repairs, further increasing municipal outlays. Meanwhile credit markets are beginning to penalize climate-exposed communities with higher borrowing costs and downgraded bond ratings, driving up the cost of the investments needed to build resilience (Butler & Uzmanoglu, 2023; Jeon et al., 2024).

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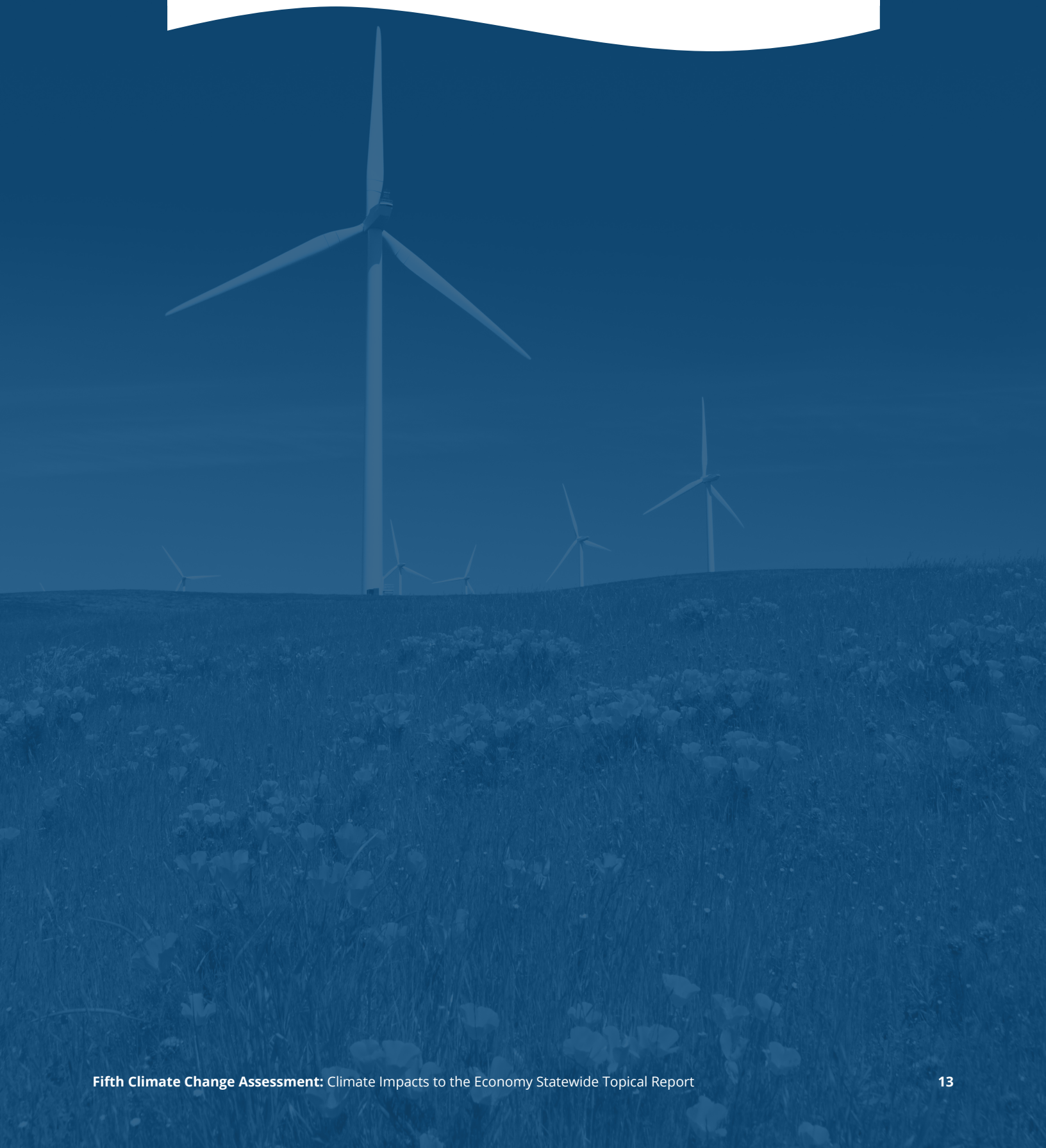
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Introduction



Climate change is accelerating across California. Since the publication of California's Fourth Climate Change Assessment in 2018, California has experienced a series of unprecedented climate disasters (NCEI, 2024). The wildfire record reflects this trend: the three most destructive fires in California history, the 2018 Camp Fire and the 2025 Eaton and Palisades fires, and eight of the state's largest by acreage have all occurred within this period (CAL FIRE, 2024, 2025). Along with experiencing fire, California has faced mounting hydrological extremes, cycling between prolonged drought and damaging floods. From 2020 to 2022, California experienced its driest three-year period on record, based on observations dating back to 1895, compounding the severe drought of 2012–2016 and contributing to continued stress on water supplies, agriculture, and ecosystems (CDWR, 2024a). In the winter of 2022-2023, a series of atmospheric rivers brought torrential downpours that ended the drought, but caused an estimated $4.7 billion in economic losses (NCEI, 2024). While California's natural climate variability contributes to such events, scientific evidence shows that human-caused climate change is increasing their frequency, intensity, and duration, with growing consequences for communities, economies, and ecosystems (Williams et al., 2019; Swain, 2021; Hsiang et al., 2023).

California's economy is the fourth largest worldwide, ranking behind only China, Germany, and the United States as a whole (PPIC, 2026). Consequently, the economic impacts of climate change in California have rippling effects nationally and globally. These impacts permeate every aspect of life—affecting public health, household expenses, labor productivity, business viability, tax revenues, and social stability (Carleton et al., 2016). Importantly, economic impacts from climate change are nonlinear, meaning that each additional increase in temperature can cause increasingly larger health impacts and economic losses (Burke et al., 2015). Climate change impacts and associated economic consequences are projected to be unevenly distributed across regions, industries, and communities in California (Roh & Alamo, 2022).

This report offers an economic valuation of historic and projected impacts of climate change on California across multiple sectors while also highlighting proven adaptation strategies that offer cost-effective responses to climate challenges. The report is part of the broader effort of the California Climate Change Assessments, which are mandated by Senate Bill (SB) 1320 (Chapter 136, Statutes of 2020) to be assembled at least every five years. The Second Assessment, published in 2009, included the State's first comprehensive economic analysis of climate impacts. This report expands and updates that foundational work, providing up-to-date evidence on the scale of economic risks from climate change facing California today.

Box 1: *National Climate Assessment*

California's approach is informed by, and contributes to, broader national efforts to understand and respond to climate change. The National Climate Assessment (NCA) series, mandated by Congress through the Global Change Research Act of 1990, is one of the main mechanisms used to periodically integrate and disseminate research on national climate change trends and impacts. The Fifth NCA (NCA5) was published in 2023 and provided information that agencies, policymakers, and stakeholders can use to support critical decisions on infrastructure, risk management, and economic resilience (Kynett, 2025). However, federal work on NCA6 has been suspended following the April 2025 decision to discontinue funding for the US Global Change Research Program (Reuters, 2025). California's ongoing assessments ensure that decision makers continue to have access to the scientific foundation necessary for effective statewide adaptation and resilience planning. The contents of NCA5 can be found on the US Climate Resilience Toolkit's website.

Scope of Report

This report examines the direct and indirect economic effects of climate change across key sectors of California's economy, synthesizing evidence from peer-reviewed academic research, government agency reports, and analyses by private and nonprofit organizations. The analysis is organized into three interconnected systems that together encompass much of California's economic landscape:

- **Social Systems:** This section focuses on human-centered economic activities, including public health costs, labor productivity and workforce dynamics, educational infrastructure and outcomes, and government operations and fiscal capacity.
- **Built Systems:** This section addresses the critical infrastructure that underpins economic activity, encompassing real estate markets and property insurance, transportation networks, and water and energy systems.
- **Natural Systems:** This section examines sectors that are heavily dependent on natural resources, including agriculture, fisheries, forestry, and tourism, which face direct exposure to changing temperature, precipitation, and fire patterns.

Scope Limitations

This report does not address sector-specific carbon emissions profiles, decarbonization strategies, or policy recommendations for reducing state greenhouse gas emissions. Instead, it focuses on the economic consequences of climate impacts, complementing other state assessments that examine emissions reduction and clean energy transition strategies such as CARB's 2022 Scoping Plan for Achieving Carbon Neutrality and its ongoing update process.

This report draws on rigorous quantitative evidence of economic impacts, including monetized estimates of damages and costs associated with climate change-related hazards. Where possible, it also describes the costs and benefits of adaptation actions that households, businesses, and government can take. Importantly, the analysis is limited by the available quantitative evidence. It is not an exhaustive inventory of all climate-related economic impacts in California, nor does it cover all options for adaptation. In many cases, these impacts and adaptation costs and benefits are difficult to measure because of data gaps or methodological challenges.

For California Native American Tribes, climate-related economic impacts may extend beyond property damage and market losses to include harms to cultural sovereignty, food sovereignty, culturally significant landscapes, traditional food systems, and stewardship responsibilities. These impacts may not be fully captured in standard economic assessments. For more information, refer to the Fifth Assessment's "Tribal and Indigenous Communities Statewide Topical Report".

Box 2: *The Challenge of Estimating Statewide Gross Domestic Products Impacts*

The Congressional Budget Office projects that the US GDP in 2100 will be about 4% lower under climate change than it would be if temperatures remained at 2024 levels (Congressional Budget Office, 2024b). Similarly, the Fifth National Climate Assessment estimates that national annual GDP growth will slow by approximately 0.13 percentage points for every 1°F (0.56°C) increase in global average surface temperature (Hsiang et al., 2023). No comparable set of estimates yet exist for California's statewide, economy-wide GDP impact.

Estimating the magnitude of climate change's effect on future GDP remains challenging because damages vary across sectors and regions, adaptation may reduce or redistribute impacts over time, and long-term projections depend on uncertain future emissions, climate conditions, and economic trends. This is even more challenging at the state level because of inter-state economic linkages and because statistical power is reduced when estimating climate impacts on smaller geographies. Nevertheless, the available research consistently indicates that rising temperatures are expected to reduce the size of state and local economies over time, although the precise magnitude remains uncertain (Colacito et al., 2019; Kahn et al., 2021). **Appendix B** discusses these sources of uncertainty in greater detail, and Appendix C summarizes example estimates of climate-related economic damages in California.

Sources of Climate Risk

Climate risks in California arise largely from extreme heat, shifting precipitation patterns, wildfires, and sea level rise. These main climate hazards affect economic activity in unique ways. Each chapter of this report emphasizes the more impactful and destructive climate hazards for each sector.

Temperatures: Annual average temperatures in California have increased by 2.5°F (1.39°C) since 1895, with the rate of warming intensifying significantly during the last 30 years (Kosmala-Dahlbeck et al., 2025). According to California's Fifth Climate Change Assessment (the Fifth Assessment)'s LOCA2 Hybrid downscaled climate projections, compared to a 1981–2010 baseline, temperatures are expected to rise by another 4.0°F (2.2°C) by mid-century (2041–2070); by the end of the century, this increases to 5.2–6.5°F (2.9– 3.6°C) under moderate- to high-emissions scenarios. Extreme heat events are also expected to intensify and become more frequent. For instance, Fresno is projected to experience 43 extreme heat days annually by 2050–2099, compared to just 4.3 days historically (Scripps, 2025).

Variable Precipitation: California has experienced increasingly severe and persistent drought conditions in recent decades, including the 2012–2016 drought, followed by an even drier three-year period from 2020 to 2022—the driest on record in observations dating back to 1895—contributing to continued stress on water supplies, agriculture, and ecosystems (CDWR, 2024a). By late-century, droughts that historically occurred once every 20 years are expected to occur once every 10 years, and once-in-a-century droughts may occur about once every 20 years (Pierce et al., 2018; Hilberg & Kershner, 2021). Hotter and drier conditions are projected to cut the Sierra Nevada snowpack by more than one-third by 2050 and by over half by 2100, reducing both surface and groundwater supplies (Climate Resilience California, 2024).

These drying trends are expected to be accompanied by more intense wet-season storms, especially atmospheric rivers, which can bring heavy rainfall after prolonged dry periods and increase flood damages (CDWR, 2024a). Atmospheric rivers have caused an estimated $620 million

per year in flood damages in California, on average, between 1978–2017 (Corringham et al., 2019). The Winter 2023 Storm event, comprising nine atmospheric rivers, caused an estimated $4.7 billion in economic damages in California (NCEI, 2024). Research projects that atmospheric rivers will carry increasing moisture loads and drive more extreme precipitation events, even as overall precipitation frequency declines (Gershunov et al., 2019).

Wildfires: Climate change is extending California's wildfire seasons, driving earlier seasonal onset and longer duration, alongside projected increases in chronically extreme fire-weather conditions (Madakumbura et al., 2025). Climate change has contributed to approximately 50% of the observed increase in vegetation dryness, or fuel aridity, which has driven a doubling of the cumulative area burned by forest fires since 1984 (Williams et al., 2019). Average annual wildfire losses in California totaled $117.4 billion between 2017–2021, across direct and indirect losses (Paci et al., 2023), while wildfire smoke exposure from 2008–2018 contributed between 52,000–56,000 premature deaths statewide (Connolly et al., 2024). Researchers estimate that under a moderate-emissions scenario (SSP2–4.5), the average area of forest burned annually by summer wildfires in northern and central California could more than double by 2031–2050, relative to the 2002–2021 average (Turco et al., 2023).

Sea Level Rise: By 2050, California's sea level is projected to rise by an average of 0.8 feet (0.24 meters), and by 1.6–3.1 feet (0.5–0.95 meters) by 2100, according to the State of California Sea Level Rise Guidance: 2024 Science and Policy Update (Adusumilli et al., 2024). A sea level rise of 1.6 feet (0.5 meters) could inundate $17.9 billion worth of buildings statewide (Barnard et al., 2019). By 2100, as much as $150 billion in coastal property and over 600,000 people could be subject to dynamic flooding events (Barnard et al., 2019). Some of the most at-risk areas are the Humboldt Bay Area, San Francisco Bay Area, and parts of Southern California where cliff erosion rates exceed the state average (Adusumilli et al., 2024; Barnard et al., 2019). Estimates that combine sea level rise with storm surge, and that count infrastructure as well as buildings, are considerably larger. One regional assessment identified over $230 billion in parcel value and roadway adaptation costs at risk in the San Francisco Bay Area alone under 1.4 feet of sea level rise combined with a 100-year storm (MTC, ABAG, & BCDC, 2023). This figure is not directly comparable to the statewide estimate above, which reflects buildings inundated by sea level rise alone.

Cascading and Compounding Impacts

Cascading impacts occur when one climate hazard triggers a chain of effects that spread beyond the initial event, including through disruptions to critical supply chains and other interconnected systems. For example, extreme heat can create cascading impacts: high temperatures increase electricity demand for cooling, strain the power grid, raise the risk of outages, and potentially leave households without air conditioning or refrigeration when cooling is most critical. A single day of exposure to extreme heat, or severe wildfire smoke, can have long term health impacts; repeated exposures can place growing pressure on healthcare systems, reduce worker productivity, and strain household budgets (Chen & Li, 2023; Ehlers, 2022).

Compound climate impacts occur when multiple hazard events happen close together, overlap, or interact in ways that amplify damage and create broader economic disruption than any single hazard would cause on its own (Bowers et al., 2024; Ehlers, 2022). For instance, when a multi-year drought is followed by intense precipitation, dry soils are less able to absorb water and flash

floods form, amplifying flood damages to critical infrastructure and property (Mullens & Engström, 2025). Heat, drought, and wildfire can also interact as a compound hazard, as extreme heat intensifies drought stress and dries vegetation, while prolonged drought increases fuel aridity, together creating conditions for larger or more severe wildfires.

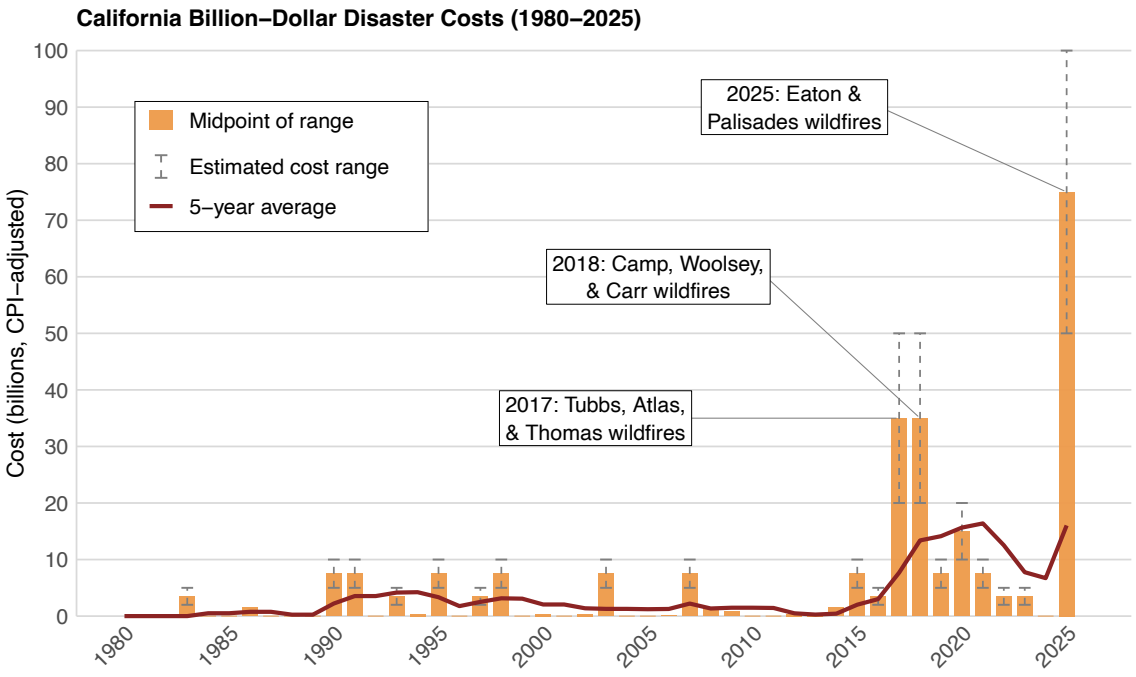
Increasing Extreme Climate Events and Damages

California has experienced more frequent and severe extreme weather events with damages exceeding $1 billion per event, as shown in **Figure 1** (NCEI, 2024). The frequency and cost of these events have escalated sharply in recent years, highlighting the growing economic burden of climate-related hazards. Since the release of California's Fourth Climate Change Assessment (the Fourth Assessment) in 2018, there have been 13 climate disaster events with losses that have exceeded $1 billion in California (Climate Central, 2026). These events highlight the growing fiscal exposure of state and national economies to climate-related shocks. Notably, these billion-dollar disaster events do not include extreme heat events, since most heat waves are not tied to insured property damage, which is a major factor in qualifying as a billion-dollar disaster (NCEI, 2024).

These extreme climate events are strongly linked to human-caused climate change (Barnes et al., 2025; Turco et al., 2023; Vicedo-Cabrera et al., 2021). For instance, anthropogenic warming made the conditions for the January 2025 Los Angeles wildfires an estimated 35% more likely (Barnes et al., 2025). Between 1996–2021, anthropogenic (human-influenced) climate change has been linked to increases in California's wildfire burned areas by 320%, beyond what natural variability alone would have caused (Turco et al., 2023). Additionally, attribution research has also linked anthropogenic warming to greater heat-related mortality, reduced drought recovery, accelerating sea level rise, and heavier atmospheric-river precipitation (Vicedo-Cabrera et al., 2021; Williams et al., 2024; IPCC, 2021; Huang et al., 2020).

The Role of Adaptation

The degree to which climate change generates economic impacts on households, businesses and society as a whole depends not only on the magnitude of physical hazards, but also on the exposure, vulnerability, and adaptive capacity of affected communities, infrastructure, ecosystems, and economic sectors. Different locations will be exposed to different climate-related hazards, but even the same climate stressor can produce different economic outcomes across locations depending on the assets and populations exposed, the sensitivity of local systems, and whether households, businesses, local governments, and public agencies have the resources, information, institutional capacity, and technology needed to respond and reduce risks over time. Adaptive capacity varies across California by region and sector, which means climate damages reflect not only where hazards occur, but also who can prepare for, absorb, and recover from them. To the extent the evidence allows, this report identifies sector-specific adaptation options and their potential to reduce damages. However, more research is needed on the cost-effectiveness and limits of different adaptive responses, including the investments and technologies that could expand feasible adaptation options across regions and sectors.

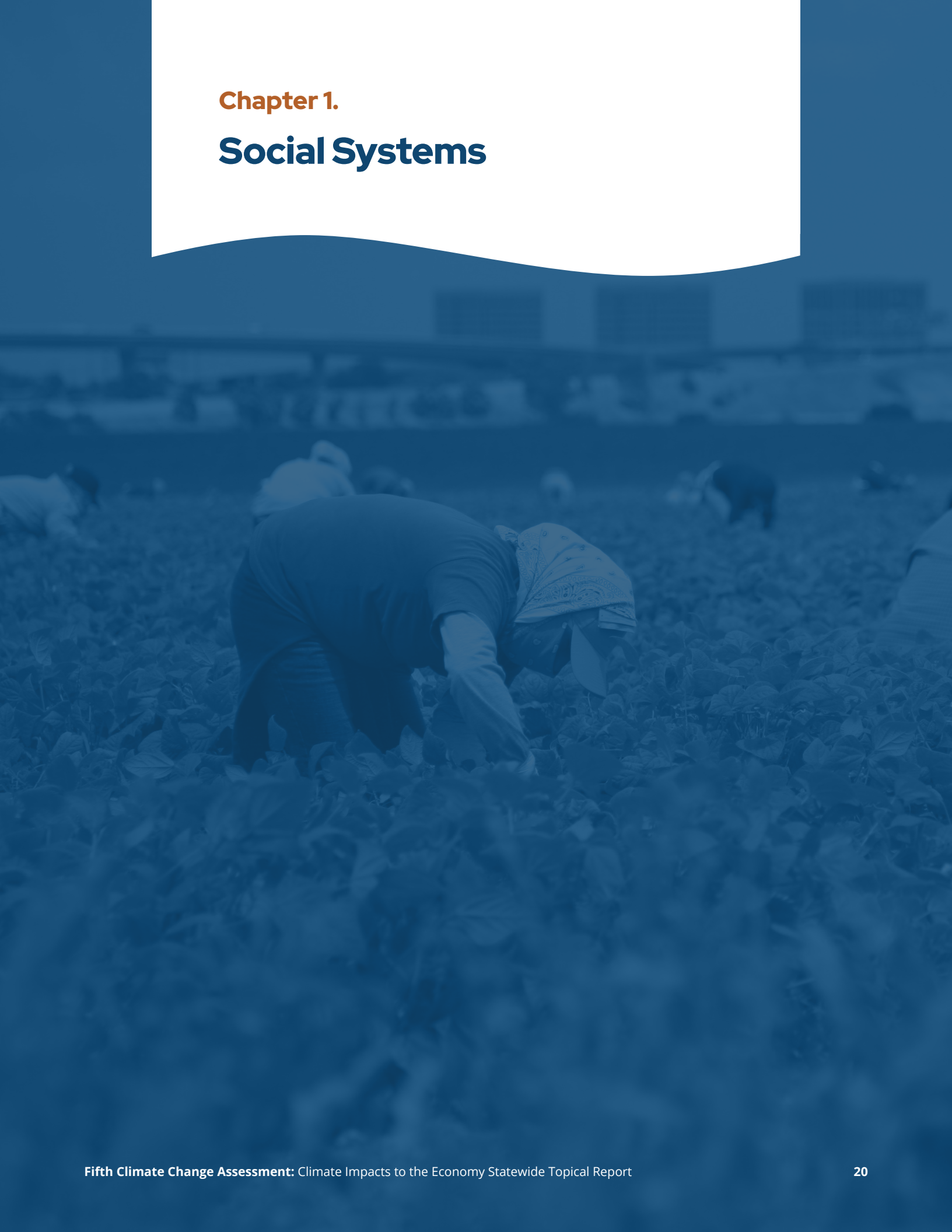


Billion-Dollar Disasters in California 1980-2024

Figure 1: *Rising average cost of billion-dollar weather and climate disasters (wildfire, drought, flooding, and freezes) in California over the past 45 years, from 1980–2025. Source: (NCEI, 2024; Li & Yu, 2025).*

Chapter 1.

Social Systems



Climate change is altering key environmental conditions that shape where Californians live and work, their health and wellbeing, and how public institutions operate under growing climate stresses. Rising temperatures, more frequent and severe extremes, and compounding hazards such as wildfire smoke, flooding, and drought interact with social and economic conditions to influence mortality risk, patterns of illness and injury, and demand for health and emergency services (Brown & Petek, 2022; Carleton et al., 2022a; CDI, 2024; Liao & Kousky, 2022). The most vulnerable to these climate-risks include communities with lower incomes, communities of color, outdoor workers, people experiencing homelessness, children, older adults, and people with underlying health conditions who often face higher exposure with fewer resources to adapt (OPR, 2018).

This Social Systems chapter examines how impacts of climate change translate into broader economic impacts on people, both immediately and over the long run, across health, work, education, and government. It assesses pathways through which climate change affects mortality, morbidity, labor supply and productivity, workforce safety, student learning, and the fiscal position of state, local, and Tribal governments.

1. Health

Key Takeaways

1. **Health impacts are among the largest components of monetized climate damages.** Across seven major California heat events between 2013–2022, premature mortality accounted for approximately 460 deaths and over $5 billion in estimated social welfare costs (CDI, 2024). Older adults and outdoor workers bear the greatest risks, facing higher heat-related death rates, hospitalizations, and economic hardship from lost wages (Brown & Petek, 2022; Carleton et al., 2022a; CDI, 2024). These impacts are not distributed evenly: inland regions of the state face the greatest health risks from rising temperatures (Cal-Adapt, n.d.).
2. **Health harms from heat and wildfire smoke last well beyond the disaster period.** Lingering health impacts from climate-hazard exposure, including heat exposure during pregnancy or early childhood, can lead to years of increased healthcare costs, developmental challenges, and reduced earning potential (Chersich et al., 2020; Foo et al., 2024; Picciotto et al., 2024). These long-term costs are not captured in standard disaster reports, yet they accumulate across households and public systems (Cherry et al., 2021; Heft-Neal et al., 2023; Qiu et al., 2025; Vicedo-Cabrera et al., 2021).
3. **Health shocks ripple across the entire economy.** Heat and smoke reduce on-the-job productivity and raise injury risks for climate-exposed outdoor workers, lowering earnings while increasing demand on public spending programs including workers' compensation (Park et al., 2021). Worsening population health increases public and private healthcare costs, strains hospital capacity, reduces consumer spending, and slows economic growth as more households face missed workdays and long-term health burdens. Some healthcare systems also face higher

borrowing costs tied to climate risk, raising capital expenses, and per-patient costs in highly exposed regions (Carleton et al., 2022a; Lopez et al., 2024).

Climate change represents a significant public health challenge facing California, with extreme heat waves and wildfire smoke being the two most deadly health stressors (Brown & Petek, 2022; EPA, 2021). Vulnerability to heat-related health impacts arises from three components: the extent of exposure to high temperatures, the sensitivity of individuals or populations to heat, and their adaptive capacity to cope with or respond to heat stress (Manangan et al., 2016). Some places will face more frequent or intense high-temperature events, and some will differ in their ability to mitigate heat because of infrastructure, housing characteristics, air-conditioning penetration, and baseline preparedness.

Heat and wildfire smoke exposure can lead to both acute and chronic conditions that increase healthcare and health insurance costs. Prolonged heat stress is associated with chronic kidney disease and increased risk of heart disease, stroke, and arrhythmias, while wildfire smoke exposure can impair respiratory function up to ten years after the initial exposure (Aguilera et al., 2021; Cherry et al., 2021; Moyce et al., 2020; Qiu et al., 2025). When the two hazards occur together, their effects compound, amplifying risks of hospitalization and premature death (Chen et al., 2024; Qiu et al., 2025; Rahman et al., 2022). For more information on the impacts of climate change on public health, see the Fifth Assessment's "Public Health" report prepared by the California Department of Public Health.

1.1 Climate Change and Mortality Risk

Globally, mortality is the largest driver of projected climate-related economic losses, with a substantial share of costs linked to premature deaths associated with extreme heat and wildfire smoke (Carleton et al., 2022b; Connolly et al., 2024). Mortality plays an especially important role in estimates of climate-related economic damages once the costs of adapting to avoid increases in mortality risk are taken into account (Carleton et al., 2022b).

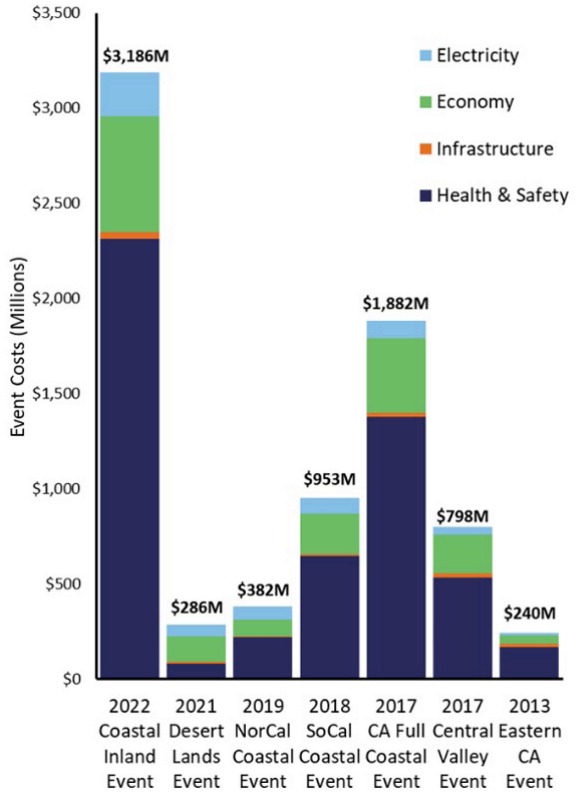
To quantify these mortality-related economic losses, economists use the value of a statistical life (VSL), an approach to valuing mortality risk reductions based on estimates of individual willingness to pay (HHS, 2025). VSL provides a dollar estimate of benefits for an avoided premature death, calculated as the amount that a large group of people would collectively be willing to pay for a reduction by one death in mortality risk across the population (CARB, 2023). Importantly, this estimate does not reflect specific costs associated with mortality, such as hospital expenditures, but rather aggregated societal preferences for risk reduction (CARB, 2023). VSL estimates are periodically updated to account for inflation, income growth, and evolving empirical evidence. In 2000, the US Environmental Protection Agency's economic guidelines recommended a VSL of approximately $6.2 million in 2000 dollars. In comparison, the US Department of Health and Human Services uses a central VSL estimate of $13.7 million in 2026 analyses, which is projected to increase over time at a real annual growth rate of 1.1%, consistent with long-term earnings growth (HHS, 2025; Viscusi & Aldy, 2003). Even relatively small changes in mortality risk can translate into large estimated economic damages when applied across large populations.

1.1.1 Heat-Related Illness and Mortality

Extreme heat can cause heat-related illnesses, worsen chronic health conditions, increase hospitalizations and emergency room visits, and has been linked to adverse pregnancy outcomes and declines in mental health (Basu et al., 2008; Chersich et al., 2020; Thompson et al., 2018). The relationship between climate and mortality is highly uneven and nonlinear: as temperatures rise, death rates increase more steeply in some places than in others, depending on socioeconomic conditions, housing quality, and access to healthcare (Burke et al., 2015; Carleton et al., 2022a). The Central Valley and Inland Desert regions face the greatest mortality risks from rising temperatures in California. Under a moderate-emissions scenario (RCP 4.5), projections indicate that extreme heat could result in an additional 15–20 deaths per 100,000 residents in the inland desert regions by 2050 (Carleton et al., 2022a).

Across all ages, even a moderately hot day between 86–93.2°F (30–34°C) has been shown to increase monthly emergency department visits for a wide range of symptoms and health conditions by 0.5–1% (Gould et al., 2025). Older adults are especially at risk: in the last two decades, Californians aged 65 and older experienced the greatest increase in hospitalizations of any age group due to temperature extremes, with mortality rates rising at both very high and very low temperatures (Gould et al., 2025). Children under five have also shown heightened vulnerability, accounting for a disproportionate share of emergency room visits during heat events (Gould et al., 2025). Studies have found that an extra day with mean temperatures above 89.6°F (32°C) in utero and in the first year after birth is associated with a 0.1% reduction in adult annual earnings at age 30 (Isen et al., 2017).

The California Department of Insurance quantified losses from seven major extreme heat events in California between 2013–2022 at $7.7 billion, spanning health impacts, economic losses, infrastructure damage, and energy disruption, as shown in **Figure 2** (CDI, 2024). Health impacts across the seven events included approximately 460 excess deaths, 5,000 hospitalizations, 10,600 emergency department visits, and 344 adverse birth outcomes (CDI, 2024). Premature mortality accounted for the largest share of costs, with social welfare losses ranging from $77 million to $2.2 billion per event, accounting for more than $5 billion across all seven events (CDI, 2024; HHS, 2025).



Estimated Costs by Category for the Seven Extreme Heat Events

Figure 2: *Estimated costs of seven extreme heat events across four categories: electricity, economy, infrastructure, and health and safety. Note that health and safety represent a significant portion of these costs. Source: (CDI, 2024)*

Box 3: *Health Impacts of Climate-Driven Ozone Increases*

Warming temperatures are associated with increases in ground-level ozone by accelerating the photochemical reactions between nitrogen oxides and volatile organic compounds (Fu & Tian, 2019). Climate-driven increases in ground-level ozone may lead to an estimated 550 additional premature deaths per year nationwide by 2050 under a moderate-emissions scenario (RCP 4.5), with estimates ranging from 300–810 additional deaths (EPA, 2017). This corresponds to $4.1–$11.1 billion in mortality-related economic damages annually, when applying a VSL of $13.7 million.

Box 4: *Adaptive Health Responses to Mitigate Effects of Extreme Heat*

Multiple adaptation options are available to households, businesses, and jurisdictions to reduce adverse health impacts of extreme heat. These options span investing in cooling technology, providing heat alerts and action plans, urban and building design, income support, and providing access to healthcare. However, not all interventions are supported by rigorous evidence of impact on health outcomes (Burke et al., 2025).

Providing information about extreme temperatures, including heat alerts, can reduce health impacts of extreme heat, though the evidence is mixed (Benmarhnia et al., 2016, 2019; Burke et al., 2025). The effectiveness of cooling centers has not yet been rigorously evaluated in reducing heat-related health outcomes (Burke et al., 2025).

Heat resilience depends on heat-specific interventions, such as passive and active cooling, alerts, and public health messaging, as well as broader systems that shape adaptive capacity, including affordable energy access, reliable electricity, healthcare access, income support, and worker protections (Burke et al., 2025). Across the US, the spread of residential air-conditioning ownership since the 1960s has substantially reduced heat-related mortality—a 10 percentage-point increase in residential AC ownership was associated with about a 10% reduction in heat-related mortality risk (Barreca et al., 2016; Jerrett et al., 2024). Affordable energy access and reliable electricity are central to broader adaptive capacity. Studies find that higher residential energy costs can worsen temperature-related mortality by constraining heating or cooling use (Barreca et al., 2022; Chirakijja et al., 2023). Reliable electricity is also a health protection because outages during extreme heat can interrupt cooling, medical devices, refrigeration, and health services. Evidence shows that power outages also increase heat-related mortality and heat-related ambulance attendances (Ai et al., 2026; Xu et al., 2025).

Healthcare access also shapes heat resilience by improving access to acute care, insurance, and community health services during periods of elevated risk. In the US, the rollout of community health centers across counties in the 1960s and 1970s reduced the harmful effect of heat on mortality by an estimated 14% (Burke et al., 2025; Mullins & White, 2020). These findings suggest that investments in routine healthcare capacity can reduce climate-related health risks even when they are not designed specifically as climate adaptation measures.

Worker protections provide a more directly targeted adaptation pathway. California's Heat Illness Prevention Standard for Outdoor Places of Employment requires outdoor employers to provide heat illness training, drinking water, shade, cool-down rest periods, emergency response procedures, and additional high-heat protections when temperatures reach 95°F (35°C). Evidence shows that the standard was associated with a 75–90% reduction in the effect of extreme heat on workplace injuries in targeted industries, making it one of the clearest California-relevant examples of a heat adaptation policy with measured occupational health benefits (Park et al., 2021).

Heat resilience is also shaped by neighborhood and built-environment conditions. Passive cooling and urban greening can reduce heat exposure, although causal evidence linking these interventions to reduced heat-related mortality at scale is lacking and remains a key research priority (Bhamare et al., 2019; Han et al., 2024). Evidence across heat waves, hurricanes, and wildfires shows that households in neighborhoods with stronger social ties and higher social capital experience lower mortality rates, stronger mental health resilience, and faster recovery, independent of socioeconomic status (Aldrich & Meyer, 2015; Rosenthal et al., 2021).

Together, this evidence suggests that reducing heat-related health risks requires both targeted heat protections and broader investments in energy affordability, electricity reliability, healthcare access, worker safety, social cohesion, and heat-resilient buildings and neighborhoods.

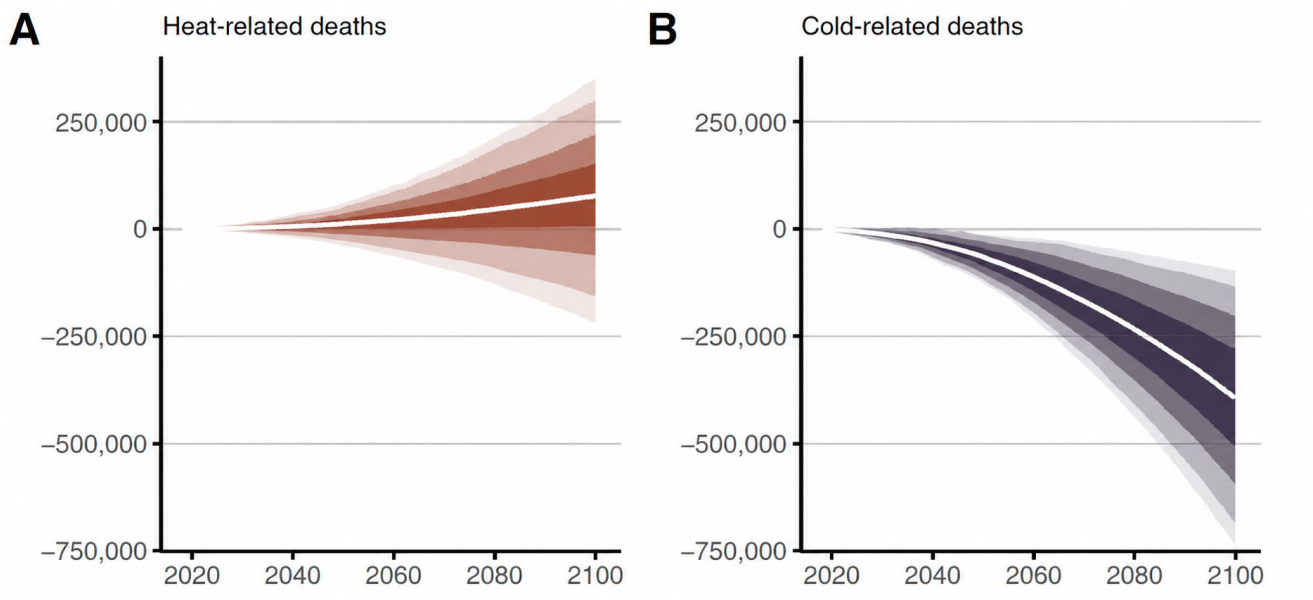
PROJECTED ECONOMIC BURDEN OF HEAT-RELATED MORTALITY

As California's climate continues to warm, extreme heat events are projected to become more frequent and prolonged, posing growing risks to public health. In the Central Valley, heat events that historically lasted 2–3 days could extend to nearly two weeks by 2050 (Brown & Petek, 2022; CNRA, 2025). Across the state, warming temperatures are projected to cause about 560 additional heat related deaths per year in California by 2050, increasing to 703 additional deaths per year by 2100, under a middle-of-the-road emissions scenario (SSP 2–4.5) (Gould et al., 2025). Using a 2026 VSL of $13.7 million, these additional deaths correspond to roughly $7.7 billion in economic losses per year by 2050 and $9.6 billion per year by 2100.

While heat-related deaths are projected to rise across all scenarios and studies, the net effect on temperature-related mortality in California is contested because warming is also projected to reduce cold-related deaths in winter. A recent California-specific study estimates that, under a middle-of-the-road emissions scenario (SSP2–4.5), projected reductions in cold-related deaths outweigh increases in heat-related deaths, resulting in a net decrease in total temperature-related mortality in California, as shown in **Figure 3** (Gould et al., 2025).

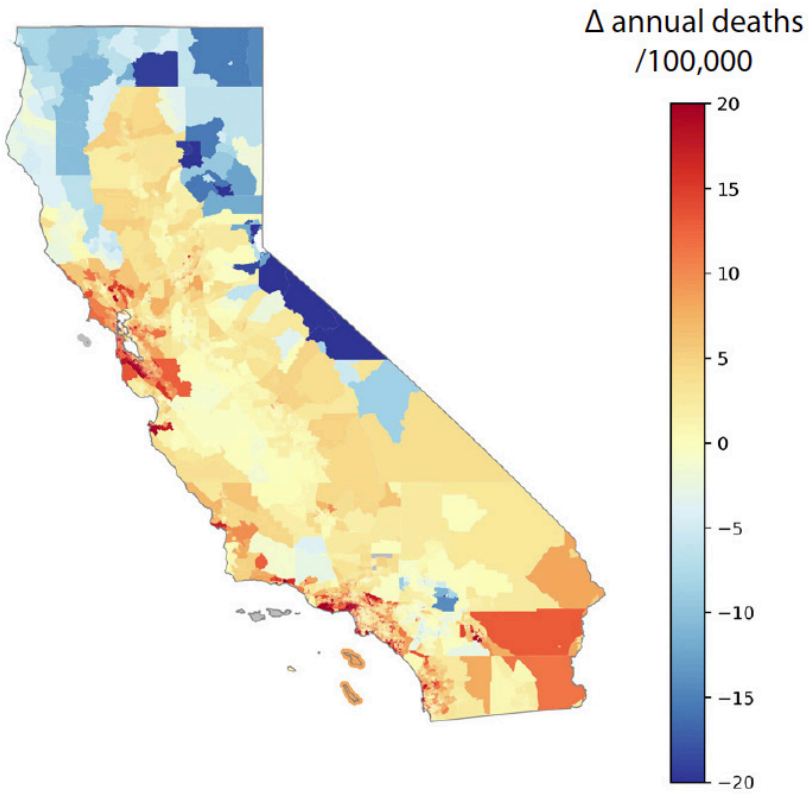
In contrast, a study introducing the California Climate Vulnerability Metric (CVM) finds that mortality damages remain a dominant component of climate vulnerability in most of the state, with some reduced cold-related mortality limited to northern and high-elevation areas, as shown in **Figure 4** (Carleton et al., 2022a). The CVM applies a globally representative mortality-temperature framework—one that varies the temperature-mortality relationship by income levels and by baseline temperatures—to California census tracts under RCP 4.5 (Carleton et al., 2022a, 2022b).

How much climate change will increase heat-related mortality in California, and whether these increases will be larger or smaller than decreases in cold-related mortality, remain areas of active research. Estimates across studies differ for two main reasons: whether the underlying dose-response relationship is California-specific or estimated from national or global data and whether the costs of adapting to avoid deaths are counted alongside the deaths themselves. Regardless of the overall change in temperature-related mortality, studies agree that heat-related mortality will increase and adaptation efforts to limit it are important.



County-Level Projections of Heat- and Cold-Related Mortality in California, 2020–2100

Figure 3: *Projected changes in heat-related mortality (A) and cold-related mortality (B) in California, 2020–2100, under a middle-of-the-road emissions scenario (SSP2–4.5). Under this scenario, emergency department visits and heat-related deaths rise with warming, while cold-related deaths decrease. Bands reflect uncertainty across climate models. Source: Gould et al., 2025*



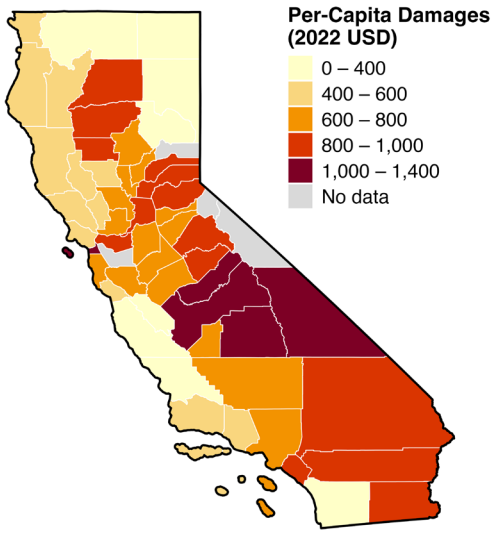
Human Mortality Impacts from Climate Change in Annual Deaths Per 100,000 Population in 2050

Figure 4: *Median estimates of the changes in mortality rates (deaths per 100,000 people) due to climate change in 2050 under a moderate emissions scenario (RCP 4.5). The greatest increases in human mortality risk from warming are projected to occur in California's major population centers, including the San Francisco Bay Area and greater Los Angeles region, as well as in the Central Valley and southeastern parts of the state. Meanwhile, many areas in Northern California may see mortality risk decrease, due to milder winters. Source: (Carleton et al., 2022a)*

Box 5: *Framework for Evaluating Damages and Impacts Projected Climate-Mortality Estimates*

The Framework for Evaluating Damages and Impacts (FrEDI) provides monetized estimates of climate damages by degree of warming, drawing on a synthesis of sector-specific impact models across the US (EPA, 2024). FrEDI is a peer-reviewed, reduced-complexity model that was developed and disseminated by the Environmental Protection Agency (EPA) for estimating climate-related physical and economic damages in the US. At 3°F (1.67°C) of global warming relative to the 1986–2005 baseline, FrEDI provides a common metric for comparing the relative magnitude of climate-driven economic damages across sectors and regions. For context, 3°F (1.67°C) of warming by 2100 is most comparable to the low-radiative forcing and strong-mitigation pathway RCP 2.6, which projects roughly 2.7–3.6°F (1.5–2.0° C) of global warming by 2100.

Figure 5 presents projected annual damages from excess climate-related mortality per-person in California under 3°F (1.67°C) of warming (EPA, 2024). As shown, under a low-emissions pathway, projected annual damages from excess climate-related mortality range from $0 to $400 per person in some coastal areas and exceed $1,000 per person in the most impacted inland regions. The largest burdens fall on the Central Valley and southeastern interior counties. In a high-risk county such as Fresno, these per-capita damages translate to approximately $1 billion to $1.4 billion in annual economic losses county-wide from climate-related deaths alone, based on its current population of roughly one million residents. While **Figure 4** and **Figure 5** both describe climate-related mortality impacts, they differ in time horizon (2050 vs. 2100), emissions scenario, geographic resolution, and unit of analysis, so the magnitudes are not directly comparable.



Projected Per-Capita Annual Damages Due to Excess Mortality Under 3°F of Warming, by County

Figure 5: *These projections are estimates of annual economic damages in a scenario where the population is constant over time and, by 2100, global surface temperature increases by 3°F (1.67°C) relative to the 1986–2005 baseline, comparable to pathway RCP 2.6, a low radiative-forcing pathway. Damages are highest in inland counties, where higher heat exposure contributes to greater projected health risks. This figure uses information from the 5th National Climate Assessment and the US EPA Framework for Evaluating Damages and Impacts (FrEDI) analysis (Barreca et al., 2016; Deschênes & Greenstone, 2011; EPA, 2024; Hsiang et al., 2017, 2023).*

1.1.2 Wildfire Smoke's Impact on Health

Wildfire-smoke-driven mortality represents a major component of climate damages, with recent research showing that the monetized impacts of smoke-related deaths can rival or exceed those from other climate hazards at the national scale (Qiu et al., 2025). One reason wildfire smoke has such large health impacts is that fine particulate matter with a diameter of 2.5 µm or less (PM2.5)

in wildfire smoke is up to 10 times more harmful than PM2.5 in ambient air pollution from other sources—including traffic, freight, industry, and agriculture—and it results in higher rates of respiratory hospitalizations (Aguilera et al., 2021; Busiek, 2024; Chen et al., 2021). Wildfire smoke contributes to asthma, cardiovascular disease, and premature deaths by increasing inflammation, oxidative stress, and weakening immunity (Brown & Petek, 2022; Reid & Maestas, 2019). Wildfire smoke also degrades indoor air quality, with one study finding that average indoor PM2.5 levels in the San Francisco and Los Angeles areas nearly tripled during wildfire events (Liang et al., 2021).

Between 2008–2018, wildfire smoke-related PM2.5 in California caused an estimated 52,000 to 56,000 premature deaths, with an economic value of lost life ranging from $432 billion to $456 billion (USD, 2015; Connolly et al., 2024). In 2020, the compounded occurrence of the largest wildfire season in California's modern recorded history, with 4.3 million acres burned, and exposure to the COVID-19 pandemic created dual respiratory impacts (Cal FIRE, 2020). Across 92 counties in California, Washington, and Oregon, PM2.5 from wildfire smoke during the 2020 fire season was associated with an estimated 19,742 excess COVID-19 cases (95% CI: 7,062–31,310) and 748 excess COVID-19 deaths (95% CI: 398–1,102) (Zhou et al., 2021).

California is projected to see the largest increase in wildfire-smoke-related mortality of any US state by 2050, with smoke PM2.5 projected to contribute to 5,060 excess deaths per year under a high-warming scenario (SSP3–7.0), compared with the 2011–2020 baseline (Qiu et al., 2025). By 2050, wildfire smoke may account for 24% of California's population-weighted PM2.5, meaning that nearly one quarter of fine-particles that people are exposed to in the state will come from wildfires rather than other emission sources (Qiu et al., 2025). Because wildfire-smoke PM2.5 is treated as a separate category from regulated anthropogenic PM2.5 in many air-quality and emissions inventories, these growing smoke-driven exposures are often not fully reflected in traditional emissions-reduction accounting and planning. In fact, in 2020 alone, wildfires in California emitted about 127 million metric tons of CO□-equivalent, nearly double the greenhouse gas reductions California achieved between 2003–2019 (Jerrett et al., 2022).

Estimates indicate that across the continental US, the combined health and economic burden of wildfire-related PM2.5 mortality and morbidity will rise sharply, from about $7 billion per year in the historical baseline to roughly $36 billion per year by 2090 under a moderate emissions scenario (RCP4.5) (Neumann et al., 2021). These trends indicate that without significant intervention, the health impacts of wildfire smoke will continue to escalate, straining healthcare systems and driving up public and private costs.

Box 6: *Economic Valuation of Daily Smoke Exposure*

Estimates of the economic cost of wildfire smoke exposure vary widely depending on methodology. Cost-of-illness approaches indicate that daily per-person impacts are approximately $9.50, while willingness to pay estimates to avoid a day of smoke exposure range from $85 to $95 (Richardson et al., 2012). This discrepancy between the cost-of-illness and willingness to pay estimates suggests that conventional health cost estimates capture only a fraction of total damages, omitting broader welfare losses such as reduced quality of life, productivity impacts, and behavioral disruptions. Consistent with this, another study, using a life-satisfaction approach, found that US adults would pay an average of $373 to avoid a single day of wildfire smoke exposure within a six-month period, with rural residents willing to pay $130 more than urban residents—highlighting variation in exposure risk and perceived costs across populations (Jones, 2017).

1.2 Disproportionate Health Impacts on Vulnerable and High-Risk Populations

The US Centers for Disease Control and Prevention define social vulnerability as a community's capacity to prepare for, respond to, and recover from hazards, such as climate-related disasters (CDC, 2024b). They measure this using four sets of indicators: (1) socioeconomic status (poverty, unemployment, income, and education), (2) household composition (age, disability, and single parenthood), (3) minority status and language, and (4) housing and transportation factors (CDC, 2024b). Communities with higher social vulnerability are at greater risk of climate-related economic and health harms because they often face multiple, overlapping challenges, such as chronic illness, underinsurance, limited access to healthcare, and poor-quality housing (EPA, 2021; Jerrett et al., 2024). Populations that are especially vulnerable to climate-related health threats include those that are lower-income, living with preexisting health conditions, working primarily outdoors, or are older adults, pregnant, or infants and young children (CDC, 2024b).

Climate-related risks for outdoor workers are examined in greater detail in *Chapter 1, Section 2.1.1 Heat and Labor Supply Impacts for High-Risk Workers.* Additional analysis of racial inequities in climate impacts is provided in the Fifth Assessment's "Racial Equity and Climate Justice Statewide Topical Report".

1.2.1 Disproportionate Health Impacts Among California's Older Adults

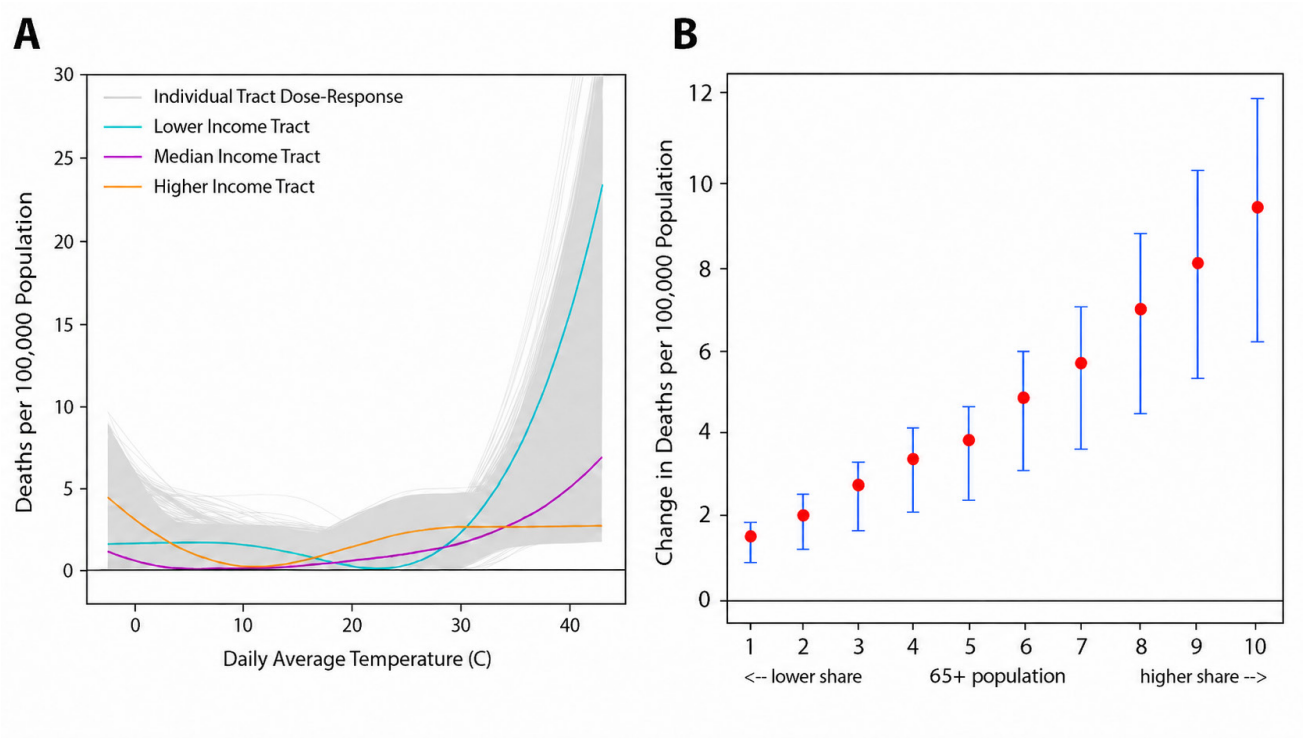
Older adults in California face disproportionately high health risks from climate-related hazards, particularly extreme heat and wildfire smoke, and those living on lower or fixed incomes are especially vulnerable because limited financial resources constrain their ability to afford cooling, safe housing, and medical care (Carleton et al., 2022a; Miller et al., 2021). This vulnerability is particularly consequential because the older adult population is growing: In 2020, 5.7 million Californians were 65 or older, and by 2040 there will be approximately 9 million seniors in the state (Johnson et al., 2025).

Recent analysis of more than 8,000 California census tracts shows clear income-based differences in heat-related mortality risk among residents age 65 and older, as shown in **Figure 6** (Carleton et al., 2022a). In higher-income communities, mortality rates among older adults remain relatively stable even when temperatures near 104°F (40°C), while in low-income neighborhoods mortality rises sharply, exceeding 20 additional deaths per 100,000 residents during extreme heat events (Carleton et al., 2022a). These differences reflect variation in access to air conditioning, housing quality, and healthcare (Liu & Smith-Greenaway, 2024; Romitti et al., 2022). The same study finds that census tracts with a larger share of residents age 65 and older experience greater temperature-related mortality overall, whereas wealthier tracts demonstrate higher adaptive capacity and lower impacts (Carleton et al., 2022a).

Wildfire smoke exposure has more recently emerged as a growing public health concern, particularly for older adults. Using Medicare data for the entire US elderly population, researchers estimate that wildfire smoke accounts for one in every 240 deaths and one in every 145 emergency room visits among adults aged 65 and older (Miller et al., 2021). At the level of individual exposure, a single-day microgram per cubic meter (1 $\mu g/m^3$) increase in PM2.5 from

wildfire smoke increases mortality in this age group by approximately 0.62 deaths per million over the following three days (Miller et al., 2021). Based on the value of life-years lost, these mortality effects translate to an estimated cost exceeding $6 billion annually (Miller et al., 2024). Applying the national wildfire smoke attribution ratios to California's projected 2040 elderly population suggests that wildfire smoke exposure could be associated with an additional 1,700 deaths and 32,000 emergency room visits annually—and likely more, given that California bears disproportionately high wildfire smoke exposure relative to the national average.

For California Native American communities, these heightened climate-related risks have broader community-level consequences because Tribal Elders often serve as primary caregivers, knowledge holders, and anchors of cultural continuity. Protecting Elders from extreme heat and wildfire smoke is therefore critical not only for their individual health, but also for sustaining language, cultural practices, and intergenerational care within Tribal communities (Edwards et al., 2024; Norton-Smith et al., 2016). For more information on climate impacts to the health of Tribal communities, see the Fifth Assessment's "Tribal and Indigenous Communities Statewide Topical Report".



Heat-Related Mortality Impacts for Californians Age 65+

Panel A. Mortality-Temperature Responses for Adults 65+ by Income

Panel B: Projected Heat-Related Mortality Impacts from a 1°C (1.8°F) Temperature Increase by County Share of 65+ Population

Figure 6: *Panel A (left) shows census-tract dose-response functions for heat-related mortality among adults age 65+, highlighting lower-, median-, and higher-income tracts, with grey lines for all 8,057 tracts statewide. The data show that communities with higher incomes are far less vulnerable to the mortality risks of extreme heat than communities with lower incomes. Panel B (right) shows the projected change in deaths per 100,000 adults age 65+ associated with a 1°C increase in daily mean temperature, by county share of older adults. The data show that mortality risks rise sharply in counties with larger older-adult populations. Source: (Carleton et al., 2022a)*

1.2.2 Infant and Maternal Health Impacts from Heat and Wildfire Smoke

Climate-induced heat and wildfire smoke exposure during pregnancy increase risks of preterm birth, low birthweight, certain birth defects, pregnancy complications, and infant mortality (Bekkar et al., 2020; Foo et al., 2024). Each day of exposure to wildfire smoke during pregnancy is associated with a 0.49% increased risk of preterm birth, with the highest risk occurring during the second trimester (Heft-Neal et al., 2022). Every 1 μg/m³ increase in average wildfire PM2.5 exposure during pregnancy is associated with a 1.3% increase in preterm birth risk, with the strongest associations occurring during the second and third trimesters (Picciotto et al., 2024). A baby born preterm can have increased risk of infant mortality, developmental delays, chronic respiratory conditions, higher lifetime costs of healthcare, and reduced educational and economic attainment later in life, which contribute to long-term health and economic burdens for affected individuals and families (Amjad et al., 2021; Black et al., 2007; CDPH, 2025a; Rundell & Panchal, 2017; Waitzman et al., 2021).

Black and Hispanic mothers are consistently identified as having a higher risk for premature births and neonatal intensive care unit (NICU) admissions during heat waves, even after accounting for socioeconomic status and other factors (Bekkar et al., 2020; Cil & Kim, 2022; Khalili et al., 2025). Nationally, Native American people experience some of the highest pregnancy-related mortality rates among major racial and ethnic groups, and most of these deaths are considered preventable (CDC, 2024a; Petersen et al., 2019). These patterns underscore the importance of working in partnership with Tribes and urban Indian health organizations to design climate and maternal health interventions that reflect Tribal sovereignty, priorities, and cultural practices (National Indian Health Board, 2024).

Box 7: *Severe Maternal Morbidity*

In addition to increasing the risk of preterm birth, climate-related heat exposure during pregnancy has been linked to severe maternal health complications. A study of over 400,000 pregnancies from 2008–2018 found that high or extreme heat exposure during pregnancy—particularly in the third trimester—increased the risk of severe maternal morbidity by 27%, with specific complications including cardiac arrest, eclampsia, heart failure, and sepsis (Wu et al., 2023). The estimated additional hospital cost per case of severe maternal morbidity is $5,800 (Phibbs et al., 2022) and California has a severe maternal morbidity rate of 112.3 per 10,000 delivery hospitalizations (March of Dimes, 2024).

Box 8: *Short and Long-Term Costs of Climate-Induced Preterm Births*

Preterm births have significantly higher direct medical costs and represent a substantial economic burden for individuals and the healthcare system. The median cost of childbirth in California for families with health insurance ranges between $20,400 and $25,100 (FAIR Health Inc., 2024). In comparison, the median cost per preterm infant requiring a neonatal intensive care unit (NICU) admission in the US is around $270,000 (Lai & Lorch, 2023).

The lifetime economic costs of preterm birth average $64,815 per birth when combining immediate medical expenses with reduced lifetime earning potential, ranging from $28,367 for late preterm births (32–36 weeks) to $344,355 for extremely preterm births (< 28 weeks) (Waitzman et al., 2021). In the long run, each pound at birth around the mean birth weight is associated with a 7 percent increase in average adult earnings, independent of family background (Black et al., 2007). Each day with mean temperatures above 89.6°F (32°C) in utero and in the first year after birth is associated with a 0.1% reduction in adult annual earnings at age 30 (Isen et al., 2017).

Between 2007–2012, California had an estimated 6,974 preterm births attributable to wildfire smoke exposure (Heft-Neal et al., 2022). California's Institute of Public Health estimates that eliminating preventable particulate matter air pollution, including wildfire smoke, could prevent approximately 3,000 premature births annually, avoiding $170 million in direct medical costs and $980 million in lost lifetime earnings each year (Institute of Public Health, 2018).

1.3 Health Care Delivery and Emergency Operations

Climate-related disasters are placing mounting strain on California's healthcare delivery and emergency response systems. Both extreme heat and wildfire smoke are associated with significant increases in emergency department visits and hospital admissions for cardiorespiratory conditions (Gould et al., 2024, 2025; Liu et al., 2017; Santodomingo et al., 2024). The acute care burden can be severe and rapid during extreme events: the January 2025 Palisades and Eaton fires produced an eightfold increase in the share of wildfire-associated emergency department visits in Los Angeles County within days of ignition (Kajita et al., 2025). Looking ahead, warming temperatures are projected to generate approximately 1.5 million additional emergency department visits in California between now and 2050, with additional annual emergency department costs reaching about $52 million by 2050 (Gould et al., 2025).

Additionally, both wildfire smoke exposure and extreme heat events are associated with adverse mental health outcomes, including increased emergency department visits for mood disorders, anxiety, and substance use disorders (Molitor et al., 2023; Nori-Sarma et al., 2022). Both wildfire smoke and extreme heat have been independently linked to elevated suicide risk. Evidence shows that wildfire PM2.5 increases monthly suicide rates by as much as 2.0% in rural US counties, with effects concentrated among men and working-age adults (Molitor et al., 2023). Similarly, each 1°C (1.8°F) rise in monthly average temperature is associated with a 0.7% increase in suicide rates across US counties, with no evidence of adaptation over time (Burke et al., 2018).

Wildfire and heat events can damage infrastructure, displace medical staff, and reduce the availability of essential services through both direct destruction and power outages. For example, the 2018 Camp Fire led to the loss of 100 hospital beds in the town of Paradise, placing increased burdens on nearby health systems in Butte County (Brown & Petek, 2022). The grid failures that wildfires and extreme heat reliably produce carry particular consequences for individuals reliant on electricity-dependent medical equipment, who already experience higher rates of outpatient care and exacerbated respiratory conditions in the weeks following wildfire smoke

exposure (McBrien et al., 2023). The broader healthcare safety net is similarly exposed: a Direct Relief survey during the October 2019 statewide blackouts found that only 44% of California's community health centers had any backup energy source when the grid failed, and even those with generators faced operational triage—choosing between powering refrigerated medications, electronic health records, or basic lighting (Sherer, 2019). Seven million Californians depend on these nonprofit community health centers as their primary source of care, particularly in rural and low-income areas (Sherer, 2019).

1.3.1 The Rising Costs of Fighting Wildfire

Direct state costs for wildfire prevention and response have surged in recent years. The California Department of Forestry and Fire Protection (CAL FIRE)'s wildfire resilience funding increased from approximately $100 million in 2015–2016 to roughly $700 million in 2025–2026, but most of the state funding supports wildfire response activities (LAO, 2026). Total CAL FIRE spending on wildfire response nearly doubled over the past decade, rising from $2.2 billion in 2017–2018 to $4.2 billion in 2024–2025 (LAO, 2025a). To meet growing wildfire demands, CAL FIRE also expanded the positions it dedicates primarily to wildfire response by around 85% over the same period, from approximately 5,800 to 10,800 (LAO, 2025a).

As California's fire seasons grow longer and more severe, the mental health of firefighters represents an urgent labor and public health policy concern. Firefighters are exposed to dangerous conditions and high levels of smoke pollution, which lead to elevated risks of injury, illness, and mortality (Andersen & Saber, 2025; Navarro et al., 2019). The psychological toll on first responders is substantial, with firefighters reporting increased rates of post-traumatic stress disorder, depression, grief, and suicide coinciding with increases in wildfire activity (CalMatters, 2025; Psarros et al., 2017; Wagner et al., 2021). While CAL FIRE does not systematically track suicide or post-traumatic stress disorder (PTSD) diagnoses, the agency's peer-support program recorded a more than twelvefold increase in contacts, from 1,362 in 2011 to 17,310 in 2021, reflecting the mounting psychological burden of increasingly severe fire seasons (Cart, 2022).

California has taken steps to recognize the occupational mental health burden on its wildfire workforce through Senate Bill (SB) 623 (2023), which extended workers' compensation PTSD coverage for firefighters, peace officers, and emergency responders through January 2029, building on protections originally established in 2020 (California State Legislature, 2023). As wildfire seasons intensify, protecting the mental health of the firefighting workforce will be a core element of California's climate resilience strategy.

1.3.2 Climate Disasters and Healthcare Finance

Financial pressures on healthcare facilities' operational costs intensify during climate-related emergencies. The increased cost of delivering healthcare to those that are underinsured or uninsured can translate into higher daily costs for hospital stays (Wilson & Cutler, 2014). For example, emergency rooms earn a 39.6% profit margin on privately insured patients but lose 15.6 cents on every dollar spent treating Medicare patients and 54.4 cents per dollar on uninsured patients (Wilson & Cutler, 2014). As a result, hospitals that primarily serve socially and economically disadvantaged communities face disproportionate economic burdens during climate

events, where the demand for care rises sharply (Banzhaf et al., 2019). Surges in care demands may lead hospitals to ration care resources, reduce average length of stay, or discharge patients earlier, which can result in excess mortality even in patients whose conditions are not directly related to the climate event (Aguilar-Gomez et al., 2025).

Beyond operational costs, climate-related disasters also drive up the cost of financing healthcare infrastructure, a less visible but equally consequential fiscal burden. When hospitals and nursing homes face repeated climate-driven demand surges, credit markets perceive them as higher-risk borrowers and charge higher interest rates on the municipal bonds that healthcare facilities rely on to fund construction, equipment, and facility upgrades. Nationwide, an increase by one standard deviation in wildfire smoke pollution is associated with a 0.064% increase in hospital borrowing costs and a 0.121% increase in nursing homes borrowing costs (Lopez et al., 2024). These effects are 50–100% higher in high-poverty communities and communities with high proportions of Black and Hispanic populations (Lopez et al., 2024). Over the next decade, smoke-related increases in interest expenses for healthcare systems could total an additional $570 million and raise per-patient care costs by $250 in the most affected areas nationwide (Lopez et al., 2024).

Wildfire smoke in California generates financial externalities for neighboring and downwind states, as jet stream dynamics transport fine particulate pollution thousands of miles eastward, extending health and economic impacts far beyond the fire perimeter. In Nevada, for example, wildfire smoke from California's record 2020 wildfire season significantly worsened air quality, and researchers estimate it would have added 17.8 basis points to hospital bond yields and 23.8 basis points to nursing home yields in Nevada, translating to an estimated $1.6 million in additional interest costs on a typical $90 million hospital bond and $0.9 million on a $30 million nursing home bond (Lopez et al., 2024).

Box 9: *Area for Future Research: Quantifying Health Impacts of Climate-Driven Water Contamination*

In California, stormwater runoff after intense precipitation events can negatively impact water quality. When rainfall overwhelms sewage and stormwater systems, pathogen-laden runoff can pollute drinking and recreational water sources, leading to outbreaks of E. coli, norovirus, hepatitis, and gastrointestinal infections (Lynch & Shaman, 2024). Imperial Beach, on the southern coast of San Diego County near the Tijuana River outlet, is regularly affected by elevated fecal indicator bacteria following large rain events due to stormwater runoff and limited water treatment capacity in the Tijuana River basin (Aguilera et al., 2019; Bendix, 2023). Recreational waterborne illnesses alone cost the US health system between $2.2–$3.7 billion annually, but this estimate does not separate out illnesses from particular climate-driven events or associated drinking-water failures (DeFlorio-Barker et al., 2018).

Wildfires also pose growing risks to drinking-water systems; the combination of fire and high heat can degrade pipes, mobilize toxic compounds, and introduce chemical contaminants into water distribution systems, sometimes rendering tap water unsafe for extended periods after fires (Solomon et al., 2021a). Data on illness cases and health costs from climate-driven water contamination remains limited in California and are an area for future research.

1.4 Crime and Conflict

Climate change is altering crime patterns in the US, as higher temperatures and extreme weather are linked to increases in violent and property crime (Choi et al., 2024; Goin et al., 2017). Evidence suggests that high temperatures increase irritability and aggression, impair judgment and decision-making, and exacerbate underlying mental health conditions (Plante & Anderson, 2017). Researchers estimate that a 1°C (1.8°F) increase in average temperature may yield a 6% increase in violent crime rates, as many as 25,000 more serious and deadly assaults per year in the US alone (Plante & Anderson, 2017). Dense urban neighborhoods are especially vulnerable to rising temperatures. Urban heat islands are areas where dense concentrations of heat-absorbing surfaces like buildings and pavement, combined with limited vegetation, make local air temperatures several degrees warmer than nearby, less-developed areas (EPA, 2025a). These areas consistently face both higher temperatures and higher violent crime rates (Teron, 2023). In California, more than 3.2 million residents of the Los Angeles area and 1.36 million residents of the San Diego area live in census tracts with an urban heat island index of 8°F or higher, about 45% and 55% of each urban area's population, respectively (Climate Central, 2023).

Over the course of this century, national projections indicate that continued warming could lead to roughly 22,000 additional murders, 180,000 rapes, 1.2 million aggravated assaults, 260,000 robberies, 1.3 million burglaries, 2.2 million cases of larceny, and 580,000 vehicle thefts (Ranson, 2014). Beyond direct losses to life, health, and property, these trends are expected to carry wider societal costs, including higher expenditures on policing and insurance payouts, reduced worker productivity, and community destabilization (NATO Veterans Research, 2024; Ranson, 2014). At the neighborhood level, repeated exposure to violence is associated with lower trust among neighbors, reduced collective efficacy, and less use of shared public spaces, changes that can weaken community organizations and make it more difficult to sustain local crime prevention efforts (Fagan et al., 2014).

While heat demonstrates clear links to violent crime, different climate stressors have been found to influence crime differently, revealing the complex pathways through which environmental change shapes criminal behavior. For instance, California's 2011–2015 drought significantly increased property crime by approximately 9.65% but had no measurable effect on violent crime (Goin et al., 2017). The drought's economic and social consequences, including rising water costs, dried-up wells in rural communities, agricultural job losses, and heightened financial stress, likely created conditions that elevated burglary, larceny, and motor vehicle theft (Goin et al., 2017). These differences between heat-driven violence and drought-driven property crime demonstrate that climate stressors affect criminal behavior through different pathways, producing context-specific patterns that vary by hazard type.

2. Labor

Key Takeaways

1. **Extreme heat is already costing California millions in lost labor hours and wages.** Across seven California major heat events from 2013–2022, lost work time in climate-exposed industries totaled over $531 million, ranging from $7.7 million to $210 million per event (CDI, 2024). Heat-related workplace injuries cost California $525–$875 million per year from 2001 to 2018, considering healthcare costs, wage loss, and disability (Park et al., 2021).

2. **Extreme heat and wildfire smoke reduce labor supply and productivity.** Exposure to high temperatures and wildfire smoke reduces hours worked, increases fatigue, raises absenteeism, and reduces worker productivity—with the largest impacts observed among outdoor workers and indoor workers in buildings without adequate cooling or air filtration (Borgschulte et al., 2024; Carleton et al., 2022a; Graff Zivin & Neidell, 2014; Langer et al., 2023).

3. **Wildfires can cause persistent labor market disruptions beyond the initial recovery period.** Major wildfires can destroy homes and workplaces, leading to out-migration and sustained job losses in affected communities (Radeloff et al., 2024). While construction employment may increase temporarily with rebuilding efforts, overall job growth can remain depressed for at least three years after a fire (Coulombe & Rao, 2023; Walls & Wibbenmeyer, 2023). Insurance payouts and government aid can help with recovery, but historically these responses have only partially offset declines in local economic activity (Luo, 2023).

Climate change poses a growing threat to California's workforce, with heat and smoke exposure driving injury and long-term health consequences that ripple across labor markets and household finances. For outdoor and climate-exposed workers, these hazards can reduce on-the-job productivity, contribute to absenteeism and reduced output, and directly impact earning potential (Carleton et al., 2022a; Lopez et al., 2024; Park et al., 2020; Roh & Alamo, 2022). The most climate-exposed industries, or high-risk sectors, include agriculture, forestry, construction, transport, outdoor-based hospitality and recreation, and manufacturing in facilities lacking climate control (Carleton et al., 2022a; Heinzerling et al., 2020; Roh & Alamo, 2022; Scott et al., 2025). Workers in these sectors also tend to earn low wages and have few resources to avoid hazardous conditions, meaning climate-driven labor losses are both concentrated on the most economically vulnerable workers and compound pre-existing inequities (Park et al., 2021).

Many Tribal economies in California are also anchored in these outdoor and land-based activities, including agriculture, fisheries, forestry, and nature-based tourism, leaving Tribal employment, incomes, and local economic development pathways sensitive to climate-driven disruptions (Whyte et al., 2023). For more information on climate impacts to Tribal communities, see the Fifth Assessment's "Tribal and Indigenous Communities Statewide Topical Report".

Many labor impacts of climate change arise through health-related pathways, which are addressed in *Chapter 1, Section 1 Health* of this report. This chapter focuses specifically on how climate change affects the workforce, including impacts on labor supply, labor productivity, and workplace safety.

2.1 Labor Supply

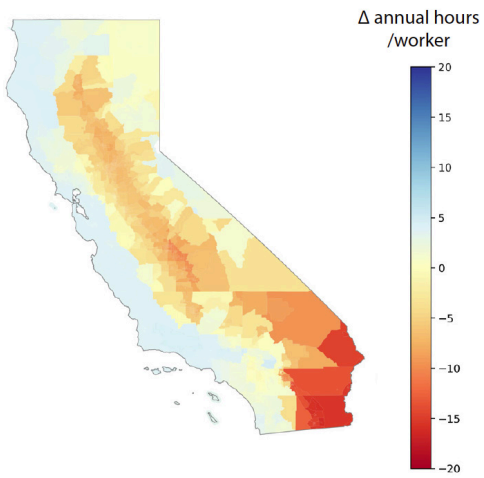
2.1.1 Heat and Labor Supply Impacts for High-Risk Workers

Extreme heat has already imposed measurable economic costs on California's labor market. During an extreme heat event in 2022 that lasted 14 days, lost work time among exposed workers was valued at $210 million, with construction and manufacturing workers experiencing the greatest losses (CDI, 2024). This estimate is based on how workers reduce their work time on hot days; it does not include the economic harm of increased prevalence of heat-related illness and workplace injuries (CDI, 2024). In the US, California experiences the second-largest heat-related labor losses. Researchers estimate that California's heat-related labor losses increased from approximately $2.1 billion in the 1980s to $2.4 billion in the 2010s, second only to Texas, where losses rose from $3.3 billion to $4.1 billion over the same period (Zhang & Shindell, 2021). On an annualized basis, reduced labor output averaged about $95 million per year in California, compared with roughly $150 million per year in Texas (Zhang & Shindell, 2021).

Even slight increases in temperature can impact labor supply. One nationwide study finds that workers in climate-exposed industries reduce time spent working on days when maximum temperatures exceed 85°F (29.4°C), with reductions reaching nearly one hour on days above 100°F (37.8°C) (Graff Zivin & Neidell, 2014). Most of the decrease in time worked was found to happen at the end of the day, when workers were already fatigued from prolonged heat exposure (Graff Zivin & Neidell, 2014).

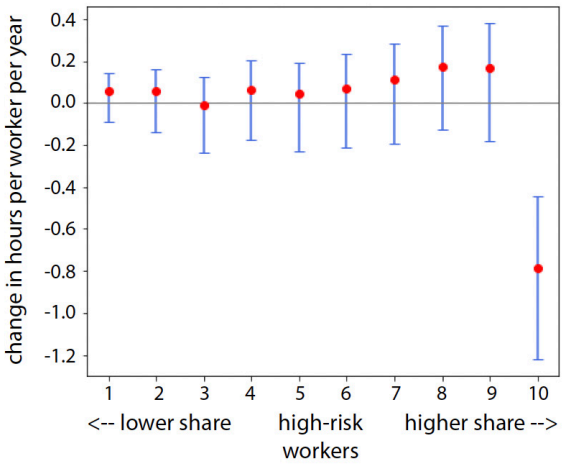
Lower-wage workers in climate-exposed industries and inland regions are especially vulnerable, as they are more likely to live and work in hotter locations and experience larger marginal increases in risk on extreme heat days (Park et al., 2021). By contrast, the San Francisco Bay Area economy is more heavily driven by technology, information, and professional services industries, whose largely indoor workforce is comparatively more protected from heat, smoke, and variable precipitation (CVL Economics, 2024).

Projected reductions in work hours are especially pronounced in California's climate-exposed, high-risk outdoor sectors. As shown in **Figure 7**, median estimates for 2050 under a moderate-emissions scenario indicate losses of about 5–10 work hours per worker each year in much of the Central Valley, and 15–20 hours lost per worker annually in parts of the southeastern desert region (Carleton et al., 2022a). **Figure 8** further illustrates how these losses are highly uneven: census tracts with the very highest shares of high-risk workers experience a sharp drop in labor hours, underscoring how concentrated employment in outdoor work amplifies climate vulnerability (Carleton et al., 2022a; Rode et al., 2022). Additionally, workers in high-risk sectors lose substantially more hours on both extremely hot and cold days compared to those in low-risk sectors, as shown in **Figure 9**, underscoring the greater vulnerability of outdoor and physically demanding jobs (Carleton et al., 2022a; Rode et al., 2022).



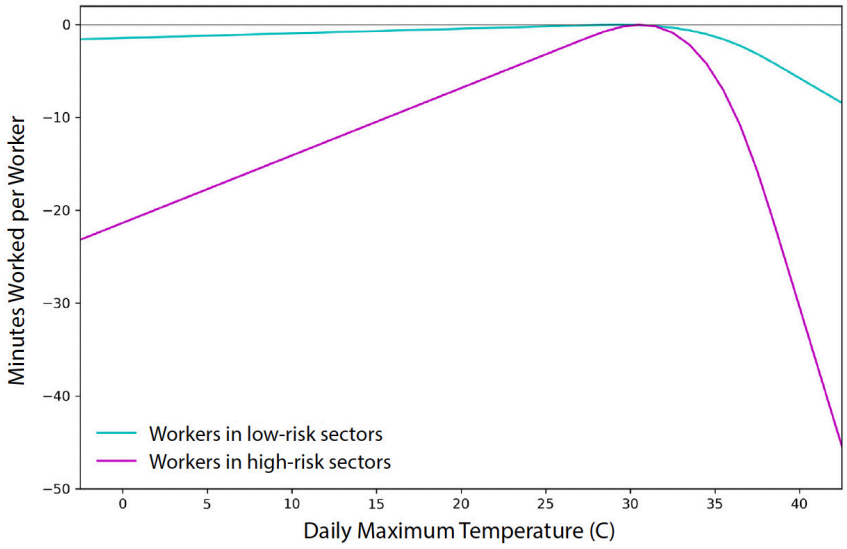
Change in Hours Worked Per Worker in High-Risk Sectors in 2050

Figure 7: *Median estimates of the annual effects of climate change in 2050 under a moderate emissions scenario (RCP 4.5). High-risk sectors in the Central Valley may experience a decline of 5–10 hours worked per worker annually by 2050, while those in the southeastern part of the state could see reductions of 15–20 hours per worker annually. Source: (Carleton et al., 2022a)*



Labor Impacts in Census Tracts by Share of High-Risk Workers

Figure 8: *In census tracts with relatively few high-risk workers, changes in hours worked per person remain close to zero, indicating limited overall effects, but at the very highest share (decile 10), workers lose nearly an hour per year on average, reflecting the greater vulnerability of physically demanding, outdoor industries to extreme heat and climate stressors. Source: (Carleton et al., 2022a).*

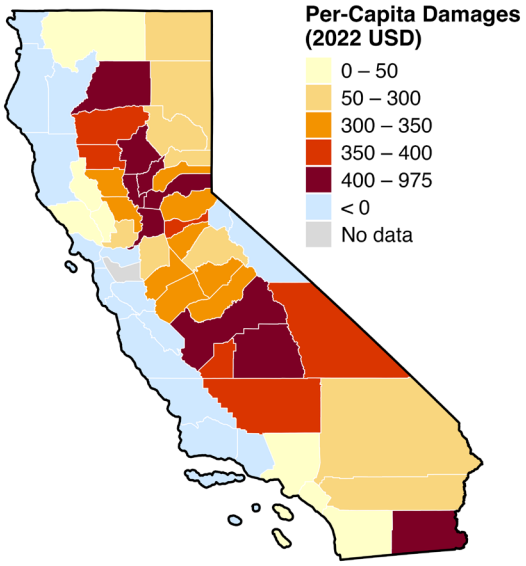


How Temperatures Impact Hours Worked in Low-Risk and High-Risk Sectors

Figure 9: *Daily maximum temperatures affect hours worked in high- and low-risk sectors. High-risk jobs lose more work time in both extreme heat and cold (magenta line), while low-risk jobs show smaller changes (teal line). These dose-response functions are used to project future climate impacts on labor supply. Source: (Carleton et al., 2022a).*

Box 10: *FrEDI Projected Climate-Labor Loss Estimates*

Figure 10 presents projected annual economic damages from lost hours worked under 3°F (1.67°C) of warming on a per person level (EPA, 2024). These projections are estimates of annual economic damages in a scenario where the population is constant over time and, by 2100, global surface temperature increases by 3°F (1.67°C) relative to the 1986–2005 baseline, comparable to RCP 2.6, a low radiative-forcing pathway. Inland counties, including those in the Sacramento Valley and Central Valley, are expected to have higher per-capita labor damages relative to coastal counties, which may see modest increases in hours worked as fewer frost days extend the workable season. At a county level, a loss of $400 per person in a county of 1 million people, such as Fresno County, would translate to roughly $400 million in lost work output or wages county-wide annually due to higher temperatures. Note that these estimates reflect only impacts from temperature and do not account for additional labor disruptions from precipitation, wildfire smoke, or other variable weather conditions. While **Figure 7** and **Figure 10** both indicate heat-related reductions in work capacity, they differ in time horizon (2050 vs. 2100), emissions scenario, geographic resolution, and unit of analysis (decreased hours per worker vs. per capita annual monetary damages), so the magnitudes are not directly comparable.



Projected Per-Capita Annual Damages from Decreased Work Hours under 3°F of Warming, by County.

Figure 10: *Damages are concentrated in hotter inland and agricultural regions, where outdoor and physically demanding work is more exposed to extreme heat. This figure uses information from the 5th National Climate Assessment and the US EPA Framework for Evaluating Damages and Impacts (FrEDI) analysis, which quantified these losses by multiplying hours lost by wage rates (EPA, 2024; Neidell et al., 2021).*

Box 11: *Climate Risk to Farmworkers*

Farmworkers face heightened vulnerability to climate extremes because the work is physically demanding, typically low-wage, and often lacks comprehensive health insurance and workplace protections, so climate-related job losses and illnesses can quickly destabilize household income and health (Carleton et al., 2022a; GCH Task Force, UC Santa Cruz, 2024; Ornelas et al., 2022).

Agricultural employment in California is highly seasonal, with employers hiring an estimated 415,000 full-time equivalent roles in a typical year, while monthly employment peaks at nearly 500,000 workers in the summer and falls toward 300,000 workers in the winter (UC Davis, 2025). Because many workers are employed for only part of the year or move across employers, California agricultural employers report roughly 885,000 unique workers annually, or about 2.1 workers for each average agricultural job (UC Davis, 2025). Peak agricultural labor demand often coincides with the hottest months of the year, concentrating large numbers of farmworkers in the fields precisely when temperatures, humidity, and wildfire smoke are most hazardous, contributing to disproportionate rates of heat illness, heat-related kidney injury, and fatal heat events (Adewumi-Gunn & Constible, 2022; Carleton et al., 2022a). Drought and water shortages can compound labor impacts. For instance, back-to-back drought years in 2021 and 2022 were estimated to reduce direct employment in crop production and food and beverage processing by roughly 14,700 and 19,400 full- and part-time jobs, respectively, across California (Medellín-Azuara et al., 2022).

Agricultural workers also face elevated risks of contracting Valley fever, a fungal infection caused by inhaling airborne spores of *Coccidioides* that live in dry soils in parts of California and the broader Southwest (Cooksey et al., 2020). Climate change-driven increases in temperature and altered precipitation patterns, particularly cycles of drought followed by heavy rainfall, are expanding conditions favorable for *Coccidioides* growth and airborne dispersal in California (Gorris et al., 2019). In 2017, there were nearly 7,500 reported cases of Valley fever in California, and the estimated lifetime costs were approximately $94,000 per case, including $58,000 in direct medical costs and $36,000 in indirect costs, for a statewide total of roughly $700 million; these estimates do not include economic costs associated with premature mortality (Wilson et al., 2019). Between 2015–2021 there were an average of 80 deaths and 1,000 hospitalizations annually from Valley fever in California (Jerrett et al., 2024). Following a large spike in *Coccidioides*, driven by the 2020–2022 drought followed by the heavy winter storms of 2022–2023, California reported 10,519 Valley fever cases between April 2023 and March 2024, and in 2024, California had a record 12,500 reported cases (Camponuri et al., 2025; CDPH, 2025b, 2026). Valley fever is underestimated because cases may be misdiagnosed, go underdiagnosed, or remain unreported when individuals do not seek medical care; the true number of Valley fever cases may be 10–18 times higher than reported case counts, and Valley fever-related deaths may be 5–6 times higher than reported mortality counts (CDC, 2024d).

Box 12: *Heat Adaptation Measures for Worker Safety*

Heat-related illness is preventable, and California's Division of Occupational Safety and Health requires employers to take steps to prevent heat-related illness in both indoor and outdoor workplaces (Smith et al., 2022). California became the first state to adopt an outdoor heat standard in 2005 (Cal DIR, 2026). California's outdoor heat standard requires a suite of employer protections that directly address several of the most important heat-risk pathways, including access to drinking water, shade, preventative cool-down rests, high-heat procedures, emergency response procedures, acclimatization, training, and a written heat illness prevention plan. Evidence shows the effectiveness of California's outdoor heat standard has grown over time as employers have adopted improved heat-safety mechanisms: from 2010–2020 heat-related deaths among outdoor workers dropped by an estimated 33%, preventing approximately 34 worker deaths per year (Dean & McCallum, 2025).

While these standards have driven significant improvements in worker safety, field research shows that compliance with baseline requirements does not always translate to full protection for individual workers. A study of 588 Latino farmworkers across 30 California farms during summer in 2014 and 2015 found that despite compliance with heat safety protocols, 11% of workers experienced dehydration and 8% reached core body temperatures above 101.3°F (38.5°C) during field work, highlighting the need for proactive, sustained interventions (Mitchell et al., 2017a).

2.1.2 Wildfire and Labor Supply Impacts

Wildfires can have mixed effects on local labor markets—while wildfires generate immediate employment gains during emergency response operations, local economies experience heightened employment losses in the post-fire period (Nielsen-Pincus et al., 2013). In the aftermath of a fire, hazardous conditions, infrastructure damage, and the destruction of homes and businesses can displace people and jobs (EPS & IEc, 2021). Employment growth can be negatively impacted for at least three years after a wildfire event (Coulombe & Rao, 2023). Insurance payouts, federal disaster aid, and other government assistance can stabilize these communities and reverse some of the labor force losses by supporting local recovery and rebuilding efforts (Coulombe & Rao, 2023; Walls & Wibbenmeyer, 2023).

California-specific evidence indicates that wildfire smoke contributes to substantial work loss. Using California Health Interview Survey data from 2015–2018, researchers estimated that wildfire-specific PM2.5 contributed to 0.7–2.6 million work-loss days per year in California, with associated economic losses of $129–$521 million annually (Meng et al., 2024). National evidence indicates that an additional day of wildfire smoke exposure reduces quarterly per-capita earnings by about 0.1%, with average annual earnings losses of roughly $125 billion in 2018 dollars from 2007–2019 (Borgschulte et al., 2024). Texas-based evidence also suggests that wildfire smoke can increase workplace injury costs. Using workers' compensation claims from 2005–2018, researchers estimated that a severe smoke day would increase daily workplace injury claims by 45%, adding approximately $108,600 in injury costs per 100,000 workers (Cabral & Dillender, 2024).

Wildfire impacts job growth particularly in smaller, rural, and less economically diverse areas (Li & Yu, 2025). For example, the 2018 Camp Fire led to a 5% decline in population growth and a 4% decrease in job growth in Butte County in the year following the fire (Li & Yu, 2025). In contrast, the 2017 Tubbs Fire led to a more modest decline in job growth of 0.5–1% in Napa and Sonoma counties (Li & Yu, 2025). Napa and Sonoma counties experienced smaller employment losses than Butte County, likely due to their larger, more diversified economies and stronger regional connections to the Bay Area (Li & Yu, 2025). The 2025 Palisades and Eaton Fires are estimated to have caused $297 million in annual wage losses due to unemployment (Li & Yu, 2025). This estimate is based on the number of destroyed homes and businesses in the three affected zip codes, combined with local annual wage data and the number of businesses and employees in each area (Li & Yu, 2025). However, longer-term employment effects, including potential population displacement and impacts on job growth, remain uncertain given the limited time elapsed since the fires.

2.1.3 Climate-Driven Labor Demand

Climate-driven changes can also lead to sectoral shifts in the labor market by altering both the demand for workers and the nature of their roles. For instance, climate-related disruptions can shorten construction seasons and interrupt work, while post-disaster rebuilding can create intense short-term demand for construction labor, producing boom-bust cycles in the sector (Coulombe & Rao, 2023; Walls & Wibbenmeyer, 2023). The demand for workers in emergency response, energy efficiency, clean transportation, and resilient infrastructure development is projected to increase due to growing climate risks (Pouy, 2024).

According to the World Economic Forum's *Future of Jobs Report 2025*, climate mitigation is ranked as the third-most important factor reshaping businesses worldwide and demand for green skills is projected to exceed supply by more than 18% by 2030 (World Economic Forum, 2025). These fields include climate-resilient infrastructure development, sustainable agriculture, and high-tech roles in data analysis, which require more technical and analytical expertise. In California, water shortages from prolonged droughts are fueling demand for precision agriculture and increasing demand for high-tech roles in data analysis, drone operation, and equipment maintenance (USDA, 2023). As climate change reshapes California's economy and alters labor demand across sectors, workforce adaptability can be strengthened through retraining, relocation support, and transitions into emerging climate-adaptive industries. *California's Jobs and Climate Action Plan for 2030* describes strategies to build a skilled, diverse workforce aligned with emissions-reduction and resilience investments (Zabin et al., 2020).

2.2 Labor Productivity

In addition to affecting how many hours people work, climate conditions can impact how productive laborers are per hour worked, especially for physically demanding outdoor work that is highly exposed to climate conditions. Extreme heat reduces worker productivity through dehydration, physical fatigue, and cognitive impairment, which decreases output per hour worked (Graff Zivin & Neidell, 2014; Langer et al., 2023). Dual exposure to extreme heat and wildfire smoke can cause cognitive decline, reduced concentration, irritability, and physical exhaustion (Cleland et al., 2022; Yin et al., 2024).

2.2.1 Extreme Heat's Impact on Labor Productivity

Extreme heat exposure is a leading cause of reduced labor productivity globally (ILO, 2019). Prolonged exposure to high temperatures can directly reduce work capacity by forcing more frequent breaks and lowering work intensity, which in turn can drive up production costs and disrupt service delivery (Brown & Petek, 2022).

Among outdoor workers, farmworkers face especially severe risks. A study of Latino farmworkers in California's Central Valley found that productivity (measured as work rate) declines by about 4% for each 1°C (1.8°F) increase in wet bulb globe temperature above typical working conditions (Langer et al., 2023). Dehydration at the end of a shift was strongly associated with work rate, as dehydration can lead to elevated core body temperatures and pose serious health risks (Langer et al., 2023).

These productivity effects may also have direct earnings consequences for farmworkers paid by piece rate, where pay depends on the amount harvested or other measurable output (Pan et al., 2021). National Agricultural Workers Survey data indicate that in 2015–2019, 10% of California farmworkers were paid exclusively by piece rate (Ornelas et al., 2022). Converted to an hourly equivalent, piece-rate wages averaged $14.87 per hour, compared with $11.61 per hour for hourly workers, indicating that piece-rate workers can earn more when they are able to sustain higher output (Ornelas et al., 2022). Evidence indicates that heat can erode this productivity advantage. In a study of 575 California farmworkers conducted during the summers of 2014 and 2015, researchers examined how heat exposure affected work effort among workers paid

by piece rate and those paid hourly (Pan et al., 2021). Piece-rate workers exerted more effort than hourly workers under moderate heat exposure (60.9–79.9°F, or 16.07–26.61°C), but this difference decreased as temperatures rose. When temperatures exceeded 85.3°F (29.62°C), piece-rate workers exerted less effort than hourly workers, indicating that extreme heat constrained productivity despite stronger financial incentives. These findings suggest that extreme heat may reduce piece-rate workers' earnings by limiting the amount of work they can safely perform, linking heat-related productivity losses directly to income reductions (Ornelas et al., 2022; Pan et al., 2021).

Indoor workers are also vulnerable to heat-related productivity losses, especially in manufacturing facilities or warehouses with inadequate cooling or ventilation (Roh & Alamo, 2022). In July 2024, California's regulation to prevent indoor heat illness went into effect, applying to most indoor work areas when temperatures equal or exceed 82°F (CDIR, 2024). As part of the statewide regulatory impact assessment for California's indoor heat standard, analysts estimated $404 million in annualized direct benefits, or $4 billion over 10 years, with business productivity impacts across covered indoor workplaces accounting for approximately $2.3 billion, or 57% of total estimated benefits (Metz et al., 2021).

2.2.2 Wildfire's Impact on Labor Productivity

Wildfire smoke exposure can reduce labor productivity by impairing workers' ability to perform tasks efficiently. Fine particulate matter from wildfire smoke has been linked to respiratory inflammation, fatigue, reduced attention spans, and cognitive impairment, all of which can diminish task performance, increase break frequency, and elevate absenteeism (Cleland et al., 2022). These productivity effects can occur in both outdoor settings and indoor workplaces without adequate air filtration, where smoke can penetrate buildings and expose workers even when they remain indoors (Carleton et al., 2022a).

California-specific evidence directly estimating wildfire smoke's effect on labor productivity remains limited. Most available studies measure related outcomes such as earnings, work-loss days, hours worked, worker presence, or health impacts rather than output per worker or task performance. Although not specific to wildfire smoke, related evidence from California agriculture shows that air pollution can reduce worker output: a study using payroll records for strawberry harvesters during the 2010–2015 growing seasons found that one standard deviation increases in ozone and PM2.5 were associated with productivity declines of 2.0% and 1.1%, respectively, measured as trays harvested per hour (Hill et al., 2024). In California, average smoke exposure increased by 3.6-fold between 2010–2016 and 2017–2023, reflecting higher frequencies of smoke days and concentrated PM2.5 episodes that exacerbate health, labor, and economic disruptions (OEHHA, 2025).

National evidence also suggests that wildfire smoke reduces labor income in ways that are consistent with productivity and work-capacity losses, though not limited to productivity alone. Between 2007–2019, wildfire smoke reduced estimated earnings by nearly 2% of annual labor income nationwide, or about $125 billion per year, and each additional day of smoke exposure reduced quarterly earnings by approximately 0.1% (Borgschulte et al., 2024).

2.3 Workforce Safety

As incidences of heat waves, wildfires, and severe storm events increase, workers in climate-exposed occupations are increasingly exposed to harsh and hazardous conditions (OEHHA, 2022). In recent years, climate impacts have led to higher rates of workplace injury, workers' compensation claims, and reduced workforce participation in highly affected industries (Smith et al., 2022). The Natural Resources Defense Council analyzed California workplace heat enforcement data from 2005–2021 and found that the Agriculture, Forestry, Fishing, and Hunting industry classification accounted for the largest share of fatal and catastrophic heat cases, representing 32% of 502 cases; within this industry classification, farmworkers accounted for 94% of cases (Adewumi-Gunn & Constible, 2022).

Vulnerable workers include low-wage workers and immigrants, many of whom occupy the most climate-exposed jobs and therefore face compounded health and earnings risks (Pech et al., 2025). These climate-exposed industries also tend to pay low- and middle-wage salaries: in 2021, median hourly pay in California was $14 for agricultural workers, $15 for forestry workers, $23 for construction workers, and $15 for landscaping workers (Roh & Alamo, 2022). As of January 1, 2024, the federal Adverse Effect Wage Rate for California rose to $19.75 per hour for H-2A visa-holding farmworkers (Lopez, 2024). In California, workers in the lowest-pay quartile suffer heat-related workplace injuries at nearly five times the rate of workers in the highest-pay quartile, with young men in physically demanding low-wage jobs facing the highest risk (Park et al., 2021). For additional discussion of climate-related occupational hazards, see the Fifth Assessment report "Climate Change-Related Occupational Hazards".

2.3.1 Increasing Worker Compensation Claims

Workers are increasingly seeking workers' compensation for respiratory illness from wildfire smoke and heat-related conditions, such as heat exhaustion and heat stroke (Hogan, 2025). When temperatures rise above 85°F (29.4°C), the risk of workplace injury increases by 5 to 7%; on days exceeding 100°F, the risk increases by 10 to 15% (Park et al., 2021). In indoor manufacturing settings, workplace injury increases by 7% on days with highs above 95°F (35°C) relative to days in the low 60s°F (15–18°C) (Park et al., 2021).

Between 2000–2022, the state recorded over 20,000 heat-related workers' compensation claims, with rates rising sharply in more recent years (Smith et al., 2022). Most heat-related claims occur in the warmer months between May and September and are concentrated in protective services, such as emergency responders, followed by farming, fishing, forestry, and construction (Smith et al., 2022). These claims can be challenging because symptoms may develop or interact with pre-existing conditions, making it difficult to document and prove that workplace heat exposure caused the injury or illness. The economic burden of heat-related workplace injuries in California, based on 2001–2018 data, is estimated to be between $525 million and $875 million per year, considering healthcare costs, wage loss, and disability (Park et al., 2021). Data from California's Workers' Compensation System show that hotter days are also linked to injuries that are not traditionally considered heat-related, including falls, vehicle accidents, and mishandled equipment (Park et al., 2021).

2.3.2 Climate Risks and Health Protection Gaps Among Undocumented Agricultural Workers

Undocumented workers make substantial contributions to California's economy, particularly in agriculture, where they account for almost 26% of the sector's workforce (Bay Area Council Economic Institute & UC Merced, 2025). Undocumented farmworkers face a dual burden: high exposure to climate-driven hazards and limited access to health coverage, increasing the likelihood that climate-related illness or missed work translates into household financial stress (Cha & Barton, 2022; Vargas Bustamante et al., 2023). A 2023 farmworker health survey identified linguistic and cultural barriers, lack of insurance, and immigration status as leading social determinants of poor health outcomes among the state's farmworkers (UC Merced Community and Labor Center, 2023). Undocumented farmworkers' access to Medi-Cal has been short-lived: after briefly achieving full eligibility regardless of immigration status in 2024, the state has since frozen new enrollment and begun rolling back coverage for this population (DHCS, 2026). Together, barriers to health care, labor protections, and disaster relief can leave workers with fewer options to avoid unsafe conditions, seek medical treatment, or recover from climate-related shocks, amplifying both the health and economic harms they face. For more information on migrant farmworkers, see the Fifth Assessment's "Racial Equity and Climate Justice Statewide Topical Report".

Undocumented workers are deeply embedded in the state's labor force, making workforce stability central to both climate adaptation and economic security. A 2025 analysis estimated that undocumented workers' direct, indirect, and induced economic activity supports more than $275 billion in California GDP, including a particularly large role in agriculture, where their labor and related economic contributions account for an estimated 14% of sector GDP (Bay Area Council Economic Institute & UC Merced, 2025).

2.3.3 Gender and Climate Vulnerability

On average, women's lower earnings and disproportionate unpaid caregiving responsibilities increase their risk of economic instability, which can amplify their vulnerability to climate impacts (GEPI, 2024). These combined risks of lower pay, unpaid care burdens, and economic instability fall heaviest on women with low incomes, women of color, single mothers, older women, and primary caregivers (Jacoby et al., 2024).

Women in California earn about 66 cents for every dollar paid to white men, with pay gaps even wider for many women of color, limiting their financial capacity to adapt to or recover from income shocks (GEPI, 2024). Women on average spend twice as much time on unpaid caregiving as men, meaning that climate-related emergencies can increase care needs for children and older adults in ways that fall disproportionately on women's time and resources (GEPI, 2024).

Health-related climate impacts are especially pronounced for older women. Because women live longer than men on average, senior women are more likely than senior men to live alone. Nearly half of women over the age of 75 in California live alone (PPIC, 2024). Older adults may experience mobility limitations that complicate evacuation, cooling access, and medical care during climate emergencies (Cornell University, 2024).

Housing and energy insecurity are also major factors shaping women's climate vulnerability. Women renters are disproportionately cost-burdened: nearly 30% spend more than half their income on rent, compared with 23% of male renters (GEPI, 2024). Single mothers face particularly acute energy burdens, with 38% of single-mother households spending more than 6% of their income on energy bills, qualifying them as energy burdened (GEPI, 2024). Women-headed households also tend to experience greater economic impacts from flooding and extreme heat and show slower economic recovery than male-headed households (Solomon et al., 2021b).

3. Education

Key Takeaways

1. **Heat and wildfire smoke can impair cognitive function and learning, and prolonged exposure is associated with lower lifetime earnings.** Short-term exposure to high temperatures and wildfire smoke is shown to lower test performance and slow skill formation; cumulatively, this translates into lower lifetime earnings and productivity (Isen et al., 2017; Park et al., 2020; Wen & Burke, 2022).
2. **Educational disruptions impose immediate and cascading costs.** Wildfire and flood closures disrupt instruction, meals, childcare, and special services (CalMatters, 2019; Li & Jimenez, 2022). Severe events can trigger prolonged displacement, chronic absenteeism, and costly temporary schooling arrangements (Cano, 2019), which can have serious consequences for student well-being and academic progress (Chang et al., 2025).

Education is a cornerstone of long-run economic growth because it equips people with the knowledge and skills they need to contribute effectively to the workforce (Barro, 2013). Education raises lifetime earnings and productivity and strengthens the state's tax base (Barro, 2013; Johnson & Jackson, 2019; Ma & Pender, 2023). California's education system includes approximately 5.8 million K-12 students across the state's 10,000+ public schools and 1,000+ school districts (CDE, 2025). Rising temperatures, wildfires, and flooding events can disrupt these learning environments, increase operating costs, and strain school district budgets. These climate-induced challenges can also exacerbate existing achievement gaps, particularly among disadvantaged students (Graff Zivin et al., 2020; Park et al., 2020). The cumulative effect of these impacts can translate into reduced learning outcomes, with downstream economic consequences in the form of a lower-productivity future workforce, reduced earnings, and slower long-term growth (Wen & Burke, 2022).

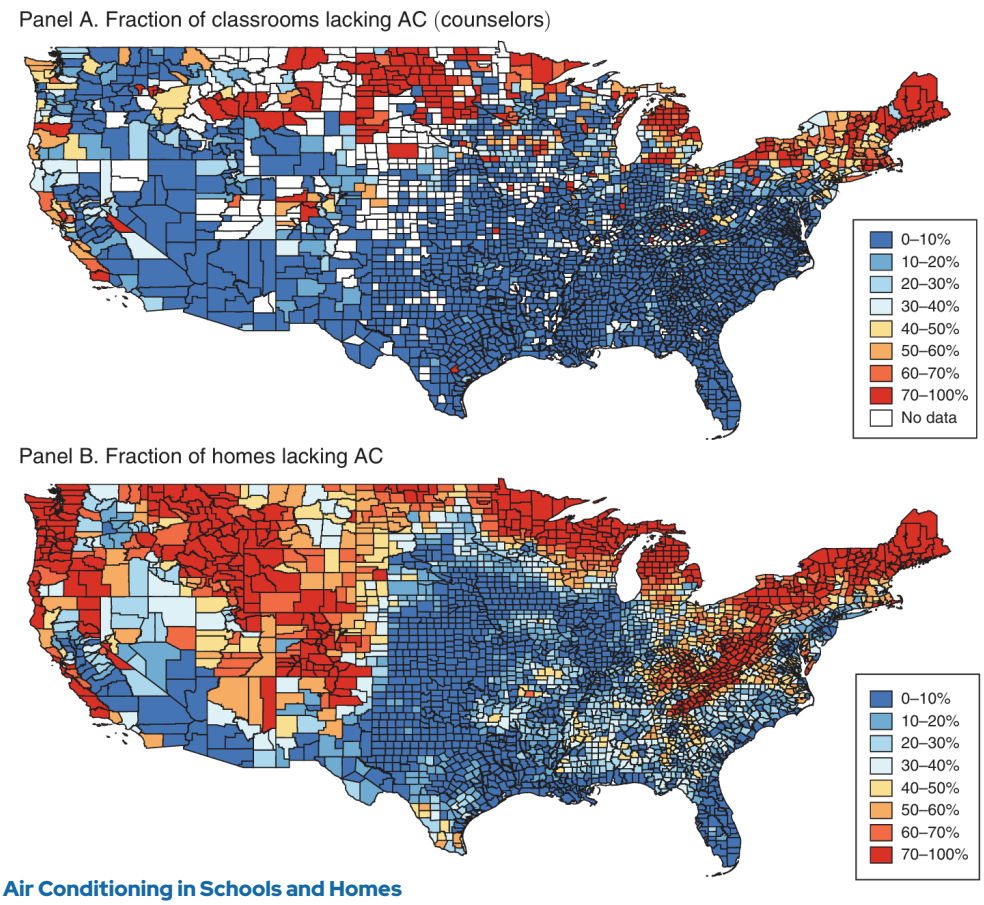
California's K-12 public schools received approximately $142.4 billion in state, local, and federal funding in 2024–25 (Lafortune & Guinan, 2025). Historically, the state has contributed the majority of this funding, with local governments providing about one-third, underscoring the state's central role in sustaining public education (Lafortune & Guinan, 2025). As climate-driven disasters intensify, local governments face growing emergency response and recovery costs, which can reduce the discretionary funds available for schools (Li & Jimenez, 2022).

3.1 Impact of Higher Temperatures on Learning and Test Performance

A growing body of evidence shows that higher temperatures impair students' test performance and are associated with measurable learning losses (Graff Zivin et al., 2018, 2020; Park et al., 2020; Roach & Whitney, 2021). These effects likely operate through both physiological and cognitive pathways: heat exposure can raise brain temperature, disrupt neuron activity and executive function, and reduce students' capacity to perform tasks efficiently (Tan et al., 2024). The impacts can occur over short periods, including during exams, as well as through cumulative exposure over the school year. Even modest increases in average maximum temperatures can reduce standardized test performance, indicating that learning is sensitive not only to extreme heat but also to small warming increments (Graff Zivin et al., 2018; Park et al., 2020; Roach & Whitney, 2021). Short-term heat exposure during exams has been shown to reduce test scores, with the largest effects among higher-performing students (Graff Zivin et al., 2020). Learning losses are largest on days above 100°F (37.8°C), but repeated exposure to less extreme heat can also accumulate into meaningful educational losses over time (Roach & Whitney, 2021). A sustained increase in temperature of 3.6°F (2°C) can lower achievement gains by approximately 7% of an average year's worth of learning (Park et al., 2020). These impacts also vary by place and adaptive capacity: the effects of higher temperatures on learning are more prominent in cooler regions, where students and school buildings are less adapted to higher temperatures (Roach & Whitney, 2021).

The economic implications of heat on learning also deepen existing educational inequalities, as hot school days disproportionately impact Black and Hispanic students (Park et al., 2020). Black and Hispanic students are about three times more affected by heat than white students, with 3–7% of the PSAT score gap explained by differences in temperature exposure (Park et al., 2020). These disparities stem from lower air conditioning access in schools and the fact that Black and Hispanic students are more likely to live in hotter regions (Park et al., 2020).

The distribution of air conditioning in classrooms and homes across the United States is shown in **Figure 11**, which highlights especially low coverage in coastal California. School air conditioning substantially mitigates heat's impact on learning, offsetting roughly 73% of its effect for the average student (Park et al., 2020). Yet that protection is unequally distributed: heat inhibits academic achievement approximately three times more for Black and Hispanic students than for white students, reflecting in part the lower rates of air conditioning in schools serving minority communities (Park et al., 2020).



Fraction of Air Conditioning in Schools and Homes

Figure 11: *County-level average fraction of classrooms (Panel A) and homes (Panel B) in the US that lack air conditioning. Coastal California counties have a higher proportion of schools and homes without air conditioning, highlighting these areas as priority candidates for future cooling investments as the risk of extreme heat grows. Source: (Park et al., 2020)*

Box 13: *Air Conditioning as an Adaptation for Reducing Heat-Related Impacts on Students*

Air conditioning is one of the most effective tools schools have for protecting students from the learning impacts of extreme heat. These benefits are also shaped by a student's broader circumstances, such as whether they have air conditioning at home, their families' resources, and the support available in their community (Park et al., 2020). As schools face rising temperatures in the coming decades, they face increased reliance on air conditioning, leading to higher utility bills for school districts (Li & Jimenez, 2022). While air conditioning is a significant ongoing cost, it is also becoming a critical and increasingly worthwhile investment in students' health, learning, and long-term opportunities.

Across the country, K-12 school districts spend nearly $8 billion a year on energy, making it their second-largest expense after teacher salaries (USDT, 2024). For many schools, air conditioning alone costs around $125,000 per year, or roughly $125 per student in a school with 1,000 students (Park et al., 2020). Even so, these investments have been shown to pay off: air conditioning in classrooms can prevent heat-related drops in test performance and can translate into an estimated $212 in recovered future earnings per student for every 1°F increase in annual temperatures (Park et al., 2020). As climate change accelerates, the financial return to installing or upgrading air conditioning in schools could increase, with median US schools seeing a return of about $500,000 per school by the 2040s and 2050s (Park et al., 2020).

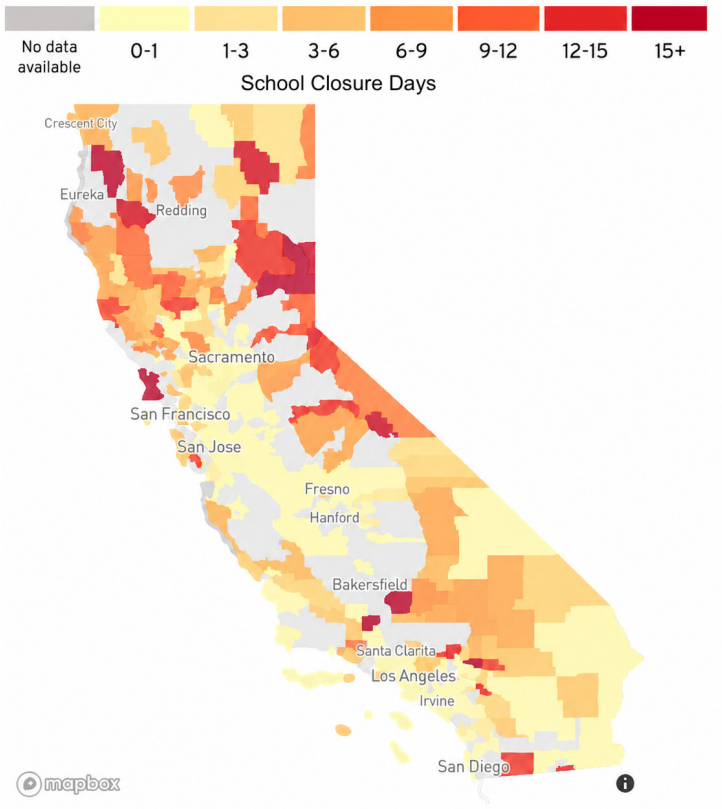
The upfront costs of installing or upgrading air conditioning or air filtration systems across school districts can be prohibitive, especially for underfunded districts. Districts serving lower-income communities often have more constrained tax bases and limited capital budgets, making it more difficult to afford climate adaptation or recovery measures (Lerner et al., 2024). As a result, already under-resourced schools may be least able to invest in resilient facilities, deepening educational inequalities (Lerner et al., 2024).

3.2 School Closures and Disruption of Education and Services

Wildfires and flooding are causing increasingly frequent school closures in California, leading to significant disruptions in education (CalMatters, 2019). Prior to 2015, no public school in California had reported losing 15 instructional days or more due to wildfire; however, between 2016–2019, more than 70 public schools reported 15 days or more of closures due to wildfires (Cano, 2019). In the 2017–2018 and 2018–19 school years, there were 9,753 wildfire-related closure days, where each closure day equals one lost day of instruction at a single public school site (Cano, 2019). As shown in **Figure 12**, disaster-driven school closure days between 2002–2019 were heavily concentrated in Northern California and Sierra Nevada foothill communities. In 2020, 104 school districts in California were subject to wildfire evacuation orders (Li & Jimenez, 2022). During the January 2025 Palisades and Eaton fires, more than 600,000 students across Los Angeles County had their schooling disrupted, including the full closure of the Los Angeles Unified School District, the nation's second-largest school district (Mehta, 2025).

School closures can expose youth to greater food insecurity and learning loss, challenges that are intensified when climate-related disasters also affect their mental health and further hinder learning (Li & Jimenez, 2022). School closures also disrupt parents' ability to work, with lower-income families disproportionately affected due to fewer resources for remote learning and alternative care, such as limited internet access, inadequate space at home for remote learning, and less capacity for adult supervision (Li & Jimenez, 2022).

Chronic absenteeism, defined as missing 10% or more of the school year, can have serious consequences for student well-being and academic progress (Chang et al., 2025). For example, the Camp Fire damaged or destroyed eight of the nine school sites in the Paradise Unified School District and led to nearly a month of canceled classes and makeshift learning environments in malls and offices; about half of the district's students moved to new schools in the aftermath (Cano, 2019). The long-term academic outcomes of the students displaced by the Camp Fire remain unknown and represent an important area for future research to better understand how large-scale climate-related displacement and natural disasters affect student learning. For a broader discussion of how climate change is reshaping patterns of displacement and student mobility, see the Fifth Assessment's "Climate-Induced Human Displacement and Migration Statewide Topical Report".



Average Emergency School Closure Days Due to Natural Disasters, 2002–2019

Figure 12: *The highest concentrations of lost instructional time due to natural disasters from 2002–2019 are in Northern California and inland foothill communities—a pattern dominated by wildfire events, most notably the 2018 Camp Fire, the single largest closure event in the dataset. Note that the 2025 Los Angeles wildfires are not reflected in these counts and significantly impacted school learning for the latter half of the 2024–2025 school year for impacted communities. Source: (CalMatters, 2019).*

Box 14: *Air Filtration in Schools as a Targeted Adaptation to Wildfire Smoke*

Wildfire smoke exposure has been shown to measurably reduce student test scores and future earnings, with larger effects for younger students and those in disadvantaged communities (Wen & Burke, 2022). A national analysis of nearly 11,700 school districts found that in severe smoke years, scores fell ten times more than in relatively light smoke years, translating into approximately $111 in reduced future earnings per student in 2016 and almost $1.7 billion in lost future income nationwide (Wen & Burke, 2022). Importantly, about 82% of these losses were borne by economically disadvantaged districts serving predominantly students of color (Wen & Burke, 2022). Children in lower socioeconomic and disadvantaged communities are also disproportionately exposed to PM2.5 pollution more broadly, which increases risks for respiratory symptoms and diminishes cognitive performance (Alter et al., 2024; EPA, 2023a; Simona et al., 2025). These disparities highlight the importance of investing in air quality improvements, such as HEPA filters, to protect student health and learning outcomes (CDPH, 2024). For a broader discussion of how air quality burdens intersect with structural racism and climate impacts, see the Fifth Assessment's "Racial Equity and Climate Justice Statewide Topical Report".

3.3 Effects on School District Budgets

School districts face considerable, and often unpredictable, costs in responding to these climate-driven emergencies. Climate hazards can inflict significant damage to school facilities, resulting in long-term fiscal burdens that include building repairs, attorneys' fees, increased transportation expenses, and rising insurance premiums (Li & Jimenez, 2022). Districts may also face increased volatility in enrollment, leading to declines in school funding from the state for communities that experience permanent out-migration after emergency events (Li & Jimenez, 2022).

School districts have varying levels of capacity to respond to and recover from large-scale disasters. For example, in the aftermath of the January 2025 Los Angeles wildfires, the Los Angeles Unified School District (LAUSD)—the second largest school district in the nation, serving over 500,000 students—committed $2.2 billion to a combined wildfire recovery and climate resilience package. The largest components of this package included up to $725 million to rebuild three fire-damaged campuses, approximately $550 million in district-wide resilience upgrades, and $700 million in greening investments (LAUSD, 2025; Nowell, 2025). By contrast, the Pasadena Unified School District, which serves approximately 15,000 students and operates on a much smaller fiscal base than LAUSD, responded to the Eaton wildfire by relocating two schools to other campuses, purchasing portable classrooms, and expanding student mental health services (Yu, 2025). The district was already facing a structural deficit of approximately $30–$35 million before the Eaton wildfire struck, and subsequently allocated approximately $15 million to rebuild Franklin Elementary, one of five district-affiliated school sites severely damaged in the fire (Pasadena Now, 2025). The disparity between these two districts illustrates a broader pattern: districts serving lower-income communities often have more constrained tax bases and limited capital budgets, making it more difficult to absorb disaster costs or invest in climate-resilient facilities and deepening existing educational inequalities.

Flooding imposes similar fiscal burdens on school districts. Of California's approximately 10,600 K-12 schools, 2,230 fall within Federal Emergency Management Agency (FEMA)-designated high or moderate flood-risk zones (Peele et al., 2023; Xie & Willis, 2023). The risk is concentrated in the Central Valley: Tulare County has more high-risk schools than any other county in the state, and in Visalia Unified alone, 38 of 42 schools face high or moderate flood danger, with 10 at high risk (Peele et al., 2023).

Recent examples from California's 2023 winter storms and atmospheric rivers highlight the fiscal vulnerability of small districts situated in floodplains. At Planada Elementary School in Merced County, a January 2023 levee breach destroyed 26 classrooms and generated an estimated $12 million in rebuild costs, which include plans to raise classrooms above the floodplain (Peele et al., 2023). In Monterey County, the March 2023 Pajaro River levee breach caused water damage across all 10 buildings of Pajaro Middle School, destroying floors and requiring extensive wall replacement due to mold (Ojeda, 2023). Cleanup costs alone reached $2.8 million, with total renovation estimated at $10–15 million; the school remained closed for the entire 2023–24 school year, displacing more than 400 students to other campuses (Ojeda, 2023). These cases illustrate a structural vulnerability: many small and rural districts lack the insurance coverage or reserve capacity to absorb major flood events, making recovery from major flood events a prolonged and financially destabilizing process.

4. Government Operations

Key Takeaways

1. **Rising disaster response costs are straining state and local budgets.** CAL FIRE's wildfire response spending increased from $2.2 billion in FY 2017–18 to $4.2 billion in FY 2024–25, an 86% increase (LAO, 2025a). Local governments also shoulder substantial disaster response and recovery costs, often without sufficient reserves to cover these expenses upfront.

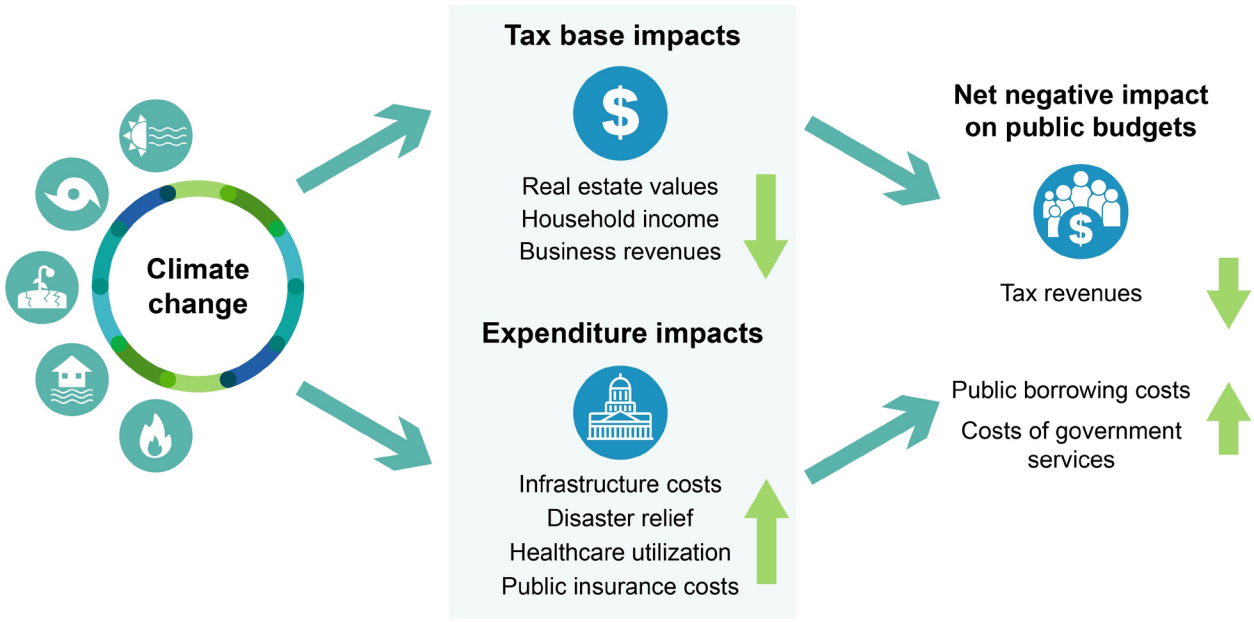
2. **Climate change is driving increased demand for public services.** Extreme heat events, flooding, and wildfires place heavy burdens on local governments, requiring expanded health services, cooling centers, emergency shelters, and infrastructure repairs (Gabbe et al., 2021; Liao & Kousky, 2022). These expanded services require staffing and resources, contributing to sustained increases in municipal operating costs.

3. **Fiscal risks extend beyond immediate disaster costs.** Climate hazards can erode tax bases, disrupt revenue streams, and increase borrowing costs for local governments. Credit markets are also beginning to price growing risks: climate-vulnerable municipalities face the prospect of higher borrowing costs or downgraded bond ratings, potentially increasing long-term capital costs for adaptation and resilience projects (Butler & Uzmanoglu, 2023; Jeon et al., 2024).

As climate change intensifies, state, local, and Tribal governments are increasingly on the front lines of disaster response, public service provision, and infrastructure recovery. Climate events can accelerate wear and tear on infrastructure, increase operating costs, disrupt revenue through reduced business activity, and increase demand for emergency services, debris removal, and temporary housing. A municipality's ability to respond to climate events is influenced by its financial resources, institutional capacity, and readiness. These factors vary widely between urban and rural communities and ultimately shape how effectively a locality can absorb, manage, and recover from climate-driven disruptions. **Figure 13** illustrates how climate change strains public finances from multiple directions by reducing tax revenues and increasing the cost of essential government services.

The scale and frequency of climate-related hazards increasingly exceed the capacity of Tribal Nations, states, and local governments to respond effectively. State agencies and federal programs—such as FEMA's Public Assistance Program, which typically covers at least 75% of eligible costs for federally declared major disasters—play an essential role in supporting municipal post-disaster response and recovery efforts. As sovereign governments, Tribal Nations may face additional administrative and financial barriers in accessing FEMA post-disaster assistance, including capacity constraints and differences in eligibility pathways compared to state and local governments, which can delay recovery (GSA, 2026).

Public spending is not only a tool for disaster response, but also a foundation for long-term climate adaptation. Strategic investment in preparedness, mutual assistance frameworks, and hazard mitigation planning can enable governments to build institutional capacity and better manage future risks. Advances in technology and innovation further enhance governments' ability to plan and respond effectively through improved hazard mapping, early warning systems, and climate-resilient infrastructure design.



Fiscal Risks of Climate Change

Figure 13: *Climate change places growing stress on government finances. Tax collections can decline when residents are displaced, real estate values fall, household incomes drop, and local business activity slows. At the same time, governments face higher costs for maintaining and upgrading infrastructure, providing disaster response and recovery, covering healthcare needs, and supporting public insurance programs. These combined fiscal pressures can weaken public credit ratings, raise borrowing costs on instruments such as municipal bonds, and limit governments' capacity to fund essential services. Source: The Fifth National Climate Assessment, Chapter 19: Economics.*

4.1 Government Costs of Disaster and Post-Disaster Response

The State of California is expected to face growing costs as it works to protect communities and respond to climate-driven disasters. Wildfire protection, in particular, represents a rapidly expanding cost: expenditures from the state's General Fund for wildfire protection have increased from approximately $750 million in 2005 to nearly $2.9 billion by 2020 (Morales et al., 2022). In parallel, CAL FIRE's annual budget increased by $2 billion between 2018 and 2024, enabling the agency to double its personnel, expand the world's largest aerial firefighting fleet, double the number of prescribed burns between 2021–2023, and invest in drone technology, artificial intelligence, and satellite-based real-time data tracking tools (GO, 2025). The 2024–25 State budget also included substantial investments in climate and natural resource resilience, allocating $297 million to address extreme heat, $858 million for flood planning and response, and $662 million towards coastal resilience and sea level rise adaptation (CDOF, 2025a).

Local governments in California incur substantial operating costs in the aftermath of disasters, as local first responders are tasked with coordinating emergency services and restoring essential infrastructure. These costs include overtime pay for emergency personnel, debris removal, temporary shelter operations, damage assessments, and emergency communications (FEMA,

2025c). Additionally, California maintains mutual aid agreements that facilitate rapid deployment of state and local emergency responders within the state, across state boundaries, and with international partners, with reimbursable costs that include overtime and backfill for deployed personnel, travel and lodging, fuel, and specialized equipment (Cal OES, 2022, 2023b).

Post-disaster response costs include debris removal activity. The clean-up effort of the 2018 Camp Fire, which destroyed close to 19,000 buildings, was the largest debris removal to date and cost CalRecycle and the California Office of Emergency Services (Cal OES) over $1.35 billion (Cottom, 2019). The 2025–26 State budget includes $2.5 billion to support ongoing debris removal and other recovery efforts in Los Angeles from the Palisades and Eaton Fires (CDOF, 2025a). In the Los Angeles area, the average cost of debris removal was $100,000 for homeowners who opted to not utilize the free State program (CDI, 2025a).

Longer-term recovery costs may involve rebuilding public facilities, restoring water and power systems, and repairing roads and bridges—expenses that can extend for months or even years after the initial event (FEMA, 2025c). While state and federal programs such as Cal OES and FEMA's Public Assistance Program can ultimately reimburse a large share of eligible disaster costs, smaller or rural municipalities often lack the reserve funds or administrative capacity to cover these expenses up front, delaying recovery efforts (NACo, 2024).

Wildfires can have a sustained negative impact on municipal budgets (Liao & Kousky, 2022). One study that analyzed municipal financial data from 1990–2015 alongside historical wildfire perimeter data found that in the five years following a wildfire, total general revenues rose by 10.5%, but total expenditures increased by 17.6%, driven largely by higher spending on public safety, community development, and transportation (Liao & Kousky, 2022). Despite some offsetting revenue increases, the overall budgetary impact was negative: excess revenues declined by $97 per capita, and municipalities were 25 percentage points more likely to run a budget deficit. Because the study period predates California's most catastrophic recent wildfire years, including 2017 and 2018, the estimates likely represent a lower bound for the fiscal impacts of more severe future fires. These findings suggest that wildfire recovery can create multi-year demands on local government services, including rebuilding, permitting, planning, emergency services, and disaster preparedness.

In the aftermath of flooding, local governments can incur significant expenses related to road closures, damage to public buildings, downed tree and debris removal, long-term infrastructure repairs, and lost revenue from business disruptions and economic slowdowns. These response and recovery efforts, while essential for protecting public health, can strain municipal budgets through increased spending on personnel, supplies, facility operations, and outreach. As a recent example, the January 2024 storm event in San Diego County caused an estimated $30.8 million in damage to public infrastructure (GO, 2024a). The same event generated 112 rescue calls, 182 flood responses, and 60 road closures for the San Diego Police Department, 148 flood rescues for the San Diego Fire Department, 13 unplanned outages reported by the San Diego Gas and Electric Company, and documented flooding impacts for more than 100 businesses (GO, 2024a).

Additionally, extreme heat can damage roadways and built infrastructure in ways that are not always recognized or counted as heat-related costs. However, available event-level estimates show that these damages can be substantial: the 2022 Coastal Inland Heat Wave generated over $6.3 million in road repair expenses for city and county governments (CDI, 2024).

4.2 Increased Demand for Public Services and Emergency Response

Climate change is driving an increased demand for a wide array of public services, placing additional strain on government operations and budgets. Heat events are associated with higher mortality, greater use of emergency medical services, and more bookings for violent offenses (Gould et al., 2025; Sturm et al., 2024). Under moderate climate projections, California is expected to see approximately 1.5 million additional temperature-driven emergency department visits cumulatively through 2050, with additional annual emergency department costs of roughly $52 million by 2050—costs that fall partly on public health systems and government-funded insurers (Gould et al., 2025). Local governments may also face costs related to opening cooling centers, extending hours at public facilities such as pools and libraries, distributing water and ice, deploying misting stations in high-traffic areas, and issuing public health alerts (CDI, 2024; Larsen, 2015). These services require additional staffing, resources, and infrastructure, contributing to higher operational costs for municipalities. For more information, see *Section 1.3: Health Care Delivery and Emergency Operations.*

Wildfire risk is similarly increasing demand for state and local firefighting services and related public safety functions. The US Forest Service is experiencing a shortage of wildland firefighters, and California is short approximately 1,250 wildland firefighters (Bozeman, 2024). Staffing shortages can increase reliance on overtime, contracted personnel, and additional equipment, raising public-sector response costs while potentially reducing emergency response capacity (Petek, 2024). Addressing this shortfall may benefit from strategic investment in workforce development, including partnerships between fire departments and school districts to provide hands-on training and career pathways for students (Bozeman, 2024).

Box 15: *Municipal-Led Climate Adaptation Planning*

In addition to responding to immediate crises, local governments can also plan for and adapt to the long-term demands of a changing climate, which require strategic investments in staffing, training, and technology (Gabbe et al., 2021). Adaptation planning also requires significant public investment. For instance, municipalities in Los Angeles County may face up to $780 million annually in climate adaptation costs through 2040 to address extreme heat, shifting precipitation patterns, wildfires, sea level rise, and related public health risks (CCI, 2024). The largest projected expenses are tied to stormwater infrastructure, cool pavements, and expanding the urban tree canopy (CCI, 2024). To reduce the impacts of extreme heat, municipalities can invest in adaptation measures such as green or blue roofs, cool pavements, and expanded tree canopy (Larsen, 2015). These adaptation efforts often require cross-agency coordination, sustained funding, and long-term planning at the local level.

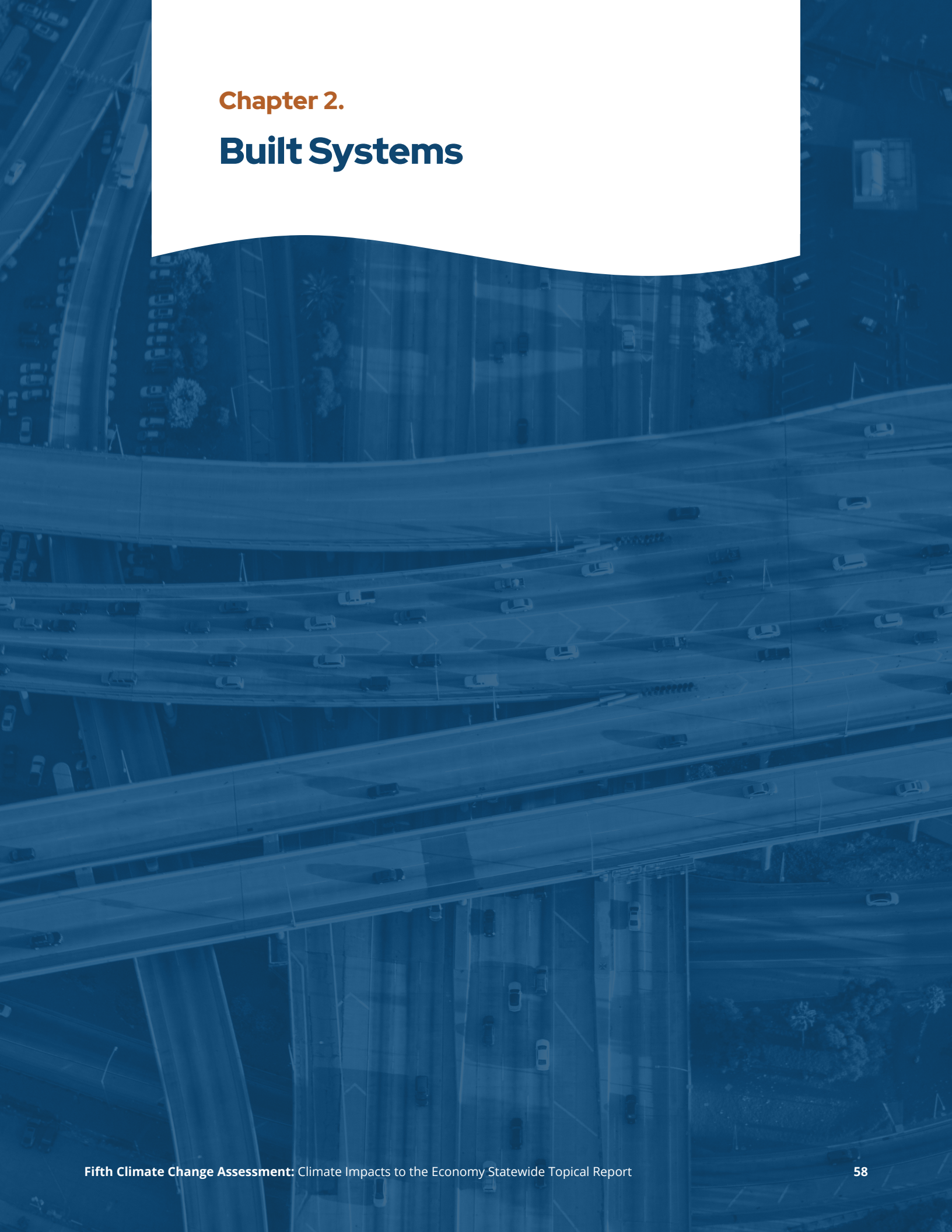
4.3 Climate Risks and Borrowing Costs

Climate-related risks are also beginning to be evaluated within municipal credit ratings and lending practices (Butler & Uzmanoglu, 2023). Despite growing climate threats, municipal bonds are still often priced without accounting for climate risks, with cities facing high flood or wildfire exposure often paying the same yields as lower-risk municipalities. As climate risks become more evident, municipal bonds from highly exposed areas may be seen as riskier, leading to higher

borrowing costs that limit local governments' ability to fund essential infrastructure and climate adaptation, potentially reinforcing a cycle of underinvestment and growing vulnerability (Jeon et al., 2024).

New research suggests that investors are beginning to factor these kinds of climate risks into borrowing costs. One study analyzed how exposure to extreme heat affected municipal borrowing across the US between 2013 and 2020 and found that places with higher heat stress paid modestly higher interest rates on their bonds (Acharya et al., 2024). For municipal bonds, jurisdictions facing annual heat-related damages equal to 1% of local GDP pay roughly 0.15 percentage points (15 basis points) more per year than otherwise similar, less-exposed communities (Acharya et al., 2024).

The municipal bond market serves as a critical tool for financing climate adaptation. In 2017, California became the first US state to surpass $5 billion in municipal green bond issuance, establishing itself as a national leader in the use of green bonds to support environmental and climate-resilient infrastructure (CBI, 2017). In 2024, the State of California passed Proposition 4, the Safe Drinking Water, Wildfire Prevention, Drought Preparedness, and Clean Air Bond Act, which established a $10 billion general obligation bond to finance climate adaptation and resilience measures available to municipalities to fund additional water and climate initiatives in categories of coastal resilience, nature-based solutions, water supply and droughts, forest health and wildfires, and extreme heat (Sencan & Cole, 2025). These bond programs illustrate how the state is using the municipal bond market to embed climate resilience into core infrastructure finance, rather than treating adaptation as a separate or ad hoc activity. For a broader overview of adaptation financing approaches and mechanisms, see the Fifth Assessment's "Adaptation Finance" report prepared by the California Department of Insurance.



Chapter 2.

Built Systems

Climate change is creating growing economic risks for California's built systems, as extreme heat, wildfires, drought, flooding, sea level rise, and severe storms damage infrastructure and disrupt operations. These climate stressors affect real estate markets, insurance, energy grids, transportation networks, and water systems, especially those assets that are designed for historical climate conditions and are nearing or exceeding their intended lifespans (ASCE, 2025).

Real estate markets face growing risks from wildfires, driving up insurance costs and increasing reliance on the state's FAIR Plan (CDI, 2025b). Extreme heat and wildfires are increasingly threatening the integrity of power lines, contributing to grid outages and costly interruptions in electricity supply, which disrupt businesses and increase operational expenses (CSIWG, 2018). Prolonged drought conditions reduce reservoir capacities, impacting water availability for residential, agricultural, and industrial uses, which can suppress economic productivity and drive supply shortages (Grenier et al., 2024; Lund et al., 2025). Sea level rise and storm surges endanger critical coastal infrastructure such as highways, rail corridors, and port terminals, exposing vital trade and transportation hubs to flooding and costly repairs (ASCE, 2025; CNRA, 2023). Additionally, more intense rainfall and flooding events overwhelm stormwater systems, leading to property damage, service disruptions, and increased public spending on emergency response and infrastructure upgrades (CDOF, 2025b; CSIWG, 2018).

5. Real Estate and Property Insurance

Key Takeaways

1. **Climate change is reshaping housing markets and eroding the affordability and availability of fire insurance.** Wildfires and floods increase delinquency, foreclosure, and mortgage risk in affected areas (Biswas et al., 2023; Issler et al., 2024). Rising wildfire risks together with increases in reconstruction costs and changes to ratemaking rules have driven up fire insurance premiums, deductibles, and non-renewal rates; home insurance premiums in California increased by more than 23% between 2017 and 2022 (Boomhower et al., 2024).

2. **Wildfire and flood insurance protection gaps expose households and governments to mounting costs.** California's FAIR Plan exposure surged from $50 billion in 2018 to about $750 billion as of March 2026, a fifteenfold increase that underscores how quickly wildfire risk is being shifted from the private market to the state's insurer of last resort (CFP, 2026). Only about 7% of California households in flood-risk areas have flood insurance, while more than $900 billion in homes and other buildings statewide are at some risk of flooding (PPIC, 2025).

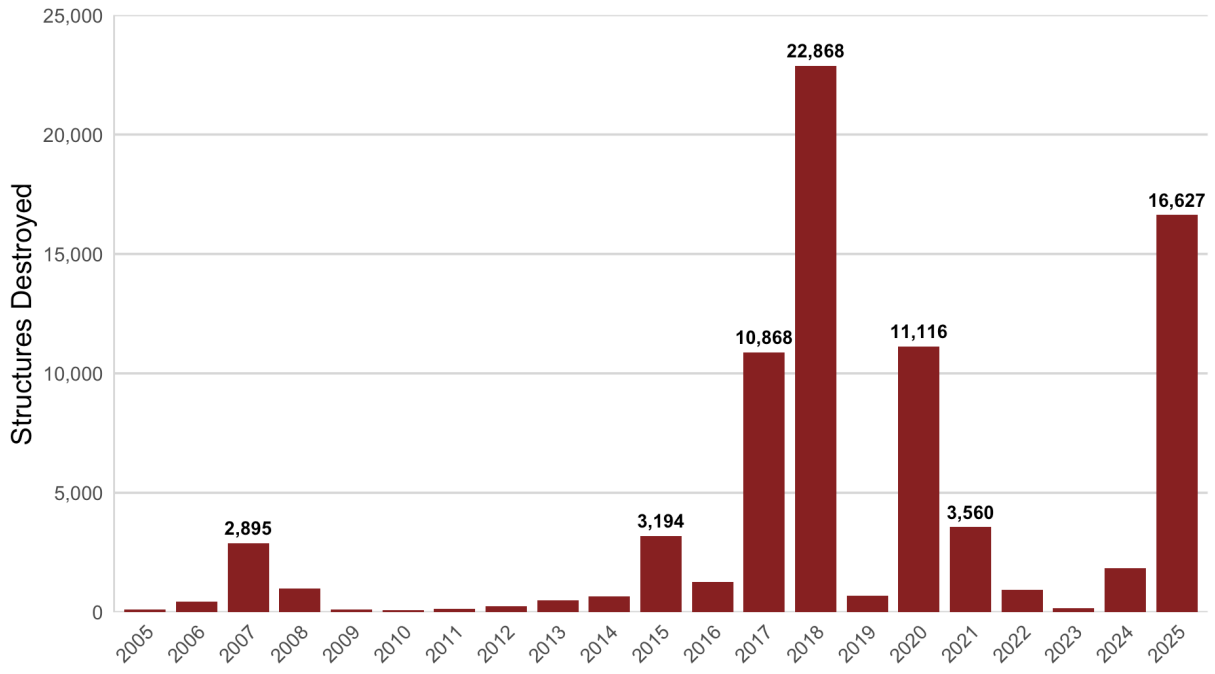
3. **Displacement after disasters carries long-term social and economic costs.** Flooding and wildfire can force costly relocation and long-term community disruption, with affordable housing units especially vulnerable to permanent loss (Buchanan et al., 2020). The 2018 Camp Fire displaced around 53,000 residents, many of whom faced downward mobility into higher-poverty neighborhoods (Chase & Hansen, 2021; Din, 2023). Large-scale displacement can weaken local tax bases and alter regional housing markets.

5.1 Wildfire Impacts on California's Real Estate Market

Wildfires can impose substantial losses to the built environment, especially during fast-growing, wind-driven events (Buechi et al., 2020). Direct costs include property damage to homes, businesses, and public facilities; damage to critical infrastructure; debris removal and hazardous-waste management; environmental remediation; and post-fire restoration to stabilize hillsides and prevent future erosion events that would put buildings and infrastructure at risk. Indirect losses include business interruption, displacement, smoke-related health costs, and reduced tax revenues. Extended recovery timelines increase overall economic impacts, with rebuilding costs often rising due to code upgrades and strained construction capacity (Pradhan & Arneson, 2020). Studies suggest that annual forest burned area in California has increased about fivefold since the 1970s, and modeling indicates that anthropogenic (human-influenced) warming explains nearly all of this change, resulting in about 320% more forest area burned over 1996–2021 than would have occurred without human-caused climate change (Turco et al., 2023; Williams et al., 2019).

Housing prices in California's post-fire market are increasing on average, compounding affordability challenges for affected communities (Issler et al., 2024). The scale of structural losses from recent wildfires is significant enough to impact both housing costs and the availability of units statewide. As one example of this pressure on supply, the Palisades and Eaton fires together destroyed roughly 9% of the homes California added in the previous year and more than 60% of the new units built in Los Angeles County in 2024 (Ahumada-Paras et al., 2025; CDOF, 2025c). This loss of housing stock may have contributed to upward price pressure nearby: home prices in neighborhoods within three miles of the Los Angeles 2025 wildfires were approximately 4% higher than the previous year (Pop-Badiu, 2025). In wildfire burn areas across California, home prices increased relative to comparable nearby unaffected areas, rising from approximately 2% above control areas in the first year after a fire to as much as 6% by year four, based on wildfires occurring between 2001–2018 (Issler et al., 2024). These effects layer onto a long-standing upward trend in California's housing market; home prices increased by 76% from 2012–2020, compared to the national increase of 47% (FRED, 2025). Price increases post-wildfires are partly driven by statewide housing scarcity and market-wide appreciation as well as post-fire reconstruction to updated building codes and larger building footprints, which together raise neighborhood property values (Issler et al., 2024).

Over the past few decades, wildfires have grown in both size and destructiveness, with megafires now an accelerating trend (Buechi et al., 2020). New methods of categorizing wildfires by their peak daily growth rates show that "fast fires," those that grow by more than 4,000 acres in a single day, are far more destructive and costlier to suppress. A national study of more than 60,000 wildfires revealed that fast fires accounted for 78% of all structures destroyed and 61% of suppression costs (Balch et al., 2024). In California, fires grew nearly four times faster in 2020 than in 2001 (Balch et al., 2024). **Figure 14** shows the emergence of highly destructive fire seasons over the past decade, with especially severe structure losses in 2017, 2018, 2020, and 2025. California's 2017, 2018, and 2020 fire seasons, and the 2025 Palisades and Eaton fires generated insured losses of roughly $12, $13, $9, and $40 billion, respectively (CDI, 2018, 2019; Bellisario et al., 2021; Bowen et al., 2025).



Count of Structures Destroyed from Wildfires in California (2005–2025)

Figure 14: *Structures destroyed defined as residence, commercial property, outbuilding, or other structure that is declared lost. Fires in 2017 include the Thomas Fire, which destroyed 1,080 structures, as well as the Mendocino Lake Complex, Central LNU Complex, Southern LNU Complex, and NEU Wind Complex incidents, which destroyed a combined total of 8,865 structures. Fires in 2018 include the Carr, Camp, and Woolsey fires, which destroyed 1,614 structures, 18,804 structures, and 1,185 structures, respectively. Fires in 2020 include the group of incidents known as the '2020 Fire Siege,' which destroyed a combined total of over 9,000 structures. Fires in 2025 include the Palisades and Eaton fires, which destroyed 6,845 and 9,419 structures, respectively. Source: (Cal FIRE, 2024, 2025)*

Wildfire impacts on real estate markets extend beyond housing. California's 2018 wildfire season had approximately $27.7 billion in capital losses, defined as the cost to repair or rebuild damaged or destroyed assets, including $23.2 billion in productive capital losses to commercial, industrial, and public assets (Wang et al., 2020). Separately, sector-level analysis estimates $9.3 billion in damages to the real estate industry, with 77.2% concentrated in capital losses (Wang et al., 2020). In the 2025 Los Angeles fires, the burn areas contained 1,863 businesses employing about 9,610 people and generating an estimated $1.4 billion in annual sales (LAEDC, 2025). These nonresidential losses connect wildfire risk to the broader real estate market through damaged commercial space, disrupted tenants and employers, and delayed reoccupation and rebuilding. The Los Angeles Economic Development Corporation estimates that business interruptions from the Palisades and Eaton fires could reduce Los Angeles County economic output by $4.6–$8.9 billion over 2025–2029 (LAEDC, 2025).

Box 16: *Growing Wildland-Urban Interface Housing Drives Future Wildfire Damage Risk*

In California, the share of housing in wildland-urban interface zones has increased about 40% from 3.6 million housing units in 1990 to 5.1 million housing units in 2022 (Kumar et al., 2025). These zones have higher fire risk and the growing exposure to high-risk areas has impacted real estate and property insurance markets (Radeloff et al., 2018). Around 70% of the largest wildfires in California in the past decade originated within 1 km (0.62 miles) from the edges of the wildland-urban interface (Kumar et al., 2025). The Sacramento Valley experienced the largest increase, with wildfire risk growing 8.7-fold (770%) over the past three decades—an average annual rate of 26%, more than double the statewide average of 12% per year (Kumar et al., 2025). The San Joaquin Valley and North Coast each saw a 5.4-fold (440%) increase at 16% annually (Kumar et al., 2025).

5.1.2 Adaptation Strategies to Increase Home Resilience Against Wildfires

Home hardening and updated wildfire building code standards can substantially reduce structure losses when homes are exposed to wildfire. In the 2018 Camp Fire, homes built after 1997 survived at more than three times the rate of pre-1997 structures (38.5% vs. 11.5%), reflecting incremental improvements in construction materials and lot spacing over time (Knapp et al., 2021). Other research shows that homes built on or after 2008 are 13 percentage points less likely to be destroyed than a 1990 home experiencing the same wildfire exposure (Baylis & Boomhower, 2026). Homes with updated building codes can also generate neighborhood-level benefits because wildfire risk is not limited to individual parcels: when homes are close together, one structure can become an ignition source for another. Research finds that each additional pre-code home within 10 meters (33 ft) increased nearby structure destruction risk by about 1.7 percentage points, suggesting that code-compliant construction can reduce structure-to-structure fire spread (Baylis & Boomhower, 2026).

New empirical evidence underscores how combining home hardening with defensible space substantially increases the likelihood that homes survive wildfire events. A recent analysis of 47,742 homes across five major California fires using CAL FIRE's Damage Inspection data finds that home hardening alone is associated with an average 25% home survival rate (Zamanialaei et al., 2025). Adding vegetation removal within the first five feet around the home (Zone 0) increases survival to about 40%, and extending defensible space treatments out to 30 feet (9.1 m) (Zone 0 plus Zone 1) raises survival to roughly 48% (Zamanialaei et al., 2025). These findings suggest that layered mitigation and home hardening combined with cleared defensible space offer substantially better protection than either intervention alone.

Homeowners can engage in targeted or piecemeal replacement efforts to keep costs manageable. Some meaningful steps to reduce vulnerability can be implemented at little to no cost to homeowners, such as removing flammable materials from decks, clearing gutters, and removing vegetation and debris from the roof (Barrett & Quarles, 2024). An estimated average mid-cost retrofit, including replacing exterior vents with flame- and ember-resistant vents, installing metal flashing at all deck-to-wall intersections, installing metal gutter guards, and replacing bark mulch with noncombustible gravel mulch, can cost $10,000 to $15,000 for a 2,000-square-foot home (Barrett & Quarles, 2024). Full retrofitting costs can vary widely. California's statewide Home Hardening & Defensible Space program reports an average of about $50,000 per home across 20 completed projects (LAO, 2025b). A comprehensive, top-tier retrofit can range from $60,000 to over $100,000, depending on scope and home condition (Barrett & Quarles, 2024). Homeowners

can reference *California's Wildfire Community Hardening Framework* for information on priority home-hardening measures, defensible space standards, and program criteria for participating in the state's home-hardening and mitigation assistance efforts (Cal OES, 2026). More information on financing options can be found in the Fifth Assessment's "Adaptation Finance" report prepared by the California Department of Insurance.

Home-hardening investments can also generate broader economic benefits. One statewide assessment identifies approximately 620,000–770,000 at-risk single-family homes in California's fire hazard severity zones and applies a prototype 2,000-square-foot home with a 100-square-foot deck to estimate retrofit costs, then economic modeling to estimate how this spending would support jobs, household income, Gross Domestic Product, and tax revenues (Risner & Delaney, 2025). The study estimates that each dollar invested in retrofitting homes yields roughly $1.70 in total economic activity, indicating that home hardening delivers a positive economic return in addition to reducing disaster losses (Risner & Delaney, 2025). This analysis estimates that moderately hardening at-risk homes is a large but tractable undertaking: upgrading vulnerable housing stock statewide is estimated to cost on the order of $16–$20 billion (Risner & Delaney, 2025). For comparison, the 2025 Palisades and Eaton fires are projected to cause $76–$131 billion in property and capital losses (Li & Yu, 2025).

However, resilience investments should be considered alongside the policies that shape where new housing is built. State and local governments already use several tools to steer growth toward lower-risk areas: zoning and land-use streamlining laws that make infill development easier; infrastructure investments in water, broadband, and transportation that support housing outside the wildland-urban interface (WUI); and General Plan Safety Elements, which under SB 379 must include climate vulnerability assessments and adaptation and mitigation measures. Some jurisdictions go further; Santa Clarita, for example, gives processing and funding preference to new residential development outside Very High Fire Hazard Severity Zones. New construction in the WUI and in moderate to very high fire hazard severity zones must also meet Chapter 7A of the California Building Code.

The importance of these land-use choices extends beyond the immediate risk to individual properties. Infill development carries lower wildfire risk to residential structures relative to expansion and leapfrog development (Syphard et al., 2013), while development in high-risk areas can impose substantial public costs. Public agencies spend roughly $1.5 billion per year protecting western US homes from wildfire, with expected protection costs exceeding 20% of home value for the highest-risk 1% of homes (Baylis & Boomhower, 2023). Home hardening and building codes reduce damages, but they work best when paired with risk-aligned land-use planning and with financing structures or cost-relief programs, including neighborhood-scale resilience efforts, that keep hardening affordable across income levels and improve insurability.

5.2 Climate-Driven Flooding Risks

California also faces growing flood risk which is projected to intensify with sea level rise and more extreme precipitation events (PPIC, 2025). Currently, approximately 4 million residents, $487.4 billion in structures, and nearly 30% of the state's agricultural production (valued at about $12.3 billion) are located within the 100-year floodplain (CDWR, 2024c). Nearly one in five Californians

live within a 500-year flood zone (CDWR, 2024c). Atmospheric rivers play a central role in shaping this risk, contributing up to half of the state's annual precipitation and driving more than 80% of observed flood damages (CDWR, 2024c; Corringham et al., 2019). Addressing these risks will require significant investment, with statewide flood management needs estimated at $95 billion over the next 50 years (CDWR, 2024c).

Projections of flood exposure vary depending on the methods used to quantify vulnerability and the sea level rise or storm scenarios applied. One analysis estimates that sea level rise of 1, 2, and 4 feet (about 0.3, 0.6, and 1.2 meters) along the California coast is projected to put approximately 10,900, 19,000, and 66,600 homes, respectively, at risk of chronic inundation, with associated property value losses of about $11 billion, $20 billion, and $68 billion, respectively (Yu, 2020). Other estimates support that by 2050, 20 inches (50 centimeters) of sea-level rise could inundate an estimated $17.9 billion worth of buildings statewide (Barnard et al., 2019). Regional estimates that include households exposed not only to chronic inundation but also to temporary flooding from storm surge can be considerably larger. One San Francisco Bay Area assessment identifies about 75,000 households at risk under 1.4 feet of sea level rise combined with a 100-year storm (MTC, ABAG, & BCDC, 2023).

Despite these projections, California's coastal real estate market only partially reflects sea level rise risk. Prior to 2024, California did not require sellers to disclose sea level rise risk in real estate transactions, relying instead on FEMA flood zone designations that reflect historical rather than projected future flood exposure. While 2024 updates added limited disclosures tied to California Ocean Protection Council-identified risk zones, FEMA maps remain the primary instrument for flood risk communication to buyers (Dadashi, 2023). Between 2011–2020, homes in flood-exposed coastal areas appreciated faster than the broader California market, even as scientific projections documented growing risk (Yu, 2020).

This pattern reflects a broader tendency of real estate markets across the US to systematically undervalue flood risk. By 2050, under a moderate emissions scenario (RCP 4.5), flood-exposed residential properties across the US are projected to be overvalued by $187 billion in unpriced climate risk, with overvaluation concentrated in coastal counties that lack robust flood disclosure laws (Gourevitch et al., 2023). Evidence from states with mandatory flood risk disclosure laws suggests these policies can meaningfully correct this mispricing. A nationwide study found that the price discount applied to flood-zone homes is significantly larger in states requiring seller disclosure, indicating that stronger risk communication could help California's coastal market better reflect the true long-term cost of sea level rise exposure (Hino & Burke, 2021). The gap between hazard risk projections and market valuations raises concerns about a future repricing shock, with potential consequences for homeowners and local tax bases that depend on property values for public revenue.

5.3 Property Insurance Markets

5.3.1 Wildfire Insurance: Increasing Premiums, Rates of Non-Renewals, and Reliance on FAIR Plan

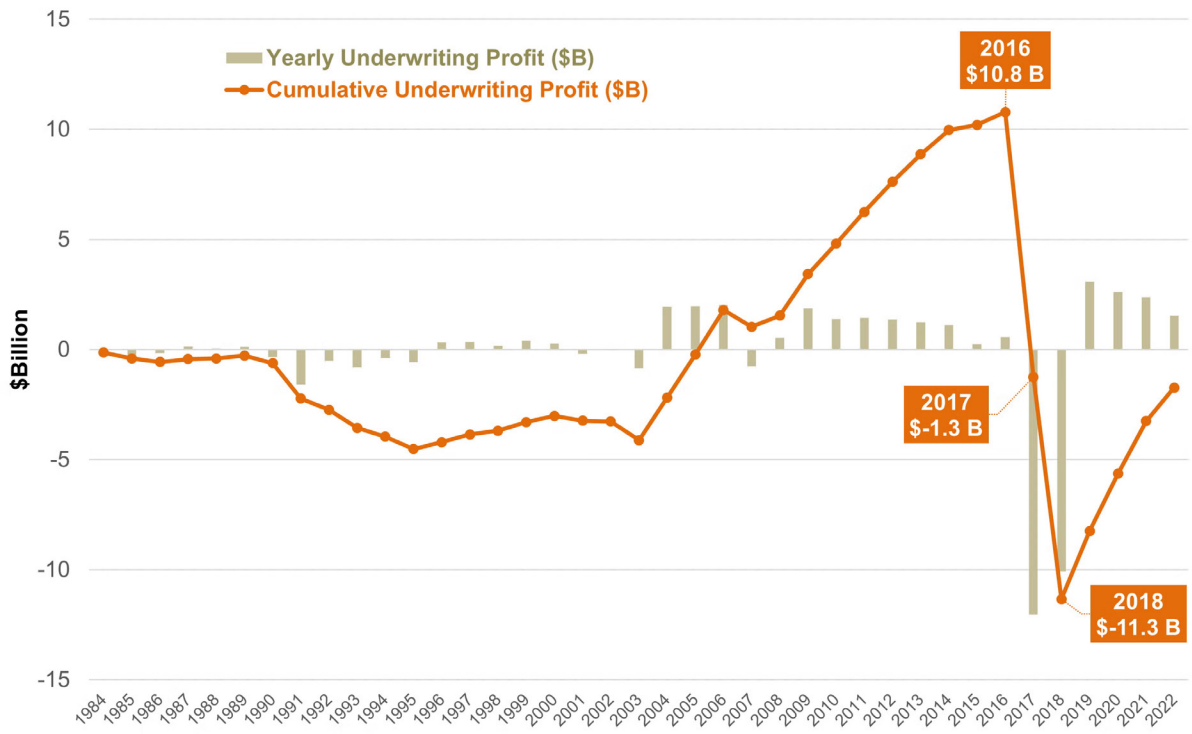
Rising premiums and reduced availability reflect climate-related risk alongside other factors. Reconstruction costs have risen sharply over the last decade; nationwide, the costs of both single-family residential construction materials and construction labor increased by roughly 45% between 2014 and 2023 (FIO, 2025). The price and availability of reinsurance, which is influenced by catastrophe losses globally, including those associated with climate-related events, also shapes what primary insurers charge and where they write coverage (FIO, 2025). The discussion of rising premiums in this section should be read with these factors in mind.

Prior to the 2017–2018 fire seasons and the reforms described below, California's regulatory framework kept homeowners' insurance premiums relatively low by tying rates mainly to historical losses and limiting the use of forward-looking wildfire models and reinsurance costs (Oh et al., 2022). This "rate suppression" meant wildfire risk was systematically underpriced, leaving insurers exposed when catastrophic losses surged after 2017 and contributing to rapid premium increases and coverage withdrawals in high-risk areas (Adarkar et al., 2025). Between 2022 and 2025, California undertook its most significant insurance regulatory reform since Proposition 103 in 1988. Under the Sustainable Insurance Strategy, insurers may now use forward-looking catastrophe models and reflect net reinsurance costs in rate filings, in exchange for commitments to expand coverage in distressed and wildfire-prone areas, alongside measures to speed rate reviews and strengthen the FAIR Plan (CDI, 2023a). These reforms are recent, and their effects on premiums and availability are not yet fully observable.

Research shows that households and communities with strong insurance coverage recover more quickly and more completely after catastrophes (Carpenter et al., 2020; CSIWG, 2018; Kousky, 2019). As premiums rise and coverage tightens in high-risk parts of the state, there is a growing risk that more households will enter future disasters underinsured or uninsured, eroding the recovery benefits that insurance can provide at the community level. Since 2022, 7 of the 12 largest homeowners insurers (the 12 together write about 85% of the California market) have paused or restricted new business despite rare increases approved or pending with the Department of Insurance (CDI, 2023b).

California's $15 billion homeowners' insurance market, the largest in the country, is increasingly shaped by wildfire risk (Adarkar et al., 2025; Center for Climate Integrity, 2025). **Figure 15** shows how property insurance companies in California experienced significant underwriting losses due to wildfires in 2017 and 2018. Following those wildfire seasons, non-renewals increased in ZIP codes with moderate to very high fire risk (Bikales, 2020; CDI, 2021), though it is important to note that a non-renewed household may end up with another admitted-market policy, a surplus lines policy, or a FAIR Plan policy. Growth in FAIR Plan policies and exposure, discussed below, is a more reliable indicator of reduced private-market availability. California counties with the highest

non-renewal rate increases between 2018 and 2023 were Lake, Nevada, Shasta, Mendocino, and El Dorado (Senate Budget Committee, 2024). Mortgage markets also face increased delinquency and prepayment rates on damaged homes after wildfires, compounding risks for lenders and homeowners (Biswas et al., 2023; CCI, 2025; Kosmala-Dahlbeck et al., 2025).



Homeowner Insurance Underwriting Profits

Figure 15: *Yearly and cumulative underwriting profits of private homeowners' insurance in California. Underwriting profit is defined as earned premiums minus incurred losses and loss-adjustment expenses minus underwriting expenses; it excludes investment income, taxes, and other non-underwriting gains. After back-to-back wildfire seasons in 2017 and 2018, homeowners' insurers aggregated an underwriting loss of over $10 billion, with 92% of the total market share of insurers reporting underwriting losses. Source: (Kousky, 2025).*

The exodus of private insurers has resulted in the rise of residual markets, often referred to as the insurers of last resort. These markets are largely made up of the California Fair Access to Insurance Requirements (FAIR) Plan, the state's high-risk insurance pool. As private insurers pulled back from high-risk areas, the FAIR Plan saw its share of the residential market grow from 1.6% in 2015 to 3.7% in 2023 (CDI, 2025c). California's FAIR Plan doubled its number of policies between 2018–2023, holding 451,000 policies as of September 2024 (First Street, 2025; Kousky, 2025). As of March 2026, the California FAIR Plan covers approximately 685,000 policies totaling about $750 billion in insured exposure, up from $50 billion in exposure in 2018 (CFP, 2026).

5.3.2 Flood Insurance: Widespread Underinsurance and Rising Exposure

Since flood insurance is typically not included in standard homeowner insurance policies, homeowners in FEMA-designated high-risk flood zones that hold a federally backed mortgage

are required to obtain coverage through the National Flood Insurance Program (NFIP). Today, nearly 180,000 NFIP policies are in force in California, with approximately $54 billion in coverage (FEMA, 2025a, 2025b). However, FEMA's Flood Insurance Rate Maps are frequently cited as underestimating actual flood risk because they do not incorporate future climate-driven hazards such as sea level rise and more intense precipitation (Schubert et al., 2024; Wing et al., 2018). Independent analysis by the nonprofit research group First Street Foundation estimates that the actual number of properties at risk is much greater, at 1.1 million and that an additional 150,000 properties will meet that threshold in the next 30 years (CDI, 2021). Of the roughly 1.1 million homes with a 1% or greater annual chance of flooding, less than half have flood insurance (CDI, 2021). Moreover, changes to the federal National Flood Insurance Program, including lapses in authorization that pause new policies and renewals, could widen California's existing flood insurance gap, and the state does not currently have a residual-market option for flood coverage comparable to the FAIR Plan.

This mismatch in flood insurance risk and coverage is evident in Los Angeles County. FEMA's 1% annual flood hazard area in Los Angeles County currently covers only about 23,000 people, reflecting a relatively narrow view of who is at risk (Sanders et al., 2023). In contrast, updated county-level modeling projects that between 1.3–2.4 million residents and $215–346 billion in property are exposed to flooding above 3 cm, or 1.2 inches (Sanders et al., 2023). In Los Angeles County, Black, Hispanic, and socioeconomically vulnerable populations are disproportionately at risk of fluvial flooding, whereas non-Hispanic white and non-disadvantaged populations are more at risk of coastal flooding (Sanders et al., 2023).

Counties that have experienced the highest historical frequency and magnitude of flood claims under the NFIP constitute key areas of concern for future flood preparedness and mitigation efforts. From 1980 through 2025, NFIP policyholders in California received over $732 million in paid flood insurance claims for roughly 34,000 claims (FEMA, 2025b). Coastal counties have more flood claims on average than inland counties; Sonoma and Los Angeles County have the highest number of historical claims in the state, receiving $130 million and $68.8 million, respectively (FEMA, 2025b). Marin, San Diego, Monterey, and Sacramento County follow, each with between $38 million and $50 million in NFIP historical payouts (FEMA, 2025b).

Underinsurance in flood-prone areas distorts both housing markets and household balance sheets. Houses in FEMA-designated flood zones across the US are currently overvalued by an estimated $43.8 billion, affecting nearly 4 million single-family homes in floodplains whose sale prices do not fully reflect known flood risk and associated insurance costs (Hino & Burke, 2021). If real estate markets fully accounted for expected flood damages and the cost of adequate flood insurance, properties in these flood zones would be worth about 4.7–10.6% less, implying price reductions of up to $106,000 for a $1 million home (Hino & Burke, 2021).

5.4 Out-Migration and the Cost of Displacement

This section highlights two case studies of climate-change-related displacement—the 2018 Camp Fire and the 2023 Pajaro flooding. More recently, the January 2025 Palisades and Eaton fires prompted mass evacuation and displacement across Los Angeles County; while long-term recovery from these fires is still unfolding, future research is expected to provide important

evidence on the household, neighborhood, and local economic impacts of forced displacement from these two events.

In 2018 wildfires displaced over 354,000 people across California, accounting for almost 30% of total new displacements recorded in the US that year (IDMC, 2019). The most prominent singular displacement event that year was the 2018 Camp Fire in Butte County, which remains the most destructive wildfire in California's history (CAL FIRE, 2025). The Camp Fire claimed 85 lives, destroyed approximately 14,000 homes, displaced at least 53,000 people, and caused $11–$13 billion in commercial and residential losses (IDMC, 2019). Evidence from postal change-of-address records after the Camp Fire shows that less affluent households tended to relocate farther than wealthier ones, and over half of adults age 65 and older who moved went more than 30 miles away (Hansen, 2019). Relocating farther from the affected area may signal constrained recovery options, as limited housing availability, financial resources, insurance coverage, or social support can reduce the feasibility of returning or rebuilding (Hansen, 2019). These displacement patterns can shape neighborhood-level real estate outcomes and influence long-run community recovery (Hansen, 2019).

The March 2023 Pajaro levee breach in Monterey County provides a recent case study of flood-driven displacement in California. On March 11, 2023, following a series of atmospheric rivers, multiple breaches along the Pajaro River forced the evacuation of approximately 3,500 residents and caused more than $300 million in direct damages (PRFMA, 2023). The flooding primarily affected low-income Latino and Indigenous farmworkers, many of whom were undocumented and therefore ineligible for FEMA (Gross, 2024). Research on rental markets following flood disasters finds that damaged lower-quality units are more likely to be demolished than rebuilt, and that renters typically lack National Flood Insurance Program coverage for the structures they occupy, increasing the risk that temporary displacement becomes permanent (Brennan et al., 2024; Koller, 2025). In Pajaro, recovery has been slow and uneven, and there is still no comprehensive accounting of how many households experienced long-term or permanent displacements (Rivera et al., 2025). For further analysis of climate-driven displacement patterns, recovery outcomes, and policy implications across California, see the Fifth Assessment's "Climate-Induced Human Displacement and Migration Statewide Topical Report."

Box 17: *Area for Future Research: Climate-Driven Displacement Costs*

The 2023 flooding in Pajaro illustrates the need to better understand the household and local economic costs of climate-driven displacement, particularly for low-income communities, renters, farmworker households, and residents with limited access to formal disaster assistance. More follow-up research is needed to quantify how displacement affects rental market recovery, household income loss, employment disruptions, debt, health, educational continuity, and long-term economic resilience (EPS & IEc, 2021; Li & Yu, 2025). Additional longitudinal tracking could also clarify how documentation status and eligibility for public assistance shape recovery outcomes.

6. Energy

Key Takeaways

1. **Extreme heat is driving sharp increases in electricity demand, amplifying peak load risk and household energy burdens.** Climate change is predicted to increase both the frequency and intensity of days above 90°F (32.2°C), raising electricity demand for cooling. Every 1°F (0.56°C) of warming above 90°F (32.2°C) significantly increases home electricity use, which stresses the grid and increases the risk of outages and blackouts (Auffhammer et al., 2017; Auffhammer, 2022; CDI, 2024).

2. **Transmission and distribution infrastructure face growing physical risks from rising temperatures and wildfire risk.** Wildfires caused by electrical power equipment, including distribution and transmission infrastructure, accounted for approximately 10% of all wildfires in CAL FIRE's jurisdiction each year from 2016–2020 (California State Auditor, 2022).

3. **Climate change is already driving record systemwide energy costs and disruptions.** Public Safety Power Shutoffs in the 2019 wildfire season generated an estimated $10 billion in lost customer value; California's three major utilities spent approximately $5.4 billion per year on wildfire mitigation between 2019–2023 (CPUC, 2024a; Wara, 2019). In California, 61% of major power outages from 2000–2023 were attributed to extreme weather (Chen & Freedman, 2024; Climate Central, 2024).

California remains a major energy-producing state: in 2024, it was the fourth-largest total electricity producer and ranked third nationally in crude oil refining capacity, though recent refinery closures are reducing in-state refining capacity (CARB, 2026; US EIA, 2025). However, California's mild coastal climate, strong energy efficiency standards, and widespread adoption of energy-saving technologies have enabled the state to achieve the nation's third lowest per capita energy consumption (US EIA, 2025). In 2024, natural gas accounted for 40% of California's in-state electricity generation, while non-GHG and renewable resources accounted for approximately 60% of in-state generation (CEC, 2025; US EIA, 2025). Within the in-state generation mix, solar contributed 23%, hydroelectric power 14%, nuclear power 9%, and wind 7% (US EIA, 2025). California's oil refineries are clustered in the San Francisco Bay Area, Los Angeles/South Coast region, and Bakersfield/Kern County (Schremp, 2015).

The energy grid is increasingly vulnerable to climate-related hazards: droughts can significantly reduce hydropower capacity, wildfires and extreme heat can disrupt solar and transmission infrastructure, and changing wind patterns and wildfire-related shutdowns can affect wind power. Similarly, crude oil refining facilities and oil and gas wells face growing risks of physical damage and hazardous emissions from sea level rise and wildfires across the state (Cushing et al., 2023; González et al., 2024).

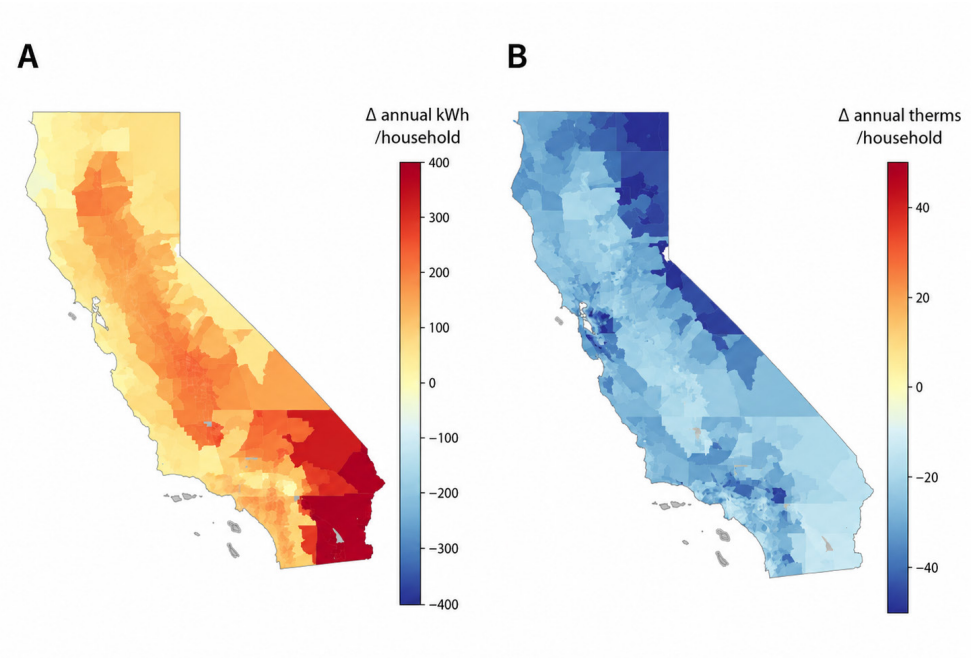
Climate hazards impose significant economic burdens on utilities and consumers through infrastructure damage, cleanup and repair expenses, service disruptions, increased operational costs, and higher electricity prices for households and businesses (Larsen et al., 2018). Nationwide, service disruptions via power outages could impose discounted cumulative costs of $1.5–$3.4 trillion (2015 dollars) on US electric utility customers through mid-century (Larsen et al., 2018).

6.1 Energy Consumption Under Rising Temperatures

Household air conditioning use is expected to increase with rising temperatures, leading to higher electricity use and higher energy costs for consumers and utility ratepayers (Deschênes & Greenstone, 2011; Carleton et al., 2022a). At the same time, extreme heat events strain the energy system by increasing electricity demand while reducing the carrying capacity of transmission lines (CDI, 2024). High temperatures can stress transformers and related equipment and cause power lines to sag and come in contact with vegetation, lowering their efficiency and increasing the risk of failure (Burillo et al., 2019; CDI, 2024). National annual climate-related costs across multiple transmission and distribution components could reach roughly $5 billion by 2030, with transformer-related costs accounting for about 40%, or about $2 billion nationally (Fant et al., 2020). A 1°C (1.8°F) increase in ambient temperature reduces the expected lifespan of large substation transformers by roughly 10%, or about four years (Fant et al., 2020). Together, this combination of higher demand and reduced transmission capacity strains the grid and can increase the frequency of service interruptions and blackouts (CDI, 2024).

Analysis of seven recent extreme heat events in California from 2013–2022 show that median household electricity consumption on days above 91°F (32.8°C) is 5.5% higher than on days at 65°F (18.3°C) (CDI, 2024). Across these events, documented power outages produced an estimated $580 million in economic losses, including $230 million in losses from a single 2022 heat wave where losses were associated mainly with lost productivity and foregone revenue for commercial and industrial businesses that could not operate during the outages (CDI, 2024).

Rising temperatures are likely to continue to drive substantial increases in electricity consumption across California, with the greatest impacts occurring in hotter central and southeastern areas (Auffhammer, 2022; Carleton et al., 2022a). Alternatively, rising temperatures are projected to reduce the number of very cold days in winter, leading to lower household demand for natural gas heating and decreases in natural gas consumption across the state (Carleton et al., 2022a). Although electricity bills are expected to rise with continued warming in the coming decades, households may see partial offsets through lower spending on other energy sources, such as natural gas, due to warmer winters. These projected changes in household electricity and natural gas use are illustrated in **Figure 16**.

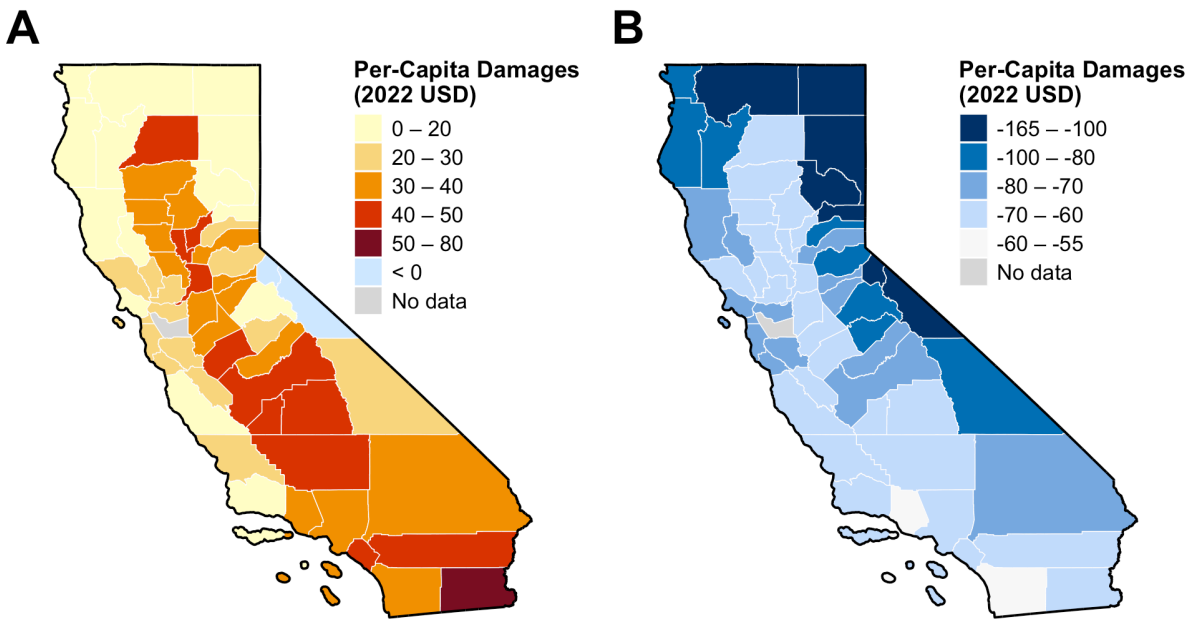


Estimated Change in Electricity and Natural Gas Consumption Per Household

Figure 16: *Median estimates of climate change effects on annual household energy consumption in 2050 relative to 2020 under a moderate emissions scenario (RCP 4.5). Panel A (left) shows projected changes in annual household natural gas consumption, measured in therms per household. Natural gas consumption is projected to decline throughout most of California, reflecting reduced winter space-heating demand under warmer temperatures. Panel B (right) shows projected changes in annual household electricity consumption, measured in kilowatt-hours (kWh) per household. Electricity demand is projected to increase across much of the state, with the largest increases in the Central Valley and the southeastern desert regions, where hotter conditions increase cooling demand. Source: (Carleton et al., 2022a)*

Box 18: *FrEDI Projected Changes in Energy Expenditures*

Figure 17 shows the projected county-level changes in annual per-capita energy expenditures. Panel A shows that electricity expenditures are projected to increase across most of California, with the largest increases concentrated in hotter inland regions, including parts of the Central Valley, inland Southern California, and the southeast. These increases likely reflect higher cooling demand as temperatures rise. Panel B shows the opposite pattern for non-electric energy expenditures, which are projected to decline statewide, with the largest decreases in northern and higher-elevation counties where warmer winters reduce heating demand. Together, the maps show that climate change is expected to shift household energy expenses from heating-related fuels toward electricity, though the net effect will vary by region, energy prices, building characteristics, and access to cooling. While both **Figure 16** and **Figure 17** show consistent directional trends—rising electricity use and spending and falling natural gas use and non-electric energy spending—they differ in time horizon (2050 vs. 2100), emissions scenario, geographic resolution, and unit of analysis (per household vs. per capita), so the magnitudes are not directly comparable.



Projected Changes in Per-Capita Annual Electricity Expenditure and Non-Electric Energy Expenditure in 2100, by County

Figure 17: *Panel A (left) shows projected electricity costs increasing across most of the state from higher cooling demand and related power-sector costs, with larger damages generally concentrated in hotter inland and southern counties. Panel B (right), "Energy (Other)," shows net benefits from reduced use of non-electric heating fuels, primarily natural gas, as warmer winters lower heating demand; these savings are largest in cooler northern and interior counties and smaller in warmer coastal and southern regions. Negative values indicate net benefits, while positive values indicate damages. These figures use information from the Fifth National Climate Assessment and the US EPA Framework for Evaluating Damages and Impacts (FrEDI) analysis to show projected per-capita annual energy impacts under 3°F (1.67°C) of global warming relative to the 1986–2005 baseline, comparable to RCP 2.6, a low radiative-forcing pathway (EPA, 2024; Hsiang et al., 2023; McFarland et al., 2015).*

Box 19: *Adaptation Strategies to Reduce Climate-Driven Outage Risks and Energy Costs*

Utilities can reduce climate-related risks to electricity infrastructure through grid hardening measures such as undergrounding power lines, replacing wood poles with fire-resistant steel poles, and creating defensible space around equipment (Butler et al., 2015; ICF, 2019). In high-risk wildfire conditions, utilities may also use public safety power shutoffs to reduce ignition risk, though these planned outages can create their own costs and disruptions for households, businesses, and critical services.

Households can reduce indoor heat exposure and cooling-related electricity demand through relatively low-cost measures such as sealing HVAC (heating, ventilation, and air conditioning) ducts, adding solar-control window films, and installing exterior window shading, particularly on sun-exposed windows. Larger investments, including attic or roof insulation and reflective cool roofs, can provide additional comfort and energy benefits, especially in older or under-insulated homes and when incorporated into planned roof or building upgrades (Sun et al., 2021).

At the state level, California has also taken steps to address climate-driven reliability challenges. In June 2022, Assembly Bill (AB) 205, AB 178, and AB 180 established the Strategic Reliability Reserve and the Electricity Supply Strategic Reliability Reserve Program to secure additional electricity resources that can be deployed during extreme events. AB 205 also expanded the California Energy Commission's authority to permit large clean energy and storage projects, including battery energy storage facilities of 200 megawatt-hours or more, and supported demand-side programs that compensate customers for reducing net load during grid emergencies. Together with California's rapid battery storage buildout, these measures help shift solar generation into evening peak hours and reduce outage risks during extreme heat events, while adding reliability costs that are recovered through state programs, utility procurement, and ratepayer-funded investments (CAISO, 2025; CEC, 2025).

6.2 Generation and Transmission Infrastructure

Climate change is increasingly exposing California's electricity system to rising temperatures, wildfire, and flooding (Moftakhari & AghaKouchak, 2019). Heat stress in the form of rising air and water temperatures reduces the cooling efficiency of power plants, leading to lower power output during the periods when demand for air conditioning spikes (Craig et al., 2018). In Los Angeles, rising temperatures are projected to reduce operational capacity systemwide by 2% to 20% by 2060 (Burillo et al., 2019). Nationwide, peak temperature changes could drive increases in capital investments for generation capacity by 3–22% (Khan et al., 2021).

Natural gas plants, refineries, and substations along the coast face growing risks from sea level rise and storm surges (Bruzgul et al., 2018). Chevron's El Segundo and Richmond refineries, which together process more than 500,000 barrels per day are especially exposed (Carlson et al., 2015). The Richmond refinery, situated in a community where 80% of residents within a mile of the refinery are people of color and 25% live below the poverty line, highlights the disproportionate environmental justice risks if climate-driven damages trigger toxic releases (Carlson et al., 2015). By 2100, an estimated 60–180 miles of natural gas pipelines in the San Francisco Bay Area could be inundated (Ju et al., 2019). The former Humboldt Bay nuclear plant sits on a shoreline that has eroded by more than 1,000 feet since 1870 and faces projected sea level rise of another three feet over the next 40 years (Upholt, 2023). Storm surges and coastal erosion threaten the site and the onsite storage of spent nuclear fuel.

Wildfire smoke and drought undermine renewable reliability. During the 2020 wildfire season, smoke-related solar losses reduced peak solar generation across California by 10–30% (Juliano et al., 2022). Prolonged droughts, characterized by reduced snowpack and lower reservoir levels, significantly decrease hydropower generation (Forrest et al., 2018; Kern et al., 2020). The 2012–

2016 drought reduced hydropower revenues by $1.9 billion and increased electricity-sector costs by an additional $3.8 billion, as reduced hydropower generation was replaced primarily with natural gas generation (Kern et al., 2020).

High-voltage transmission infrastructure is often located in remote or rural areas and is vulnerable to extreme heat, wildfires, and storm events. Extreme heat can cause power lines to sag, increasing the risk of wildfire ignition (Burillo et al., 2019; CDI, 2024). Between 2000 and 2016, wildfires caused an estimated $700 million in direct damages to the state's energy transmission and distribution systems (Dale et al., 2018). The 2018 Camp Fire cost Pacific Gas & Electric (PG&E) $385 million to repair electric distribution networks, gas transmission and distribution lines, and power generation infrastructure (Feo et al., 2020a). Transmission lines in wildland-urban interface regions around the Los Angeles Basin and San Diego face the highest wildfire risk exposure (CSIWG, 2018; Dale et al., 2018).

6.3 Increased Energy Costs to Consumers and Energy Inequities

6.3.1 Costs Borne by Consumers

Climate-driven disruptions increasingly raise costs for both utilities and customers, even when physical infrastructure is not directly damaged. Most economic damages arise from Public Safety Power Shutoffs (PSPSs), which are implemented proactively to reduce the risk of ignitions during extreme weather events (Abatzoglou et al., 2020). Power outages, both planned and unplanned, pose significant costs to businesses and public health, as they limit access to refrigeration, air conditioning, and medical equipment, with disproportionate impacts on sensitive populations and low-income households. For example, the value of lost load from the 2019 wildfire PSPSs is estimated at around $10 billion (Wara, 2019).

Over the past five years, average electricity costs in California have risen faster than inflation and have increased significantly more than in any other state (CEA, 2026), although state programs (e.g., California Alternate Rates for Energy [CARE] and Family Electric Rate Assistance [FERA] bill discount programs) have reduced the exposure of low-income ratepayers to rising energy costs, and policies adopted by the California Public Utilities Commission (CPUC; e.g., an income-graduated fixed charge) are designed to reduce it further (CPUC, n.d., 2024b). Much of this increase reflects the costs of repairing climate-damaged infrastructure and investing in wildfire-related resilience upgrades, as well as wildfire risk mitigation and liability insurance (CEA, 2026; Wiser et al., 2025). Wildfire-related grid repairs raise utility costs, which are recovered through higher customer rates (Kousky et al., 2018). In 2019, the three largest utilities in California—Pacific Gas & Electric (PG&E), Southern California Edison (SCE), and San Diego Gas and Electric (SDG&E)—collectively spent approximately $4.7 billion in wildfire related expenditures, including spending on grid hardening, vegetation management, inspections, emergency preparedness, and related wildfire-risk reduction activities (Feo et al., 2020a). Currently, wildfire-related charges add roughly $41 per month to the average Pacific Gas & Electric residential bill, $27 for Southern California Edison, and $21 for San Diego Gas & Electric (CEA, 2026). The overall effect of these climate-driven factors is an increase in the financial burden on consumers, making energy less affordable and potentially exacerbating existing economic disparities.

6.3.2 Energy Inequities

Nationwide, low-income, minority, elderly, and renting households are more energy burdened than the average household in the same city (Correa, 2023; Drehobl & Ross, 2016). Highly energy burdened households spend more than 6% of their income on energy bills, and severely energy burdened households spend more than 10% (Correa, 2023). They are less able to invest in cost-saving energy upgrades, leaving them more exposed to rising energy bills and less resilient to the economic impacts of climate-driven energy disruptions (ACEEE, 2024; Le et al., 2024). Being energy-burdened can also have detrimental effects on health, as it can affect a household's access to cooling, food, water, and housing (Correa, 2023).

Low-income households are less likely to have access to air conditioning compared to high-income households, limiting their ability to adapt to extreme heat (Brockway et al., 2021; CEC, 2018). Racial and ethnic minorities also face higher exposure to extreme heat due to a legacy of discriminatory housing policies that shaped built environments with fewer trees and green spaces, and more intense urban heat islands (Cal EPA, 2019). Although residential air conditioning significantly reduces the risks of heat-related illness and death, low-income households in California are less likely to have or afford air conditioning, limiting their ability to adapt to rising temperatures (DNV GL Energy Insights, 2020; Romitti et al., 2022).

Households in under-resourced census block groups in California have a harder time getting rooftop solar because utilities limit new connections in areas with limited circuit hosting capacity, in other words, where local wires and transformers are already near their technical limits (Brockway et al., 2021). As a result, these communities stay more dependent on the traditional power grid, are less able to protect themselves with on-site clean energy and backup power and bear a disproportionate share of health and financial risks when the grid fails or energy costs rise (Brockway et al., 2021).

7. Transportation

Key Takeaways

1. **Rail systems incur sizable delay costs from heat and face expensive coastal relocations due to sea level rise.** Thermal expansion drives speed restrictions, buckling, and rail service disruptions. The heat waves in 2013–2022 produced an estimated $70 million in losses; more than 95% of these losses were from delays (CDI, 2024). In San Clemente and along the Del Mar bluffs, coastal erosion and landslides have triggered temporary service shutdowns, and the San Diego Association of Governments (SANDAG) plans nearly $1 billion in corridor improvements, including bluff stabilization and rail relocation (SANDAG, 2025).
2. **Ports are already investing heavily to remain operable under long-term sea level rise.** California's ports face multibillion-dollar adaptation costs. For example, defending the San Francisco Bay shoreline from sea level rise and storm surge could cost roughly $110 billion

by 2050, with an additional $13.5 billion needed for San Francisco's waterfront (ASCE, 2025; Barnard et al., 2019).

Transportation infrastructure is essential to California's economy, connecting people, supporting commerce and tourism, and enabling emergency response services. It allows California to play a central role in national and global trade. California exported approximately $178.7 billion in goods in 2023 and remains one of the nation's largest goods-trading states, with total two-way goods trade exceeding $600 billion annually (GO-Biz, n.d.). California is a major aviation freight hub, ranking first among states in the continental US for inbound and outbound air freight flights and supporting domestic and international goods movement (GO-Biz, n.d.). The State's ports handle 38% of all containerized cargo entering the US along with 28% of the nation's exports (ASCE, 2025). In 2023, California's Transportation and Material Moving Occupations employed over 1.5 million people, including 517,000 jobs in the Los Angeles, Long Beach, and Anaheim metropolitan areas and 268,000 jobs in the Riverside, San Bernardino, and Ontario metropolitan areas (US BLS, 2023b). In many regions, sea level rise, shifting precipitation patterns, and extreme heat pose significant risks to the transportation system and may compromise its performance, safety, reliability, and economic performance (EPA, 2025c).

7.1 Aviation

California has 26 commercial airports, five of which—Los Angeles International Airport (LAX), San Francisco International Airport (SFO), San Diego International Airport (SAN), Oakland International Airport (OAK), and Norman Y. Mineta San José International Airport (SJC)—rank among the Top 40 US Passenger Gateways to the World (ASCE, 2025). In 2024, nearly 113 million passengers moved through California's commercial airports, representing about 11.5% of all US aviation passenger traffic (ASCE, 2025). California also has 214 general aviation airports, which support nearly 150,000 jobs and contribute over $32.7 billion to the state's total economic output (AAAA, 2022).

Sea level rise and storm surges increase flood risk for low lying coastal airports. Currently 39 of California's coastal public airport facilities are projected to be exposed to flooding from sea level rise in the next 20–40 years (Lindbergh et al., 2022). In the San Francisco Bay Area, 11 coastal airports are projected to be exposed to coastal flooding by the year 2100 (Lindbergh et al., 2022). SFO, which is constructed on a reclaimed landfill, faces heightened risk from sea level rise due to simultaneous land subsidence; projections indicate that by 2100, half of the runways and taxiways at SFO could be underwater (Shirzaei & Bürgmann, 2018). Airport flooding threatens both passenger travel and freight logistics and can lead to delays, congestion, diversions, and cancellations. Extreme flood events at airports may potentially trigger broader economic ripple effects across industry and regional supply chains.

High temperatures reduce air density and make it more difficult for airplanes to generate lift, particularly at higher elevations (Coffel et al., 2017). Such heat waves can trigger weight restrictions, which can mean fewer passengers, less cargo, or less fuel, and mostly affect airports with shorter runways and smaller aircraft (Lee et al., 2021). Asphalt can also soften and warp in heat, contributing to delays and flight cancellations (Zhang et al., 2024).

Additionally, wildfire smoke can disrupt aviation by obscuring runways and flight paths, reducing pilots' visibility and forcing stricter safety rules. As smoke lowers visibility and raises engine and equipment risks, airports often delay, reroute, or cancel flights, leading to wider system-wide disruptions. In January 2025, as fires fueled by strong Santa Ana winds burned across the Los Angeles region, LAX remained open but experienced about 500 flight delays and 13 cancellations over one weekend; passenger traffic that month was about 3% lower than in January 2024 (LAWA, 2025; Syme et al., 2025).

7.2 Roadways

California has 177,576 miles of public roads, including 15,133 miles of state highway and 12,919 miles maintained by federal agencies—the rest are maintained by local jurisdictions (ASCE, 2025). One third of California's roads are in poor condition and it is estimated that the state will face a $70 billion funding shortfall over the next 10 years despite the new investments through the Road Maintenance and Rehabilitation Program (SB1) (ASCE, 2025). These structural and fiscal vulnerabilities leave California's road network especially susceptible to damage from climate-related stressors.

Road infrastructure is vulnerable to extreme temperatures, precipitation, wildfires, sea level rise and storm surge, each of which can cause physical damage to roads, bridges, guardrails, signage, and culverts (Lissade et al., 2019). In the aftermath of disasters, emergency response and recovery efforts increase the traffic of heavy vehicles which can lead to additional damage (Nassiri et al., 2023). California ranks among the most congested states in the nation, with drivers in major metropolitan areas losing over 100 hours annually to traffic delays (ASCE, 2025). This chronic congestion can translate into slower evacuations and longer emergency response times during wildfire and flood emergencies.

Storm surges and atmospheric rivers, especially following wildfires and droughts, can cause severe debris flows, landslides, washouts, erosion, and structural damage to infrastructure, often resulting in prolonged road closures and repairs. Following a prolonged drought, California's exceptionally wet 2016–17 winter caused widespread flooding and an estimated $1 billion in damages for Caltrans-managed road infrastructure (Caltrans & WSP, 2021). Damages to the State Highway System from the 2022–23 winter storms were also assessed at $1 billion (Changizi, 2023). Average annual storm damage costs to Caltrans infrastructure rose from $179 million in fiscal year (FY) 2009–FY 2015 to $650 million in FY 2016–FY 2022 (Changizi, 2023).

Sections of California's scenic Highway 1, which traces much of the state's Pacific coastline, have suffered multiple prolonged closures due to storm-driven landslides and coastal erosion, forcing travelers onto hours-long inland detours and disrupting local tourism revenue. In 2017, the Mud Creek Landslide in Big Sur displaced 6 million cubic yards of rock and debris, caused a year-long shut down of Highway 1, and cost more than $54 million to repair (NASA JPL, 2019; Rasmussen, 2019). The same Big Sur area of Highway 1 experienced another prolonged closure after major landslides in January 2023 and February 2024, with full through travel restored on January 14, 2026 (GO, 2026). Economic losses from the 2023–2026 road closure alone are estimated to have cost the Big Sur area over $438 million in lost tourism revenue (Beacon Economics, 2025).

Most roadways use asphalt concrete, a material that softens and deforms as temperatures rise, so hotter conditions and intense wildfire heat reduce pavement stiffness and accelerate rutting and cracking under heavy traffic loads (Nassiri et al., 2023). As a result, extreme heat reduces the structural performance and durability of roads, making them more susceptible to rutting, cracking, softening, and surface deterioration. This shortens pavement lifespans and increases the need for more frequent resurfacing (CSIWG, 2018). In urban areas, roads can also amplify the urban heat island effect during heat waves, further accelerating surface damage and compounding heat exposure for nearby communities (LBNL, 2022).

Nationally, higher temperatures are predicted to add approximately 3–9% to annual pavement building and maintenance costs across the next 30 years (Underwood et al., 2017). The California Department of Transportation's annual road-related expenditures, including construction, repair, and pavement, are $2–3 billion (CalSTA, 2025). Costs to maintain, repair, and replace infrastructure are likely to increase due to growing occurrences of sea level rise, flooding, and wildfires (Caltrans & WSP, 2021). These additional costs disproportionately affect smaller local municipalities, which have fewer resources to address increased pavement deterioration.

7.3 Railways

Rail transportation infrastructure is essential to the movement of people and goods, and to the sustained growth and resilience of California's economy. California's nearly 7,000 miles of rail lines play a vital role in supporting California's port operations by enabling the efficient movement of cargo between seaports and inland markets (Caltrans, 2022). Extreme heat can cause track expansion and result in service delays or, in severe cases, derailments (CDI, 2024). Coastal erosion and flooding can damage rail foundations, undermine track stability, and lead to prolonged service disruptions (Roh & Ehlers, 2022).

Growing activity at major ports like Los Angeles, Long Beach, and Oakland is driving increased demand for freight rail to handle rising cargo volumes (Caltrans, 2024). By 2040, freight traffic is projected to reach 213.3 million tons of intermodal goods, goods that move by multiple modes such as truck, rail, and ship, underscoring the need for expanded and climate-resilient rail infrastructure (Caltrans, 2022). California's rail network also serves millions of passengers annually through a system of national, state, and regionally supported rail services. The three state-supported intercity rail services are the Capitol Corridor, Pacific Surfliner, and Gold Runner (formerly San Joaquins) lines, which had a combined ridership of over 2 million people and generated $67.6 million in revenue in 2021 (Caltrans, 2022).

7.3.1 Extreme Heat and Wildfire Impact on Rail Infrastructure

Extreme heat poses a significant threat to California's rail infrastructure, primarily through the thermal expansion of steel rail lines. Rail temperatures can be 25–35°F (14–19°C) hotter than ambient air temperatures during peak sun exposure (Dick & Bruzek, 2016). Because thermal expansion increases with rail length, an approximately 1,800-foot rail segment can expand by more than an inch for every 10°F (5.56°C) increase in temperature, increasing the risk of buckling, deformation, and heat-related service disruptions (Simon & Grist, 2024). A single mile of non-constricted rail can expand more than 2 feet in extreme heat (CSIWG, 2018). To ensure safety of

passengers and cargo, rail operators will restrict speed during higher temperatures, which leads to delays. For example, Amtrak restricts speed to 80 miles per hour when rail line temperature hits 140°F (60°C) (Simon & Grist, 2024). Unlike isolated incidents such as downed trees, heat waves pose a broader operational challenge by disrupting rail networks across entire regions (Simon & Grist, 2024). There have been three derailments attributed to extreme heat in recent years: a Bay Area Rapid Transit (BART) train in July 2022, which led to a three-day closure of the line in one direction; a freight train near the California–Arizona border in 2020; and a freight train in Tulare County in 2017 (CDI, 2024).

Delays account for the largest economic cost of extreme heat on rail lines. Across extreme heat waves in California between 2013–2022, rail damages accounted for $69 million, and more than 95% of the estimated impact was associated with delays rather than repair costs (CDI, 2024). Nationwide studies estimate the passenger value of delay for business trips at $52/hour/passenger, highlighting the high opportunity cost of disrupted service (Talebian & Zou, 2015). Under climate change, these costs are projected to grow substantially; nationwide climate modeling estimates that delay-minute costs for rail networks could exceed typical historic costs by a cumulative $25–$45 billion through 2100 under a low-emissions scenario and $35–$60 billion under a high-emissions scenario (Chinowsky et al., 2019). Adaptation measures include developing new temperature sensors, improving electronic communication systems, and revising operating rules to address increasing temperatures (Chinowsky et al., 2019).

Limited research has quantified the economic costs of wildfire-related disruptions to rail and transit service, but available evidence points to growing operational and passenger losses. Following the January 2025 wildfires in Los Angeles, LA Metro suspended fare collection on its bus and rail network and implemented detours, shuttle substitutions, and temporary suspensions on several lines in response to infrastructure damage, power outages, and hazardous smoke conditions, resulting in lost fare revenue and additional operating costs (Los Angeles Daily News, 2025).

7.3.2 Coastal Erosion's Impact on Rail Infrastructure

Coastal rail infrastructure in California is increasingly exposed to risks from sea level rise, erosion, and extreme weather events (Roh & Ehlers, 2022). These hazards threaten the structural integrity of rail tracks located on or near unstable bluffs, wetlands, and low-lying coastal areas, and can lead to track washouts or derailments. Rail lines near the coastline are especially susceptible to damage from recurring flooding and periodic storm events. High-risk coastal rail segments include areas in Santa Barbara, Orange, and San Diego counties, as well as San Pablo Bay and the Alviso Wetlands in the Bay Area and Elkhorn Slough in Monterey County (Caltrans, 2024).

These high-risk coastal rail segments include the Los Angeles-San Diego-San Luis Obispo (LOSSAN) Corridor, the second busiest intercity rail corridor in the nation, which runs 351 miles down the coast of Southern California and is the only rail line connecting San Diego to the rest of the United States. The LOSSAN Corridor carried 3.74 million passengers in 2023 and is essential for goods movement and national security, supporting the transport of billions of dollars worth of national and international goods annually. It is designated as part of the Department of Defense's Strategic Rail Corridor Network (SANDAG, 2025). The Pacific Surfliner, the state-supported train service that runs along the LOSSAN Corridor, has experienced seven shutdowns since 2018 due to

coastal erosion exacerbated by storms and sea level rise in the Del Mar, San Clemente, and Santa Barbara areas (Carlton, 2024). The coastal bluffs in Del Mar are eroding by several inches per year, increasing the risk of track damage and service interruptions along this segment (Carlton, 2024). Due to the high costs of repeated closures, ongoing bluff erosion, and more than $140 million already spent on emergency stabilization and repairs, agencies are studying the feasibility of relocating the tracks inland (Carlton, 2024). Over the next two decades, SANDAG plans nearly $1 billion in corridor improvements, including bluff stabilization and rail relocation with a plan alternative that includes tunneling under residential neighborhoods in Del Mar (SANDAG, 2025).

7.4 Ports

California's ports are essential to the national economy; they handle approximately 38% of all containerized cargo entering the US along with 28% of the nation's exports (ASCE, 2025). The San Pedro Bay Port Complex, which includes the Ports of Los Angeles and Long Beach, is among the top 10 busiest ports in the world (GO-Biz, n.d.). Between 1980–2020, these two ports saw a nearly 20-fold increase in container traffic, resulting in a combined handling of 140 million tons of cargo each year (Walters, 2024). The Port of Oakland was ranked the ninth largest port in the nation by container volume in 2024 (ASCE, 2025). The state's other smaller, but essential, ports include Benicia, Hueneme, Humboldt Bay, Redwood City, Richmond, San Diego, San Francisco, Stockton, and West Sacramento (ASCE, 2025). Beyond handling essential cargo operations, California's ports also host passenger cruise terminals, support restaurants and hotels, offer entertainment and tourist attractions, and provide facilities for commercial fishing and recreational boating.

Sea level rise and stronger storm surges represent the most significant climate-related risks to port infrastructure and operations. Sea level rise intensifies coastal flooding that can compromise port-based commerce and goods movement, which can impede supply chains and lead to greater economic slowdown (Adusumilli et al., 2024). Seawall and shoreline-protection infrastructure is crucial to maintaining operations, but upgrades, maintenance, and repairs can be long-term and expensive. For example, the Port of San Francisco, a historic, mixed-use urban waterfront port, is advancing a broader 7.5-mile Waterfront Resilience Program with preliminary costs estimated at $13.5 billion (SF Port, 2024). This scale of investment illustrates how adapting port waterfronts to sea level rise, flooding, and seismic risk can require multi-decade planning and substantial public funding. Extreme precipitation and subsequent flooding can also damage port infrastructure. The Port of Hueneme, a small commercial port in Ventura County, experienced a once-in-1,000-year storm event in 2023 that destroyed critical shore-power equipment; repairs and hardening costs were estimated at $30–40 million (Port of Hueneme, 2024). At the same time, it is worth noting that hard armoring can carry environmental costs of its own, such as accelerated beach and habitat loss in and around these structures (Gittman et al., 2016).

Sea level rise can reduce vertical clearance under bridges, which can constrain taller ships to transit only at lower tides or to reduce cargo loads, both of which undermine port efficiency (Barnard et al., 2019). Storms also move ocean sediment into harbors, making routine dredging essential to maintain adequate sea depths for container-ship, cruise-ship, and safety vessel access. The Port of Oakland requires regular maintenance dredging of its shipping channels and berths to maintain depths of up to 50 feet (15.2 m) and accommodate large container ships

(McCarthy, 2023). The Port plans to spend $7.14 million annually on maintenance dredging in the next few years (Port of Oakland, 2024). Looking ahead, more intense precipitation events and watershed erosion may raise sediment loads and shorten dredging cycles. Maintaining navigation depths is a key adaptation measure to sustain port reliability and protect regional supply chains.

In addition to sea level rise and storm surges, heat waves can cause thermal expansion, mechanical failures, and deformation of critical components such as lock gates and lifting bridges, while rising ocean acidity from excess carbon dioxide may accelerate corrosion and structural degradation of undersea infrastructure and vessels (Sabu, 2024). Although earthquakes are not climate-driven, they remain a major hazard at California's seaports and can compound climate risks by weakening structures that must then withstand higher tides, storm surge, and chronic heat stress (Port of San Francisco, 2020). Seismic damage to port infrastructure often entails multi-year repair and retrofit timelines, during which reduced structural capacity and degraded lifelines increase vulnerability to subsequent climate hazards (Port of San Francisco, 2020). Beyond direct physical damage, operational delays and closures reverberate through supply chains and have rippling impacts affecting state, national, and global economies.

8. Water

Key Takeaways

1. **Climate stressors increase risks to water affordability and reliability.** Climate change amplifies risks to water affordability and reliability across California, especially for rural and agricultural communities dependent on aging or small-scale water systems. More than 770,000 Californians are served by systems out of compliance with state drinking water standards, and another 1.8 million by systems considered at risk of failing, and the situation is expected to worsen under climate change (ASCE, 2025; Becker, 2024; CDWR, 2025c). The State Water Project, which serves 27 million Californians and 750,000 acres of farmland, could lose 13–23% of its delivery capability due to climate change over the next 20 years if significant adaptation measures are not implemented (CDWR, 2024b).

2. **Consumers and local governments bear increasing financial burdens.** After disasters, utilities often face lower revenues as customers are displaced, and responsibility for repairs and long-term upgrades falls largely on local and regional providers, costs that are usually recovered through higher rates (Kane et al., 2025; Ross, 2025). Small communities are less resourced to recover and may resort to steep rate hikes or rely heavily on state and federal disaster aid (City of Salinas, 2025; RWQCB, 2023).

3. **Climate impacts impose direct costs on water utilities and consumers** through rate increases, surcharges, or development restrictions. After the 2018 Camp Fire, one utility recovered lost revenue through a temporary $10.54-per-customer monthly surcharge on remaining customers (CPUC, 2020). After the 2023 atmospheric rivers, the City of Salinas tripled monthly residential sewer charges for its municipal sewer system to recoup recovery costs

(City of Salinas, 2025). Drought can also constrain new development where water scarcity limits the ability of public water suppliers to serve new connections (CPUC, 2014; Feinstein & Thebo, 2021).

California's water infrastructure comprises a complex network of dams, reservoirs, canals, pipes, pumping stations, levees, and groundwater recharge facilities. The State Water Project alone includes 36 storage facilities, 26 dams, 21 pumping plants, 5 hydroelectric power plants, and 700 miles of canals, which provide drinking water to 27 million people and irrigation to 750,000 acres of farmland (CDWR, 2025c). Flood protection infrastructure, such as levees, dams, and flood bypasses, currently safeguards 1.3 million people and $223 billion in assets at risk of flooding in California's Central Valley (CNRA, 2022). Without adaptation, over the next 50 years, annual economic damages from flooding could more than double in the Sacramento River Basin and quadruple in the San Joaquin River Basin (Petek, 2025). Between 2016–2018, California spent an average of $2.7 billion per year on flood protection, with approximately three-quarters of that funding raised and used by local governments, underscoring the importance of local finance in managing escalating climate flood risks (Petek, 2025).

Climate impacts also intersect with long-standing water quality and access challenges. As of June 2024, 770,000 Californians rely on water systems that fail to meet state water quality standards and another 1.8 million Californians obtain water from systems at risk of failure (Becker, 2024). These systems are concentrated in rural and lower-income communities, particularly in the Central Valley and Central Coast, where groundwater contamination, groundwater overuse, and smaller, financially constrained water systems often overlap (Becker, 2024). During the 2012–2016 and 2020–2022 droughts, thousands of domestic wells across the state–most notably in rural San Joaquin Valley—went dry, forcing households to depend on hauled or bottled water (CDWR, 2025b). By 2040, climate change could reduce long-term State Water Project deliveries by 13–23% without significant adaptation measures (CDWR, 2024b). Because the SWP supplies water to 75 percent of California's disadvantaged communities, reduced reliability would heighten existing affordability and access challenges. Lower SWP deliveries also shift demand toward groundwater, increasing the risk of overdraft in already-stressed basins and continued land subsidence, which has already damaged conveyance infrastructure and reduced its capacity. Large and small systems alike will require substantial upgrades to keep pace with a changing climate, and these costs will increasingly strain water users, making it harder for many vulnerable Californians to secure safe and affordable water (CDWR, 2025d).

8.1 Meeting Water Demand

California's economy depends on a highly managed water system that delivers roughly 80 million acre-feet (MAF) of applied water each year for environmental, agricultural, and urban uses (Lund et al., 2024). The state's ability to meet these diverse water demands is increasingly challenged by high seasonal variability in surface water availability. Climate change is projected to further reduce California's water supplies by an estimated 1–3 MAF per year (Lund et al., 2024). These changes reduce the reliability of surface-water supplies by increasing evapotranspiration, reducing snowpack, and altering the timing and availability of surface water, making it harder to capture and store for year-round use (CDWR, 2023).

Climate projections indicate that California will experience fewer precipitation days overall, while precipitation events that do occur—particularly atmospheric rivers—are expected to become more intense, increasing the likelihood of extended dry periods punctuated by heavy rainfall (Gershunov et al., 2019). By late century, droughts that historically occurred once every 20 years are expected to occur once every 10 years, and once-in-a-century droughts may occur about once every 20 years (Pierce et al., 2018; Hilberg & Kershner, 2021). Hotter and drier conditions are also projected to cut the Sierra Nevada snowpack by more than one-third by 2050 and by over half by 2100, reducing both surface and groundwater supplies (Climate Resilience California, 2024). Prolonged droughts can reduce surface-water supplies and contribute to unsustainable overdraft, land subsidence, reduced aquifer storage, and higher extraction costs as groundwater levels fall (Cole et al., 2024; Escriva-Bou et al., 2023; Hadachek et al., 2025). During the 2021–2022 dry years, groundwater supplied roughly 64% of total water use in basins managed under the Sustainable Groundwater Management Act, compared with about 40% in average years (CDWR, 2025a). These pressures are especially pronounced in the Central Valley, which accounts for 20% of all groundwater withdrawals in the US, making its aquifer system the second most heavily pumped in the country (USGS, n.d.).

Increased groundwater extraction can require deeper wells, more powerful pumps, and higher energy expenditures. In response to the 2021 surface-water curtailments, farmers in the Central Valley invested an estimated $24 million to drill 321 new wells (Hadachek et al., 2025). Increased groundwater extraction can also reduce drinking-water access for nearby low-income communities that rely on shallower domestic wells and contribute to land subsidence that damages roads, canals, foundations, and other infrastructure (Hadachek et al., 2025; Nemati et al., 2025b). In the San Joaquin Valley, one study that linked satellite-based measurements of land subsidence with nearly 200,000 home sale transactions between 2015–2021 found that groundwater over-extraction contributed to an estimated $1.87 billion in lost housing value from subsidence-induced property devaluation, with individual homes losing 2.4–5.8% of their sale value (Nemati et al., 2025a).

Box 20: *Climate Stress on Colorado River Supplies*

Hotter temperatures and more frequent, intense droughts have reduced Colorado River flows by roughly one-fifth since 2000, shrinking storage in Lake Mead and Lake Powell and triggering mandatory shortage cuts for Lower Basin users, including California (US Bureau of Reclamation, 2021). For Southern California cities and agricultural districts that depend heavily on the Colorado River, continued water shortages from the Colorado River are driving multibillion-dollar investments in alternative supplies. The Metropolitan Water District (MWD) of Southern California has already invested $2 billion in agricultural conservation partnerships that pay participating farmers to conserve Colorado River water through partial land fallowing, crop rotation, and irrigation improvements, increasing MWD's flexibility to manage shortages and dry-year supply risks (MWDSC, 2025). Looking ahead, agencies are planning additional large-scale projects, including the $8 billion Pure Water Southern California wastewater recycling program that will produce 150 million gallons per day, and expanded desalination capacity along the coast to backstop urban demands and reduce dependence on an over-allocated, climate-stressed river (MWDSC, 2025).

8.2 Municipal Water Infrastructure

Extreme heat, wildfires, prolonged drought, heavy precipitation events, and salinization of coastal aquifers increase operational and water-quality risks for California's municipal water systems (Solomon et al., 2021a). Severe storms and flooding can damage critical components such as pipes, water meters, dams, spillways, and levees (Purohit, 2025; Sham et al., 2013). Extreme heat from wildfires can melt plastic distribution components and release toxic chemicals into drinking water (Pennino et al., 2022). After disasters, many utilities face reduced revenues as customer bases are displaced and demand falls, limiting their capacity to finance recovery and resilience investments (Ross, 2025). Although state and federal programs can bridge some emergency and rebuilding needs, responsibility falls to local and regional water providers to fund repairs and long-term climate upgrades themselves, costs that are often recovered through higher rates to customers (Kane et al., 2025).

Atmospheric rivers are a major source of stress on municipal water infrastructure because they can overwhelm stormwater, drainage, flood-control, and wastewater systems. When atmospheric rivers occur in rapid succession, economic losses from a given storm increase by roughly three to four times compared to storms occurring outside such sequences (Bowers et al., 2024). In California, atmospheric rivers caused an estimated $620 million in average annual flood damages from 1978–2017 (Corringham et al., 2019). Between late December 2022 and January 17, 2023, nine consecutive atmospheric rivers caused widespread flooding, power outages, and mudslides that disrupted water service delivery across the state. Economic losses totaled an estimated $4.7 billion, including $533 million in infrastructure damage incurred by local jurisdictions (NCEI, 2024; S&P Global Ratings, 2023). The City of Santa Cruz had to temporarily shut down the Newell Creek Pipeline after storm damage and later secured a $128 million federal loan to help replace and relocate the pipeline to improve water-system reliability (City of Santa Cruz, 2023; EPA, 2023b).

In the aftermath of the 2017 Tubbs Fire and 2018 Camp Fire, water distribution systems were found to contain high levels of volatile organic compounds with benzene levels over 8,000 times higher than the federal drinking water limit (PPC, 2025). Benzene is a known carcinogen that can cause acute symptoms such as nausea, headaches, rashes upon ingestion, and is associated with chronic illnesses including blood disorders and reproductive problems. The replacement of damaged water service lines after the 2018 Camp Fire was estimated at $300 million (Walton, 2019). In the aftermath of the 2025 Palisades Fire, the Los Angeles Department of Water and Power (LADWP) initially estimated $76 million in overall damages, a relatively modest amount compared with its $1.64 billion in water enterprise operating revenues; however, the larger financial risks may stem from potential legal liabilities and demands for additional wildfire-fighting water infrastructure, which could affect LADWP's credit ratings or increase borrowing costs for future infrastructure investments (Pierce et al., 2025). In Altadena, the Eaton Fire destroyed roughly 75% of the homes within one company's revenue base (Pierce et al., 2025).

Wildfires can impose substantial downstream costs on water systems by degrading watersheds, increasing runoff and erosion, raising treatment costs, requiring alternative supplies, and reducing reservoir capacity (Feo et al., 2020b; JEC, 2023). The US Congress Joint Economic Committee estimated that nationwide, wildfires impose watershed and water-quality costs ranging from $14.69–$146.9 billion annually (JEC, 2023). Wildfire-related water-quality impacts can persist for years, but the cumulative economic and health damages from these pathways remain poorly quantified and are an area for further research (Brucker et al., 2025; Feo et al., 2020a).

Along the coast, drought and sea level rise drive saltwater intrusion along the Sacramento–San Joaquin Delta and into aquifers, contaminating drinking and irrigation supplies (Befus et al., 2020; Lassiter, 2021; Medellín–Azuara et al., 2014; Parker & Boyer, 2019). For additional discussion of salinity-related impacts on agricultural revenues, refer to **Box 24** in *Section 9.1 Crop Yield and Revenue Impacts.*

8.3 Service Disruptions and Rising Costs to Households and Utilities

Wildfire, drought, and flooding from heavy rain events are driving up costs for households, businesses, and water utilities across California (Mount et al., 2023). Wildfires can contaminate drinking water, necessitating a "do not drink" advisory since at-home filtration systems cannot reliably remove all contaminants (SWRCB, 2019). As a result, households incur direct costs for bottled water and may experience increased utility rates to finance repairs to their community's water systems (Solomon et al., 2021a). After the 2018 Camp Fire, a public water utility serving the Town of Paradise lost roughly 90% of its service connections, and residents relied on bottled water for months while the utility relied on FEMA and state assistance to support infrastructure recovery costs (Paradise Irrigation District, 2025; Walton, 2019). Del Oro Water Company's privately owned, CPUC-regulated system lost substantial customer revenue after the Camp Fire, including a 38% reduction in service connections in its Paradise Pines District (CPUC, 2020). Across Del Oro's four affected districts, the fire eliminated 2,221 service connections, reducing the utility's total customer base by 26%. The CPUC subsequently authorized a statewide lost-revenue surcharge of $10.54-per-customer per month across Del Oro's districts for 12 months to recover an estimated $800,000 in lost revenues (CPUC, 2020).

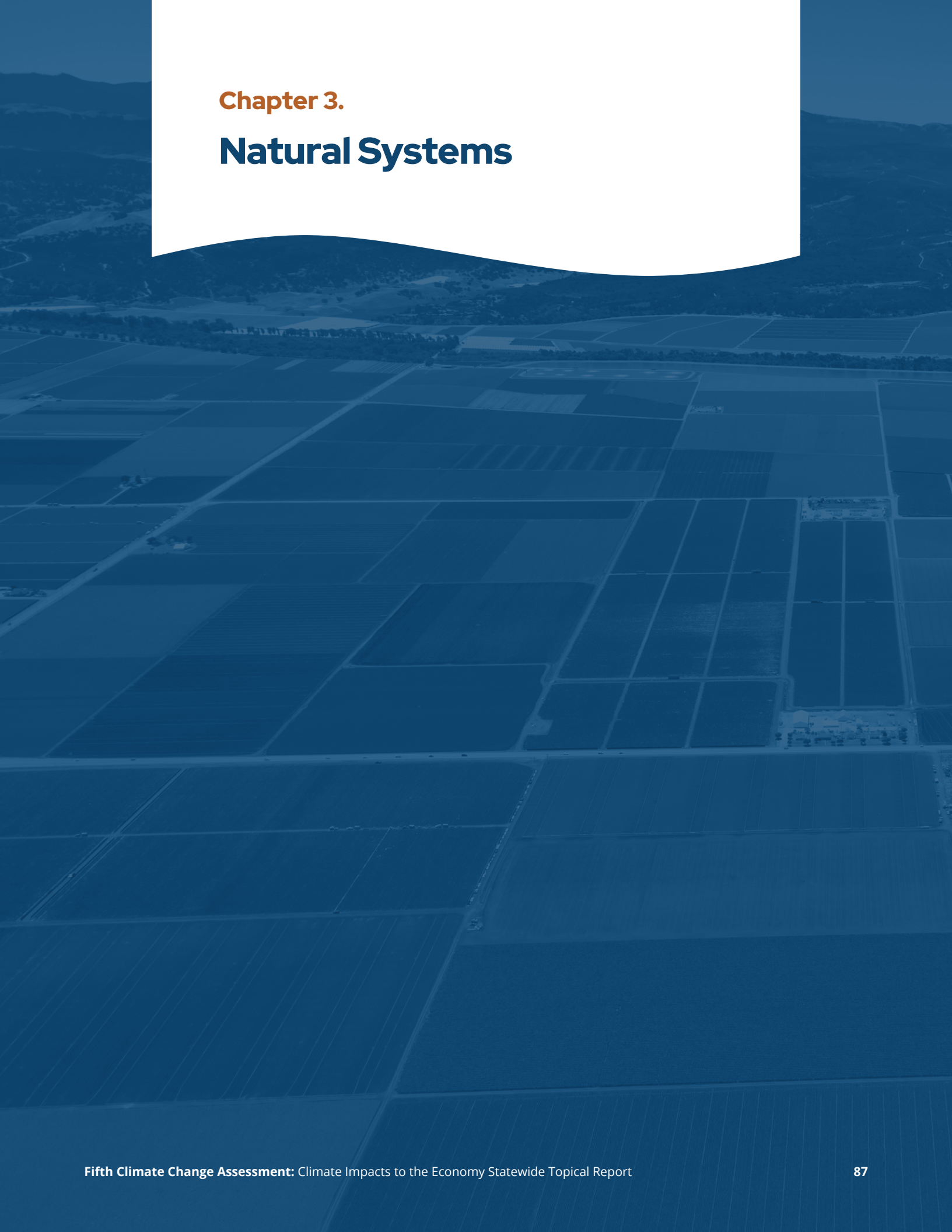
Drought can also lead to higher water bills for consumers and in extreme cases can prompt municipal building moratoriums. During the 2012–2016 drought, more than 70% of California's urban water suppliers experienced revenue declines, and as a result, utilities increased rates and fees to cover fixed costs and maintain service (Hadachek et al., 2025; Mitchell et al., 2017b). In 2015, California imposed its first-ever 25% reduction in municipal water use in response to an extreme statewide drought (Palazzo et al., 2017). As of March 2021, 37 communities in California had instituted a moratorium on new housing construction, given water supply limitations in response to the 2012–2016 drought; this mostly affected smaller communities with smaller, isolated water supplies (CPUC, 2014; Dooley, 2021; Feinstein & Thebo, 2021).

Flooding likewise carries immediate operating and customer-level costs, especially for smaller-scale water utilities in rural communities. During the 2023 atmospheric river events, several rural area water utilities in Monterey County were impacted by the flooding from the Salinas River. In San Ardo, the wastewater treatment facility was inundated by Salinas River flooding, requiring the daily hauling of wastewater to King City at a cost of $4,200 per day (RWQCB, 2023). The district, serving fewer than 500 residents, lacked sufficient financial reserves and relied heavily on FEMA, Cal OES, and Monterey County for emergency repairs and operations funding (RWQCB, 2023). The City of Salinas, which was also heavily impacted by this event, adopted a multi-year rate schedule to finance storm related upgrades, tripling the monthly sewer charge from $5.45 to $16.35 in October 2025 with a 2% annual escalation rate over the next five years to pay for storm-related damages (City of Salinas, 2025; Finance DTA, 2025).

Box 21: *Climate Stress on Aging and Failing Water Systems*

Many rural and underserved communities depend on aging water systems or domestic wells, which face escalating risks from climate change (ASCE, 2025b; Becker, 2024). These older water systems are increasingly vulnerable to corrosion and extreme weather events that accelerate leaks and failures (EPA, 2025b). The 2019 American Society of Civil Engineers' *Report Card for California's Infrastructure* identifies that approximately 28% of the Los Angeles Department of Water and Power's 6,780 miles of mainline pipe were installed before 1938 and San Francisco operates around 150 miles of drinking water pipes that are over a century old (ASCE, 2019).

Together, climate stressors such as hotter temperatures, more intense droughts, and heavier storms place growing pressure on aging pipes, treatment plants, and small, under-resourced water systems, increasing the risk of outages and water quality violations (Grenier et al., 2024). Targeted resilience investments include consolidating failing small systems into larger regional entities, replacing or relining deteriorating pipelines, upgrading treatment units, and enhancing groundwater recharge and stormwater capture (Peterson et al., 2024; SWRCB, 2025).



Chapter 3.

Natural Systems

California's natural systems sit at the heart of the state's economy. Agriculture is confronting overlapping stresses from water scarcity, rising temperatures, and wildfire smoke that reduce yields, damage high-value specialty crops, and raise food prices for consumers. At the same time, farmworkers face disproportionate health and income risks from extreme heat, drought, and smoke, with climate shocks already eliminating tens of thousands of jobs and millions of dollars in wages in recent years.

Climate-driven changes in oceans and forests also trigger cascading economic impacts. Warmer and more variable ocean conditions and prolonged drought are contributing to repeated fishery collapses, imposing substantial losses on coastal and Tribal communities that depend on these species for income and culture. Growing wildfire risk and drought stress are eroding private timberland values and future harvest potential, while Tribal forestry operations work to maintain stewardship goals under tightening financial constraints. State and National Parks, protected areas, and the broader outdoor recreation economy are also vulnerable, as drought, wildfire, storms, and landslides can damage iconic destinations, disrupt access, and lead to sizeable losses for local economies when visitation drops.

9. Agriculture

Key Takeaways

1. **California's agriculture is nationally vital but geographically concentrated in climate-exposed regions.** California is the nation's largest agricultural producer, yet production is concentrated in regions such as the Central Valley that are highly exposed to extreme heat, drought, flooding, and wildfire smoke. Because California produces several high-value specialty crops and is the nation's top dairy-producing state, climate-related losses can affect growers, ranchers, processors, exports, and consumer prices beyond the state (CDFA, 2025; USDA ERS, 2025; Glover et al., 2023; USGS, n.d.).

2. **Water extremes drive large and uneven agricultural losses.** The 2020–2022 drought reduced direct crop revenues by an estimated $1.3 billion in 2021 and $1.7 billion in 2022 (Medellín-Azuara et al., 2022). The 2023 floods damaged roughly 82,000 acres and caused about $270 million in crop revenue losses (Kishore et al., 2025), along with major dairy-sector disruptions in the Tulare Lake Basin, where floodwaters put about 100,000 cattle and more than a dozen dairies at risk (Peterson & Bardeen, 2023). These risks are especially acute in areas in the southern Central Valley, including Kern, Fresno, and the Tulare Lake Basin, where high-value crop and livestock production overlap with flood-prone land.

Although agriculture accounts for only about 1% of California's gross domestic product, it is a major economic driver in rural and agricultural regions, including the Central Valley, the Central Coast, and the Imperial Valley. California is the nation's largest agricultural producer, with farms and ranches receiving $61.2 billion in cash receipts in 2024 or roughly 12% of total US farm cash receipts (CDFA, 2025; USDA ERS, 2025). When including related support, processing, and

distribution activities, California's agricultural sector generated an estimated $311 billion in annual sales, supported more than 1.2 million jobs, and provided $84 billion in worker earnings in 2024 (Dompka et al., 2025). The highest-value agricultural commodities in California include dairy products at $8.1 billion, almonds at $5.6 billion, grapes at $5.6 billion, and cattle and calves at $4.8 billion, followed by lettuce, strawberries, pistachios, and tomatoes valued together at $10.82 billion (CDFA, 2024). Crop production accounts for roughly 70% of total farm cash receipts in California, while livestock and dairy contribute the remaining 30% (UC Davis, 2025).

The Central Valley is California's largest agricultural region and accounts for about 8% of US agricultural output by value and about 40% of the nation's fruits, nuts, and other table foods (USGS, n.d.). Fresno County is the top agricultural-producing county in the nation, with larger agricultural sales than 23 individual states (USDA, 2024a). The Central Valley is particularly vulnerable to climate-driven disruptions, including extreme heat, prolonged drought, reduced snowpack and constrained surface-water deliveries, groundwater overdraft, and more frequent smoke and wildfire events (California State Assembly, 2020; Lund et al., 2024; Pathak et al., 2018). These hazards can reduce yields, constrain water availability, and disrupt labor productivity, with consequences that propagate through national supply chains and contribute to market volatility and consumer price pressures (Kotz et al., 2024; Park et al., 2018). These climate hazards also create concentrated risks for farmworkers through direct exposure to heat and smoke and potential income disruptions from reduced or interrupted agricultural work. For more information on the impacts to Farmworkers, *see Section 2 Labor*, **Box 11**.

9.1 Crop Yield and Revenue Impacts

9.1.1 Heat Impacts on Crop Yields

Increasing temperatures are one of the most significant climate risks to agriculture, with yield impacts varying by crop, region, and timing of exposure. Extreme heat increases evapotranspiration, accelerating water loss from soils and plants and raising irrigation demand. It can also stress plants, stunt development, reduce crop quality, and lower yields (Parker et al., 2020). Perennial crops are especially vulnerable because heat exposure can affect multiple stages of development, including bloom, fruit set, maturation, and quality; in almonds, for example, yield variation has been linked to June temperature, winter conditions, and summer vapor pressure deficit (Jin et al., 2020). Extreme heat can also impact the quality of agricultural products—prolonged exposure to high temperatures can cause sunburn in fruits and vegetables, rendering them unmarketable or reducing marketability through smaller fruit size or other quality losses, even if the overall yield is not significantly diminished (Marklein et al., 2020).

Seven extreme heat events between 2013–2022 produced widespread economic losses across California's agricultural sector (CDI, 2024). Summed across all seven events, losses reached approximately $321 million in crop productivity and $527 million from reduced work time in weather-exposed industries, as shown in **Table 1**. Extreme heat is projected to drive up food prices in North America by roughly 1.4–1.8 percentage points per year by 2035 (Kotz et al., 2024).

Table 1: Summary of Economic Impacts from Seven Extreme Heat Events on Agriculture (2013–2022). *Total losses from seven extreme heat events across dairy, crop, manufacturing, and weather-exposed labor categories. Crop losses were highest during the 2021 Desert Lands Event, where extreme heat overlapped with high-value agricultural areas, while dairy productivity and dairy cow mortality losses were highest during the 2017 Central Valley Event, where affected counties included major dairy-producing areas. Manufacturing and reduced work-time losses were largest during broader coastal and inland heat events, reflecting the wider exposure of workers and heat-sensitive production activities. Source: Impacts of Extreme Heat to California's People, Infrastructure, and Economy Report (CDI, 2024).*

Heat Event	Dairy Productivity	Dairy Cow Mortality	Crop Productivity	Manufacturing Productivity	Reduced Work Time in Weather-Exposed Industries
2022 CA Coastal Inland	$17,000,000	$330,000	$72,000,000	$310,000,000	$210,000,000
2021 Desert Lands	$13,000,000	$280,000	$110,000,000	$2,600,000	$7,300,000
2019 NorCal Coastal	$210,000	$4,100	$630,000	$74,000,000	$12,000,000
2018 SoCal Coastal	$1,100,000	$61,000	$49,000,000	$84,000,000	$81,000,000
2017 CA Full Coastal	$3,300,000	$1,100,000	$14,000,000	$230,000,000	$140,000,000
2017 Central Valley	$52,000,000	$1,100,000	$58,000,000	$35,000,000	$59,000,000
2013 Eastern CA	$2,500,000	$52,000	$17,000,000	$7,100,000	$18,000,000
Totals	**$89,110,000**	**$2,927,100**	**$320,630,000**	**$742,700,000**	**$527,300,000**

Box 22: *Warmer Winters and Orchard Risk*

California has 1.2 million hectares of chill-dependent orchards that require sufficient winter chill for healthy flowering, fruit set, and production (Luedeling et al., 2009). Warmer winters create a tradeoff for orchard growers: fewer frost events may reduce the need for costly frost protection, but insufficient winter chill can disrupt bloom, fruit set, and yields in chill-dependent crops (Osorio-Marín et al., 2024). By 2050, average frost exposure is projected to decline by 63% across California's orchard-growing regions, and by more than 75% in avocado orchards (Parker et al., 2021). These avoided frost-protection hours could reduce water and electricity use in top-producing counties by more than 50,000 acre-feet and $4.2 million annually (Parker et al., 2021). Conversely, California's pistachio crop, which depends on adequate winter chill, experienced significant damage after a warm winter in 2015, resulting in more than $180 million in losses (Parker et al., 2020).

9.1.2 Drought and Crop Production

During drought, water scarcity can reduce surface-water deliveries, increase reliance on groundwater pumping, and make supplemental water purchases more expensive, constraining irrigation, forcing land fallowing, disrupting farm operations, and raising production costs (Medellín-Azuara et al., 2022). Limited water supplies heighten competition among agriculture, urban users, and ecosystem needs, creating complex management challenges (CDWR, 2023). Increased agricultural reliance on groundwater can contribute to long-term groundwater depletion and land subsidence; these water-system impacts are discussed in greater detail in *Chapter 2, Section 8.1: Meeting Water Demand.*

Statewide, the 2020–2022 drought reduced direct crop revenues by an estimated $1.3 billion in 2021 and $1.7 billion in 2022 (Medellín-Azuara et al., 2022). The Central Valley is especially vulnerable to drought and heat, leading to significant challenges in securing sufficient water for

crop production and raising livestock (Davenport et al., 2021; Medellín-Azuara et al., 2022; Purohit, 2025). This heavily agricultural region contains 75% of California's irrigated farmland and accounts for 17% of all irrigated land in the US (USGS, n.d.). In the Central Valley, drought-related reductions in crop production also contributed to gross revenue losses of $2.4 billion in 2021 and $3.5 billion in 2022 for food and beverage processing industries (Medellín-Azuara et al., 2022).

Drought impacts vary across California's agricultural regions. During the 2021 drought, the North Coast experienced estimated crop revenue losses of 24%, reflecting its greater dependence on local precipitation and surface-water systems, and less access to large-scale irrigation infrastructure (Escriva-Bou et al., 2023). Comparatively, the Sacramento Valley, which has more access to managed water infrastructure, experienced estimated crop revenue losses of 11% during the 2021 drought (Escriva-Bou et al., 2023).

Drought-related water scarcity can place upward pressure on food prices by increasing operating costs through higher water acquisition, groundwater pumping, and irrigation expenses. These supply-side pressures can contribute to producer-price increases: the US Bureau of Labor Statistics Producer Price Index for fresh and dry vegetables rose 38.1% from October to November 2022 and was 80.6% higher than in November 2021, reflecting a sharp one-month increase as well as a large year-over-year increase (Kotz et al., 2024; US BLS, 2023a). These pressures are consistent with broader evidence that heat and precipitation extremes can raise food prices by reducing agricultural productivity and tightening food supply. By 2035, food inflation in North America is projected to increase by approximately 1.4 percentage points per year under a low-emissions SSP1–2.6 scenario, based on historical relationships between temperature extremes and inflation observed from 1996–2021 (Kotz et al., 2024).

Box 23: *Drought and Rice Acreage in the Sacramento Valley*

California is the largest medium- and short-grain rice producing state in the nation, and rice production contributes $775 million to the state economy (USDA, 2024a). The majority of the state's rice is grown in the Sacramento Valley, and rice is a water intensive crop that requires an average of 5 acre-feet of irrigation water per acre (Linquist & LaHue, 2020; USDA, 2024b). During drought years, reduced surface-water deliveries can lead rice farmers to leave fields fallow; in 2022, drought conditions reduced rice acreage in the Sacramento Valley by roughly half (NASA, 2022). The declines were most pronounced in Colusa and Glenn counties, where planted rice acreage fell by 84% and 75%, respectively, compared to 2021 (NASA, 2022).

Box 24: *Salinity's Impact on Agricultural Yields*

Drought can worsen salinity risks in California's agricultural regions, threatening crop productivity, soil health, and the long-term viability of irrigated farmland (Bosworth et al., 2024; Kramer et al., 2025). In the Sacramento–San Joaquin Delta, reduced freshwater inflows during drought can allow tidal saltwater to move farther inland, affecting water supplies for agriculture, cities, and ecosystems (Bosworth et al., 2024; Kramer et al., 2025). In inland agricultural regions, salinity can also build up over time as irrigation water evaporates or is taken up by crops, leaving salts behind in soils and shallow groundwater.

In the San Joaquin Valley, over 4.9 million acres of irrigated farmland are already affected by saline irrigation water or soils; about 247,000 acres have been taken out of production due to salinity, nearly 988,000 acres are considered "highly saline," and approximately 1.48 million acres are considered "damaged" by salinity (Nicolas et al., 2023; Scudiero et al., 2017). Modeled high-salinity irrigation conditions reduced attainable relative yields to 76% for alfalfa, 50% for almonds, 70% for grapes, and 72% for processing tomatoes, underscoring that yield losses vary substantially by crop and water-quality conditions (Nicolas et al., 2023). One assessment estimated that soil salinity reduced California agricultural revenues by approximately $3.7 billion in 2014, with losses concentrated in salt-sensitive crops and regions with extensive irrigated production (Welle & Mauter, 2017).

9.1.3 High Precipitation and Flooding Impacts on Crop Production

In addition to causing more frequent and prolonged drought, climate change is also increasing the frequency and intensity of extreme precipitation events, heightening flood risk in low-lying agricultural regions (Pathak et al., 2018; Swain, 2021). While some controlled flooding can help recharge depleted groundwater aquifers, excess flooding can result in significant agricultural and infrastructure losses. Floodwaters may also carry fecal contamination when sewage systems fail or manure lagoons overflow, and can also transport other pollutants and plant pathogens, creating longer-term risks to soil health and future yields (Kaur et al., 2020; Wein et al., 2016). Under statewide food safety regulations, farmers must destroy crops if their edible portions are exposed to floodwaters, as floodwater often contains debris and a range of biological or chemical contaminants (Hampton, 2023).

Flooding from extreme precipitation events can translate into large economic losses through crop destruction, delayed planting or harvest, yield declines, livestock losses, sediment removal costs, and equipment and infrastructure repairs. Recent flood damage estimates show how these risks translate into agricultural losses: California's 2023 floods negatively affected roughly 82,000 acres of cropland and caused an estimated $270.23 million in gross crop revenue losses, with nearly all losses occurring in annual crops (Kishore et al., 2025). Losses were concentrated in the southern San Joaquin Valley: Kings County experienced the highest flood-induced crop revenue losses at $144.7 million, equal to 6.7% of the county's 2023 agricultural output, while Fresno County experienced an estimated $22.1 million in crop revenue losses (Kishore et al., 2025). These impacts reflect the overlap of high-value agricultural production with low-lying, flood-prone areas in the southern Central Valley, including the Tulare Lake Basin.

Box 25: *Drought and Flood Risk in High-Value Agricultural Counties*

A national assessment of agricultural community vulnerability found that several California counties face high exposure to drought and flooding, including Fresno, Kern, and Sonoma counties (Tanir et al., 2024). These counties face compounding pressures: prolonged drought cycles reduce water availability for irrigation, while low-lying agricultural land remains vulnerable to severe flood events driven by atmospheric rivers and seasonal runoff.

Based on FEMA National Risk Index data, estimates show that Sonoma County has the highest expected annual drought-related agricultural loss, at $57 million. This estimate reflects current agricultural exposure, annualized drought frequency, and historical loss patterns rather than a future climate projection. Because anthropogenic warming is driving more frequent and severe droughts across the western US, this baseline figure likely understates future annual loss risk (Zhuang et al., 2024). Fresno and Kern counties face the largest modeled losses from a 100-year flood event, a flood with a 1% probability of occurring in any given year, with direct agricultural damages estimated at approximately $384 million and $469 million, respectively. These high estimated flood losses reflect the overlap of flood-prone land with the extensive scale of high-value agricultural production in each region. Research finds that climate change has already doubled the likelihood of catastrophic flooding in California, and that risk continues to increase with each additional degree of warming, suggesting these baseline figures understate future exposure (Huang & Swain, 2022).

9.1.4 Wildfire Smoke's Impact on High Value Crops

Wildfire smoke can negatively affect agricultural yields when particulate matter and reduced sunlight disrupt photosynthesis and reduce crop productivity (Li et al., 2019; Orozco et al., 2024). The Central Valley can be particularly exposed to smoke because it lies between two fire-prone mountain ranges: the Sierra Nevada to the east and the Coast Ranges to the west. One study that measured wildfire smoke pollution during the 2020 and 2021 wildfire seasons found that the Central Valley experienced persistent smoke exposure for an average of 27 and 14 days, respectively, during two of the most smoke-polluted months in the region's 20-year satellite record (Orozco et al., 2024). The study measured smoke exposure using aerosol optical depth (AOD). AOD is a satellite-based indicator of smoke, dust, and other particles in the atmospheric column; AOD values near 0 indicate clean air, while values closer to 1 indicate very hazy conditions from smoke, dust, or haze. Average AOD reached 0.953 in September 2020 and 0.884 in August 2021, more than five times the region's 20-year average of 0.171.

This section focuses on selected high-value crops that are economically important to California and have documented or emerging evidence of vulnerability to wildfire smoke: almonds, wine grapes, and cannabis. These crops do not represent the full range of smoke-related agricultural damages statewide; rather, they illustrate how smoke can affect different regions, production systems, and market outcomes.

ALMOND ORCHARDS

Elevated wildfire smoke exposure can reduce sugar and starch reserves in orchard trees, diminishing the energy stores essential for growth, reproduction, and survival (Orozco et al., 2024). These physiological impacts can translate into economically significant yield losses for almonds, one of California's highest-value crops and a major global export commodity. California produces roughly 80% of the global almond supply (CDFA, 2024). The farmgate value of almonds, the value received by growers before downstream processing, transportation, marketing, or export-related costs are added, was $3.88 billion in 2023 and increased to $5.66 billion in 2024 (CDFA, 2025; Chea

& Taxin, 2025). In the Central Valley, smoke exposure during the 2020 and 2021 wildfire seasons was associated with almond yield declines of approximately 500 kilograms per hectare (446 pounds per acre) in 2021 and 2022 (Orozco et al., 2024). This study estimated that a one-point increase in AOD reduced almond yields by 1,797 kilograms per hectare (1,602 pounds per acre) (Orozco et al., 2024). These smoke-related yield losses occurred during a period when California almond cash receipts fell from $5.62 billion in 2020 to $5.03 billion in 2021, a decrease of roughly $590 million (CDFA, 2022).

WINE

The California wine industry is especially vulnerable to wildfires. Minor smoke impacts can be addressed in the processing of the grapes, but major impacts result in smoke taint, where the wine is considered faulted and no corrective measures can be taken in the fermentation process (Sullivan, 2023). Smoke taint occurs when smoke and ash permeate the skin of grapes and can increase the smokiness flavors of wine (Caffrey et al., 2019). The 2017 wildfires in Napa and Sonoma impacted approximately 500 acres of vineyards, prevented the harvest of 2,000 acres of winegrapes, and led to an estimated $75 million in economic losses, excluding damages to agricultural structures (California State Assembly, 2020). The 2020 wildfires resulted in smoke exposure that caused an estimated $4.2 billion of losses to California's wine industry from smoke taint alone and contributed to substantial increases in bulk-wine prices the following year (Crews et al., 2022; Mobley, 2021).

CANNABIS

Large-scale commercial cannabis cultivation in California began in 2016 after the state legalized adult-use, recreational cannabis. The first licensed retail shops opened in January 2018, and since then, California cannabis sales have generated more than $7.3 billion in tax revenues (CDTFA, 2025). California is the largest regulated cannabis market in the US with retail sales peaking at $5.35 billion in 2021 (DCC, 2025). However, California's cannabis industry has experienced significant losses from wildfire smoke, particularly in Humboldt, Mendocino, and Trinity counties (DCC, 2025). In 2020 alone, statewide crop losses attributable to wildfire smoke exposure ranged from 4.5–21.6%, with the estimated economic impact for the industry reaching $1.44 billion in 2020 and $970 million in 2021 (Dillis et al., 2023).

Box 26: *Adaptation in Crop Agriculture*

Climate adaptation is increasingly important for California agriculture, but the economic literature remains limited, particularly for crop-specific adaptation. Existing studies identify potential strategies for individual crops and cropping systems but provide less direct evidence on how well these measures perform in terms of, for example, their effects on yields, grower costs and returns, and outcomes across different farm types and regions. While much agricultural climate-impact research has historically focused on annual crops, recent research has focused increasingly on the distinct adaptation challenges of perennials in California, including almonds, walnuts, and grapes (Lobell & Field, 2019; Wen et al., 2026).

Annuals: In a 20-year field experiment near Fresno, researchers evaluated the effects of no-tillage, surface residue retention, and winter cover crop rotations on cotton, tomatoes, garbanzo, and sorghum (Mitchell et al., 2024). The combined no-till and cover crop system improved soil health relative to conventional practices, including better soil structure, greater water storage, and higher soil biodiversity. Water also infiltrated dramatically faster: 45 seconds under the combined no-till and cover crop system, compared with about 27 minutes under standard tillage without cover crops. This matters because faster infiltration can reduce runoff and improve on-farm water capture, while increased soil organic matter and water retention can help buffer annual crop systems against drought and irrigation constraints.

Perennials: Adaptation in perennial systems is often more constrained because planting, variety, trellis, and irrigation decisions are made years before climate impacts are fully realized. Production value from California's perennial fruit and nut crops was roughly $21.5 billion in 2023, accounting for about one-third of the state's total agricultural value (Wen et al., 2026). A cost-benefit analysis in the Central Valley found that winter cover cropping with clover mixes in almond orchards can generate positive long-run returns, with a benefit-cost ratio of roughly 1.3 over a 30-year horizon (DeVincentis et al., 2020). In wine grapes, a Napa County trial found that taller, high-wire trellises improved shade, grape quality, and marketable yield per unit of water, helping protect vineyard profitability under hotter conditions (Yu et al., 2022).

Water adaptation mechanisms: Investments that help farmland capture and replenish water can reduce supply costs and build drought resilience. In California's Pajaro Valley, a recharge net metering program gives growers rebates on groundwater-pumping fees when they capture stormwater runoff and recharge the aquifer they irrigate from (Bruce et al., 2023). Recharged water is substantially lower-cost than some alternative supplies—about $570 per acre-foot, compared with roughly $3,892 per acre-foot for desalination—and the program is projected to generate about $1.9 million in net benefits over 25 years, largely through improved basin-wide water security (Bruce et al., 2023). By stabilizing the groundwater growers draw on in dry years, such investments reduce a farm's exposure to water shortages and the high cost of replacement supplies.

Realizing these benefits takes time and capital, and adaptation can be costly and difficult to finance—particularly for smaller or newly established farms facing financial, technical, or staffing constraints (Babin et al., 2022; Ortiz-Bobea, 2021). More field evidence is still needed to understand how reliably these strategies pay off across different crops, regions, and climate extremes. Taken together, however, the available evidence suggests that well-targeted adaptation can save water, sustain or increase yields, and deliver positive economic returns. The central challenge is scaling adaptation support in ways that reach the farms and regions most exposed to climate risk and least able to absorb upfront costs.

9.2 Livestock Sector

California's livestock sector accounts for 27% of all agricultural revenues (California Rangeland Trust, 2024). In 2024, dairy products contributed $8.61 billion in cash receipts; cattle and calves contributed $4.98 billion (CDFA, 2025). California is the nation's top dairy-producing state, supplying about 18% of the U.S. milk supply from more than 1.7 million dairy cows on roughly 1,300 dairy farms (Glover et al., 2023). Four major dairy counties that are also highly exposed to flooding—Tulare, Fresno, Kern, and Kings counties—together account for 54.3% of California dairy production, or about 10% of the entire United States' dairy supply (Derrick et al., 2023). This concentration of high-value livestock production in climate-exposed regions means that climate disruptions can translate quickly into large regional and statewide economic losses.

9.2.1 Heat's Impact on Livestock

Heat stress is one of the main climate-induced stressors affecting California's livestock sector. It can reduce milk production, increase the incidence of mastitis, impair reproductive processes, and contribute to premature deaths (Das et al., 2016). Dairy breeds are especially sensitive to heat stress because they generate more metabolic heat than meat breeds (Das et al., 2016). The California Department of Insurance's analysis of seven extreme heat events between 2013 and 2022 estimated $89.1 million in dairy productivity losses and $2.9 million in dairy cow mortality losses, for a combined dairy-related impact of approximately $92 million (see **Table 1** in *Section 9.1 Crop Yield and Revenue Impacts*) (CDI, 2024). Dairy productivity losses accounted for nearly all the livestock-related damages in the CDI analysis, while mortality losses were smaller but still economically meaningful.

California's annual heat-related milk production losses could rise from approximately $200 million under a historical-climate baseline to $430 million by the 2050s and $540 million by the 2080s, assuming constant production, prices, and heat-abatement practices (Mauger et al., 2015). Losses are concentrated in major dairy regions: in Tulare County, one of the country's largest dairy-producing counties, estimated annual heat-related milk losses rise from $35 million under the historical baseline to $79 million in the 2050s and $103 million by the 2080s (Mauger et al., 2015). This study used the SRES A1B emissions scenario—an older intermediate emissions pathway broadly comparable to RCP 6.0.

The economic evidence is strongest for dairy productivity losses, while evidence on heat-related disease pathways is less often monetized. Warmer and more humid conditions may increase pathogen and vector-borne disease risks in cattle systems, raising potential management, testing, treatment, and productivity costs. For example, a 2.5-year study of eight beef-cattle ranches in California detected *E. coli* in 2.6% of 2,654 fecal samples, with detection odds increasing as soil temperature and humidity increased (Benjamin et al., 2015). Bovine anaplasmosis, a tick-borne disease endemic in many parts of California, can also cause mortality, reduced productivity, and reproductive losses, but the magnitude of future climate-related costs remains uncertain (Bouchard et al., 2019; Young, 2020).

9.2.2 Drought's Impact on Livestock

Drought-related livestock losses are largely driven by higher feed and water costs, which rise sharply when drought reduces forage availability and increases reliance on purchased inputs (Sumner et al., 2021). This creates a major economic exposure for California dairies because feed is the largest cost category in dairy production, representing about 49% of total economic production costs in 2024 (USDA, 2026). Because California dairies rely heavily on irrigated forage crops such as alfalfa, silage corn, and irrigated pasture, rising water costs and forage scarcity can directly affect profitability (Medellín-Azuara et al., 2018). For instance, in 2015, the most severe year of the 2012–2016 California drought, statewide dairy and livestock revenues fell by roughly $350 million (Lund et al., 2018). During the 2020–2022 drought, strong milk and cattle prices helped protect against large revenue losses; however, higher feed costs reduced producer margins: California silage prices were 43% higher in 2021 than the 2017–2019 average, and premium alfalfa hay was about 50% above the 2019–2020 average (Medellín-Azuara et al., 2022).

Alfalfa hay is especially exposed to drought because it is water-intensive and often flood-irrigated (Putnam et al., 2015). California has long ranked among the nation's largest alfalfa producers, but its production has fallen steadily since 2002 as growers have shifted to higher-value crops with lower water demands (Sall et al., 2023). Between 2007–2020, alfalfa acreage fell by 515,000 acres, while tree nuts added 1.03 million acres (Zhang, 2025). These shifts increase the importance of remaining forage production for California dairies, while also exposing growers to higher irrigation costs during drought. In 2021, declining groundwater levels raised pumping costs by an estimated $184 million statewide, with the largest increases occurring in the Tulare Lake Basin (Medellín-Azuara et al., 2022).

9.2.3 Flooding's Impact on Livestock

Estimated monetary losses from flood-related agricultural damage within 100-year flood zones designated by FEMA are particularly high in Kern and Fresno counties (Tugkan et al., 2024; Wein et al., 2016). Larger livestock operations in Kern and Fresno are especially vulnerable because greater shares of farms sit within floodplains, so a single flood event can generate disproportionately large losses for these operations (Tugkan et al., 2024). During the 2023 atmospheric-river floods, dairy-sector impacts were concentrated in the Tulare Lake Basin, where floodwaters put about 100,000 cattle and more than a dozen dairies at risk, and roughly 75,000 cows were relocated to permitted facilities (Peterson & Bardeen, 2023).

Heavy rain events can also overtop livestock manure lagoons, risking contamination of nearby surface water and groundwater with excess nutrients, pathogens, and antibiotics (Casteel et al., 2006; Glover et al., 2023). Adaptation strategies for manure lagoons within floodplains include transitioning from flush-lagoon systems to dry manure management, which reduces liquid waste volumes and improves resilience to heavy precipitation and overtopping (CDFA, 2025; NRCS, 2019). California's Alternative Manure Management Program, which has awarded 172 dairies roughly $113 million since 2017 to convert from lagoon-based to dry manure systems, illustrates that these transitions can also lower operating costs: an independent evaluation found that participating dairies reported reduced lagoon-cleaning, manure-hauling, bedding, and fuel costs (Babin, 2024).

Box 27: *Evidence of Livestock Heat Adaptation*

Livestock adaptation evidence is strongest for dairy heat stress, where cooling systems can reduce physiological stress and help protect milk production. Evidence for livestock adaptation to drought, flooding, and wildfire smoke is more focused on preparedness and risk management than on measured costs and returns.

Heat adaptation in California dairies centers on reducing animal heat load through shade, fans, sprinklers, and other water-based cooling systems. Producer guidance from the California Dairy Quality Assurance Program (CDQAP) estimates that cows with only minimal heat abatement, access to shade but no fans or sprinklers, lose about 650 pounds of milk per cow per year, alongside reduced feed intake of about 320 pounds per cow per year and an estimated $110 per cow annually in losses. CDQAP also reports that adequate shade can reduce cattle heat load by 30–50%, while sprinklers, soakers, misters, and foggers can further leverage the cooling benefits of shade (CDQAP, 2013, 2021). Field evidence shows that these practices are already common but unevenly implemented across dairies in California (Tresoldi et al., 2017). These estimates suggest that more complete cooling systems can function as economic adaptation by protecting animal health and farm revenue as heat exposure increases.

10. Aquaculture and Fisheries

Key Takeaways

1. **Climate change is driving repeated fishery collapses and costly disaster assistance.** Shifts in ocean conditions linked to stronger climate change driven El Niño and La Niña events have caused sharp population declines in key commercial species. Between 1994 and 2020, Congress allocated $170 million tied directly to environmentally-driven collapses of West Coast fisheries (Bellquist et al., 2021; NOAA Fisheries, 2025).
2. **Salmon populations face existential threats from warming, drought, and wildfires.** The 2023-2025 closures of California's salmon fisheries due to critically low stocks have resulted in annual losses of $15 million in ex-vessel value and over $45 million in wider economic impacts, devastating fishing and Tribal communities who rely on salmon as a cultural and economic resource (Cal OES, 2023a; Hoopa Valley Tribal Council, 2024).

Fish and seafood are an essential part of California's natural resources, contributing to recreation, cultural traditions, and economic livelihoods across the state. California's wild-capture commercial fishing and seafood industry supports more than 193,000 jobs and generates $7 billion in income, $31.2 billion in sales, and $11.1 billion in value-added impacts (NOAA, 2025). Key wild-capture fisheries in California include market squid, Dungeness crab, Pacific Sardine, and red sea urchin (CDFW, 2024). Historically, salmon fisheries have been a cornerstone of California's commercial fishing sector, but following the collapse of salmon stocks in 2022, the State closed all commercial ocean salmon fisheries in 2023, 2024, and 2025 (FISHBIO, 2025).

While commercial wild-capture fisheries remain vital to California's coastal economy, aquaculture (farmed seafood) has emerged as a growing and complementary source of seafood production. Globally, aquaculture surpassed wild-caught production for the first time in 2018, reflecting rising demand, pressures on wild fish stocks, and the need for more stable and scalable seafood production systems (Coomber, n.d.). Valued at $200 million, California's aquaculture industry contributes about 6% of total US commercial aquaculture value (CAA, n.d.; Wright et al., 2025). Aquaculture fisheries in California produce oysters, abalone, mussels, clams, seaweed, catfish, tilapia, sturgeon, striped bass, and rainbow trout (Coomber, n.d.). Together, wild caught and aquaculture fisheries support coastal and inland economies, provide food security, and contribute to seafood production in local and global markets.

10.1 Federal Disaster Aid in Response to Climate-Driven Fishery Collapses

Shifts in ocean conditions driven by climate change are accelerating declines across many California fisheries (NOAA Fisheries, 2025). Nationwide, an estimated 85% of fishery disasters have been attributed to extreme environmental events, such as drought and marine heat waves, often in combination with overfishing and habitat loss (Bellquist et al., 2021). Between 1994–2020, more

than $1.8 billion in fishery disaster relief was appropriated nationwide, $170 million of which was linked directly to environmentally driven disasters in West Coast fisheries (Bellquist et al., 2021; NOAA Fisheries, 2025).

Recent California fishery disaster declarations have involved Pacific sardine, Dungeness/rock crab, red sea urchin, and salmon fisheries, reflecting multiple climate-sensitive pathways including low stock biomass, harmful algal blooms, marine heat waves, drought, and unfavorable ocean and river conditions (Cai et al., 2023; NOAA Fisheries, 2025). NOAA approved federal disaster assistance for the 2015–2016 California Pacific sardine fishery, allocating $1.64 million, with a later 2017–2019 sardine disaster allocation bringing total recent sardine disaster relief to about $3.86 million (NOAA Fisheries, 2025). Then in late 2015, El Niño-driven ocean warming fueled a toxic algal bloom that contaminated Dungeness crab habitat from Santa Barbara to the Oregon border, leading to extensive fishery closures. Economic losses totaled an estimated $48.3 million, representing 71% of the commercial value of Dungeness crab during the 2015–2016 season (NOAA Fisheries, 2025).

Continued marine heat waves and El Niño events have contributed to widespread kelp loss. Over the past decade, an estimated 95% of surface kelp in Sonoma County and 90% in Mendocino County died off due to warming ocean temperatures (NOAA Fisheries, 2025). Kelp forests along the California coast serve as a primary food source and critical habitat for many marine species, including red sea urchins. Between 2016–2024, California filed four federal fishery disaster assistance declarations and received nearly $5 million in relief for revenue losses associated with the decline of its red sea urchin fisheries (NOAA Fisheries, 2025).

10.2 Declining Salmon Populations and Impacts on Coastal and Tribal Communities

Salmon fisheries are a cornerstone of California's coastal economy and Tribal ways of life, yet they increasingly face intensifying climate-driven stressors—including drought, warming rivers, wildfires, harmful algal blooms, and degraded habitat—shown to significantly reduce survival across life stages (Moyle et al., 2017). Historically low salmon stocks in 2023 prompted the closure of California's recreational and commercial salmon fishery for non-Native American harvest, which continued in 2024 and 2025 (Bonham, 2025). These closures have resulted in the loss of approximately $15 million in average annual ex-vessel value, with additional estimated economic impacts exceeding $45 million across both commercial and recreational fisheries annually (Cal OES, 2023; CDFW, 2021; NOAA Fisheries, 2023). Exvessel value refers to the revenue fishers receive at the dock for the first sale of their catch, or the price per pound paid to the vessel when landings are unloaded, before any processing, wholesaling, or retail markups occur. The repeated closures represent a major economic setback for fishing-dependent communities.

These recent closures reflect a broader ecological decline that has unfolded over decades. The Klamath River historically supported more than 1.2 million salmon, yet, by 2017, returns had fallen to just 11,000 fish (Visit California, n.d.). Researchers warn that without substantial intervention, California could lose 45% of its native salmon species by 2050 and 74% by 2100 (Moyle et al., 2017). However, after decades of advocacy and leadership by the Karuk, Yurok, Klamath, Hoopa

Valley, and other Klamath Basin Tribes, the recent Klamath River dam removal—the largest river restoration project in US history—reopened over 400 miles of historical habitat and will serve to improve conditions for long-term salmon recovery (NOAA Fisheries, 2024a). Initial post-removal monitoring has documented salmon returning to parts of the Klamath Basin that had been inaccessible for over a century and improved water-quality conditions. Full population-level benefits will take time to materialize, since many Klamath Chinook follow a roughly three-year life cycle; fish hatching in 2024–2025 will not return until at least 2027–2028, when stronger signals of recovery can be evaluated (NOAA Fisheries, 2024b).

Box 28: *The Importance of Salmon to Tribal Identity and Livelihoods*

Salmon are integral to the lives and cultures of many California Native American communities, including the Yurok, Hoopa Valley, Karuk, and Wintu Tribes. In California, the Yurok and Hoopa Valley Tribes possess federally reserved rights to harvest up to half of the harvestable surplus of Klamath River fish (Pacific Fishery Management Council, n.d.). Several Congressional federal fishery disaster assistance requests in recent years have come from Native American communities across California, Oregon, Washington, and Alaska (NOAA Fisheries, 2025).

Between 2018–2021, the Yurok Tribe was awarded a total of $15,986,342 in federal fishery disaster assistance for lost earnings of their Klamath River Fall Chinook Commercial Fishery, reflecting the severe economic impacts of recurring stock collapses and environmental stressors on Tribal fishing communities (NOAA Fisheries, 2025). Yurok Chairman Thomas P. O'Rourke, Sr. said "In Yurok Country, two years without a commercial fishing season has an impact that is similar to a plant shutting down in a one-company town...We are doing everything in our power to find ways to help our people to supplement their lost income. We have people who haven't been able to catch up on bills for two years." (Danovich, 2018).

In a 2024 letter to the US Secretary of Commerce, the Hoopa Valley Tribe described how the 2023–2024 salmon fishery closures on the Klamath–Trinity system left their 3,600 members without enough fish to meet subsistence and ceremonial needs, causing "enormous economic strain" as families lost an invaluable food resource (Hoopa Valley Tribal Council, 2024). For more information on climate impacts to Tribal communities, see the Fifth Assessment's "Tribal and Indigenous Communities Statewide Topical Report".

11. Forestry Economy

Key Takeaways

1. **Climate change imposes costs on California's forestry economy through two channels: by lowering the market value of timberland as an asset, and by destroying trees that would have supplied future timber harvests.** Private timberland values in California, Oregon, and Washington have fallen by about 10% over the past two decades—about $11.2 billion in total losses, with $6.2 billion attributed to climate change affecting wildfire risk expectations and drought impacts (Wang & Lewis, 2024). High-severity wildfires that burned from 2018 to 2021 are projected to reduce California timber harvest by $12.7 billion over the next 50 years, the equivalent of seven years' worth of harvest and an average of 4,300–5,900 jobs per year (MBG Inc., 2023).
2. **Tribal forestry faces climate pressures while continuing to prioritize stewardship.** Due to climate impacts, aging infrastructure, and limited milling capital, Tribes have harvested about

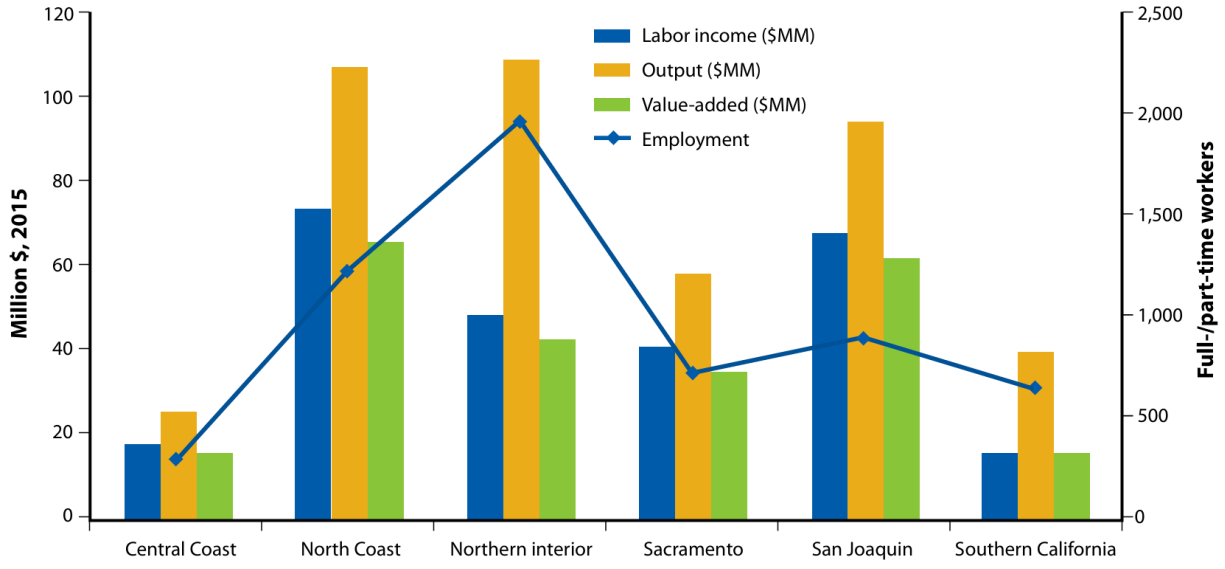
40% of their allowable annual cuts between 2020 and 2023, costing an estimated $85 million in missed stumpage income—revenue from selling standing timber—in 2023 alone (BIA, 2024).

Climate change is intensifying stress on forest ecosystems by increasing wildfire risk, drought severity, warming temperatures, and insect and disease outbreaks (Hartmann et al., 2022). Higher temperatures and reduced water availability weaken trees, making them more vulnerable to pests and pathogens, while prolonged drought can cause widespread tree mortality and create additional fuel for wildfires (CFPC, 2023; Morris et al., 2018; Stephens et al., 2018). Large-scale die-offs can also shift forest composition, leading to lower-density forests or conversion to non-forest vegetation (OEHHA, 2022; Steel et al., 2023). The loss of large, old trees further disrupts ecosystem function, as they support surrounding vegetation through nutrient-sharing mycorrhizal networks (Gilhen-Baker et al., 2022). Recent remote-sensing analysis mapped approximately 91.4 million dead trees across California's vegetated landscapes using 2020 aerial imagery, underscoring the scale of mortality already occurring under these stressors (Cheng et al., 2024).

Forests cover one-third of the state's land area, 33 million acres, and are primarily concentrated in the northern and central regions of the state (UC ANR, n.d.). From 2014–2016, an estimated 83 million trees died in the Sierra Nevada region due to the combined impact of drought and bark beetle infestation (Sierra Nevada Conservancy, 2019). An additional 30 million trees were destroyed by wildfire in the same region, resulting in a total of more than 110 million dead trees in just three years (Sierra Nevada Conservancy, 2019). This mass die-off contributed to the transition of about 30% of the southern Sierra Nevada's conifer forests to non-forest vegetation between 2011 and 2020 (Steel et al., 2023). Throughout California, bark beetle disturbances have resulted in approximately $93 million per year in lost recreational services across affected forest regions between 2005–2016 (Sánchez et al., 2021).

11.1 Forestry and Forest-Product Industries in California

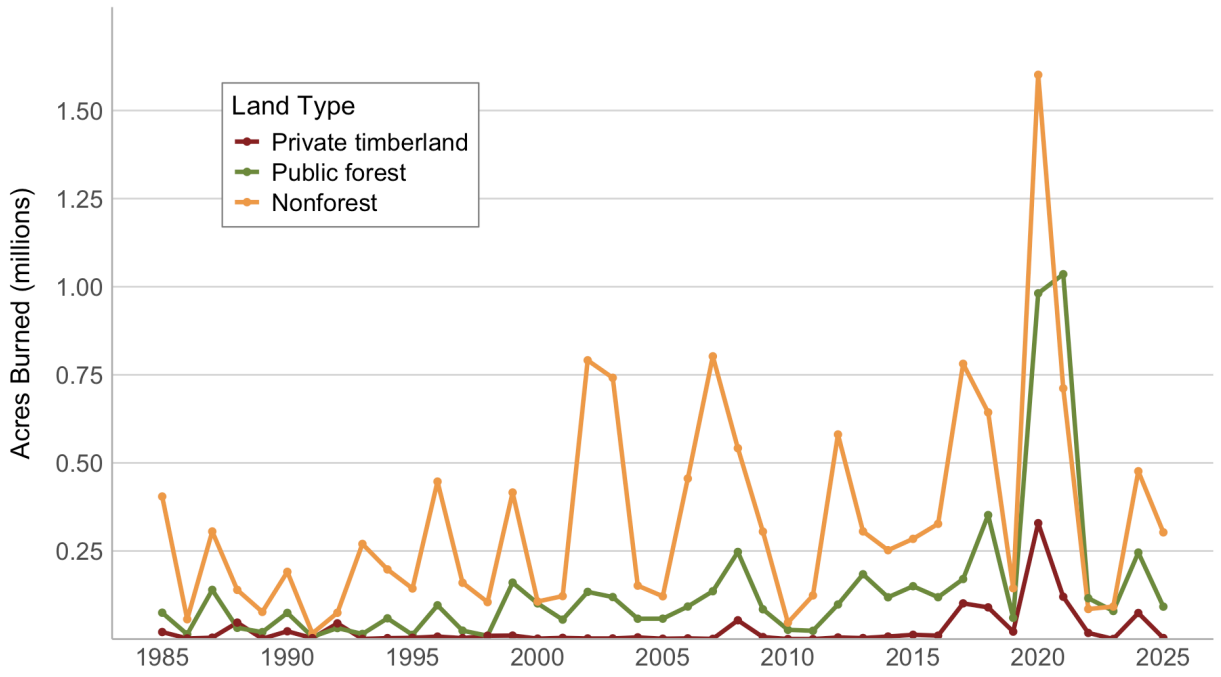
The Forestry and Forest-Products (FFP) industry in California has a total economic output of $22 billion per year and employs 81,800 full- and part-time workers with nearly $5 billion in labor income per year (Standiford et al., 2020). Of California's total FFP output, 95% comes from forest products manufacturing, such as solid wood products and pulp/paper manufacturing (Standiford et al., 2020). The remaining 5% of FFP output is from the forestry and logging sector, which is concentrated in the North Coast and interior regions, as shown in **Figure 18**, and is more vulnerable to increases in drought, wildfires, and pests (Standiford et al., 2020).



Geographic Distribution of the Forestry and Logging Sectors

Figure 18: *Direct economic contribution of forestry and logging across six California forest regions in millions of dollars ($MM). The North Coast and Northern Interior regions together account for approximately half of statewide forestry and logging output and 56% of sector employment, while the Sacramento and San Joaquin regions also account for sizable shares of output. Dollar values are reported in millions of 2015 dollars; employment is reported as full- and part-time workers. Source: (Standiford et al., 2020).*

Much of California's private timberland is located in coastal landscapes and in lower-elevation areas near national forests, where proximity to large public-land fires raises perceived risk and can negatively impact timberland values (Wang & Lewis, 2024). In western US forests, the largest share of wildfire-related economic losses to privately owned timberland arises not from stands that burn directly, but from reductions in land values as buyers capitalize higher wildfire risk into prices and from higher risk-related costs such as insurance (Wang & Lewis, 2024). **Figure 19** shows that wildfires have affected primarily public or non-forested lands across Washington, Oregon, and California; however, over the past two decades, increased wildfire risks have lowered private timberland values by about 10% across California, Oregon, and Washington (Wang & Lewis, 2024). This is roughly equivalent to $436 per acre, or $11.2 billion in total, with an estimated $6.2 billion attributed to human-caused climate change (Wang & Lewis, 2024).



Acres Burned by Large Wildfires in California by Land Type (1985–2025)

Figure 19: *From 1984–2025, annual burned acreage increased substantially across the state, with the largest increases occurring on other land uses and public forestland rather than on private timberland. Private timberland accounts for a much smaller share of burned acreage. Source: (Wang & Lewis, 2024)*

From 2018–2021, over 1.5 million acres of forest were burned by high-severity wildfires, which typically kill more than 75% of overstory trees (MBG Inc., 2023). That level of loss is often considered stand-replacing, with big implications for shade, seed sources, habitat, and the likelihood of type conversion (Stevens et al., 2017). This direct fire damage projected out over the next 50 years is estimated to reduce future timber harvest by 11 billion board feet, valued at $12.7 billion (assuming current product values), or an average 221 million board feet (MMbf) per year (MBG Inc., 2023). At a 3% discount rate, the present value of the economic loss is $6.5 billion (MBG Inc., 2023). This potential loss of timber harvest could result in an average of 4,300–5,900 fewer jobs per year in forestry, logging, and wood products manufacturing in California over the next 50 years (MBG Inc., 2023).

While there have been numerous efforts to understand the economic impacts of climate change on forests, important gaps remain. A notable gap in empirical research regards the impact of climate change on non-market dimensions of forestland such as biodiversity and ecosystem services (Carleton & Hsiang, 2016). Addressing these gaps is essential for informing both landowner adaptation strategies and broader forest policy and management decisions.

Box 29: *Adaptation in Forestry*

Nature-based solutions in forests, or ecological management, use several techniques to reduce wildfire severity and spread, including fuel reduction treatment via prescribed burning, mechanical thinning, mastication, and expanding defensible space around structures (CAL FIRE, n.d.). In addition to moving forest composition toward larger and more widely spaced trees, strategic forest restructuring has also been used to alter species composition toward more fire-resistant varieties. For example, a study testing the response of carbon pricing on private forestland in the western US shows that landowners shifted away from Douglas-fir and planted more hardwoods and ponderosa pine, which are more climate-resilient species (Hashida & Lewis, 2019).

11.2 Tribal Forest Management

Tribal forestry markets face structural and financial challenges across the US. Between 2020–2023, Tribes harvested only 40% of their allowable annual cuts (BIA, 2024). Allowable annual cuts are harvest limits set in Tribal forest management plans developed in coordination with the Bureau of Indian Affairs. This underharvesting cost Tribes an estimated $85 million in missed stumpage income in 2023 alone, against annual stumpage income that otherwise ranged from $50–$79 million (BIA, 2024). These harvesting shortfalls are due to intentional Tribal forestry management decisions as well as barriers such as climate impacts, limited capital to modernize outdated mills, and a large backlog of road infrastructure maintenance (BIA, 2024). Of the approximately 47,000 miles of roads located on Indian trust forest lands, more than 43,000 miles require repair or maintenance, with estimated costs exceeding $1.3 billion (BIA, 2024).

Despite these constraints, stumpage income—revenue from selling standing timber—remains a critical economic driver for many Tribes. In 2023, national Tribal stumpage income exceeded $50 million, with Tribes in Oregon and Washington consistently accounting for roughly three-quarters of national stumpage income (BIA, 2024). In California, the Hoopa Valley Tribe consistently reports the highest earnings, totaling $9.26 million between 2018 and 2023, (BIA, 2024). The Hoopa Valley Tribal Reservation is the largest forested reservation in the State of California and encompasses more than 100,000 acres of timberland along the Trinity River (Battaglia, 2023; Hoopa Valley Tribal Council, n.d.). Guided by their Forest Management Plan, the Tribe's Forestry Department uses a modified clear-cut method that leaves several mature trees standing to promote soil health and protect ecosystem integrity. Each year, they harvest approximately 400 acres of mature timber (Hoopa Valley Tribal Council, n.d.). Other Tribes in California harvest intermittently and at smaller scales. The Yurok Tribe earned $126,000 in 2020 and the Tule River Tribe $144,000 in 2019, while the Round Valley Indian Tribes, La Jolla Band of Luiseño Mission Indians, and Mooretown Rancheria report harvest values of less than $15,000 annually (BIA, 2024).

In 2025, the Yurok Tribe, the largest Tribe by population in California, expanded its stewardship of ancestral forests and acquired more than 47,000 acres, the largest "land back" deal in California history (Alexander, 2025). This was financed in part through California's cap-and-trade carbon offset program for forest carbon sequestration (Alexander, 2025; Beck, 2021). The Yurok Tribe has implemented improved forest management, restoring redwoods, mixed conifer forests, and native grasslands, and use of cultural burning to support increased hazelnut production for basketry (CARB, 2021; Marks-Block et al., 2021).

In the pre-colonial era, Indigenous burning played a central role in shaping California's landscapes. By applying low-intensity fire in regular intervals, Tribal communities reduced fuel loads, promoted the growth of fire-adapted species, maintained old growth forests and grasslands, and supported healthy ecological systems (Klimaszewski-Patterson et al., 2021). This stewardship created resilient ecosystems that could better withstand drought, pests, and wildfire. Cultural burning continues to be a vital form of Tribal forest management, sustaining ecosystem services and reinforcing cultural traditions (Long et al., 2021). California Tribes recognize specific trees, such as black oak and coast redwoods, not merely as sources of food or material, but as cultural keystone species embedded in their spiritual, ecological, and community practices (Rainer, 2020; Yosemite Conservancy, 2023). These traditions underscore a deep-rooted relationship with the land and highlight the importance of uplifting Indigenous ecological knowledge within forest management and conservation efforts. For more information on climate impacts to Tribal communities, see the Fifth Assessment's "Tribal and Indigenous Communities Statewide Topical Report."

12. Tourism and Recreation

Key Takeaways

1. **Protected areas and parks are highly vulnerable to climate-driven disruptions.** During extreme drought years, visitation declined by 8–9% at Yosemite and Sequoia & Kings Canyon National Parks, while heavy wet years reduced access and dropped visitation by 16.6% at Pinnacles National Park (Jenkins et al., 2023; Wilkins & Horne, 2024). The 2020 CZU Lightning Complex Fire burned 97% of Big Basin Redwoods State Park and forced a 2-year park closure (CA State Parks, 2025; Jenkins et al., 2023; US DOI, 2023).

2. **Climate-driven disruptions to mobility amplify tourism and recreation losses.** Wildfires, flooding, landslides, and coastal erosion can wash out roads and railways, cutting off access to parks and tourist destinations for prolonged periods, reducing revenue for nearby businesses. For example, atmospheric rivers in January 2023 caused the Regent's Landslide which closed Highway 1 access to Big Sur for over 3 years, with estimated economic loss of nearly $438 million (Beacon Economics, 2025).

California is a unique destination for tourists around the world, offering an expansive coastline, major urban centers, and a vast diversity of natural landscapes, which attract both domestic and international travelers. Tourism is a major part of the state's economy; in 2023, visitor spending surpassed $150 billion, generating $12.7 billion in state and local tax revenue, and supporting over 1.1 million jobs (GO, 2024b). Tourism is deeply intertwined with the state's natural environment, with more than one-fourth of the state's land area preserved as recreational areas, national seashores, or wildlife refuges (CNRA, 2024). The increasing frequency and intensity of climate-related hazards can have cascading effects that can alter ecosystems and impact visitation to protected areas and surrounding local economies. The economic consequences of climate change on California's tourism are multifaceted, ranging from direct damages to infrastructure and businesses to indirect losses from decreased visitation and disrupted operations.

12.1 Effects of Weather and Climate on Recreation and Tourism

Nationwide, outdoor recreation participation is highest on moderately warm days, between 70–80°F (21–27°C), and declines by around 15–20% on very hot days, above 86°F (30°C), as people shift activities indoors or to cooler times of day (Chan & Wichman, 2022). Heat can make outdoor activities uncomfortable or unsafe, deterring visitors and reducing demand for accommodations and services. This reduced demand can translate into lost revenue for hotels, restaurants, and other tourism-dependent businesses (Day et al., 2013). While extreme heat may suppress recreation in hotter regions, it can simultaneously increase demand for cooler destinations. In the Lake Tahoe basin, every 10°F (5.6°C) increase in lowland temperatures is associated with roughly 1,200 additional vehicles entering the basin and 27,000 additional daily vehicle miles traveled, contributing to congestion, emissions, and deteriorating visitor experience (Hui et al., 2023).

Wildfire events may prompt public health advisories, park closures, canceled events, and reduced participation and revenues in outdoor recreation due to health risks (Feo et al., 2020b; Heft-Neal et al., 2023). From 2008–2017, wildfire smoke is estimated to have caused about $655 million per year in welfare losses to outdoor recreation on federal and state lands in California (Gellman et al., 2025). In January 2025, Los Angeles International Airport saw a 3.0% decline in passengers compared to January 2024, partly attributed to wildfire-smoke-related disruptions and flight cancellations (Visit California, 2025). Between 2014 and 2024, wildfire and heat disrupted or cancelled roughly 70 cultural and recreational events across California (McKinley et al., 2025).

California's recreation and tourism economy is also exposed to precipitation variability. Decreased precipitation may lead to reduced snowpacks which can impact winter sports, shortening ski seasons and raising snowmaking costs. Lower snowpack also reduces water levels in reservoirs such as Shasta, Oroville, and Folsom, limiting boating, fishing, and other water-dependent summer recreation (Wilkins & Horne, 2024). Sea level rise and storm surges also pose a long-term threat to coastal beach communities. The economic costs of sea level rise to California's beach communities are substantial, including increased damage to coastal properties, erosion of beaches, destruction of road and railways, and reduced appeal for beach-related activities (King et al., 2008). For example, the six-week closure of Highway 1 near Big Sur after the March 2024 Rocky Creek slip-out alone cost businesses an estimated $50 million (Colón, 2024). Additionally, in December 2024, powerful storms caused 150 feet of the Santa Cruz Wharf, a major tourism and recreation hub and the longest wooden pier in the United States, to collapse. Built in 1914, the wharf faces rising annual maintenance costs and storm risks, and the collapsed section will not be rebuilt due to ongoing vulnerability (Burke, 2024). In Southern California, Venice Beach, an iconic tourist destination in Los Angeles, could lose $450 million in tourism revenue by 2100 under a 1.4-meter sea level rise scenario (King et al., 2016). Additionally, climate impacts to airports and highways may interrupt regional mobility, leading to travel delays, higher transportation costs, and reduced accessibility to destinations, which in turn place added pressure on local tourism economies.

Box 30: *Higher Temperatures Shorten Inland Desert's Snowbird Season*

Increasing temperatures are expected to significantly impact California's desert regions, which attract large numbers of winter tourists, particularly retirees, from Canada and colder US states, often referred to as "snowbird" visitors. In the Coachella Valley, seasonal residents make up approximately 25% of the adult population, with between 60–70% staying for 5 months or more (Yañez et al., 2020). However, the increased likelihood of extreme heat may reduce visitation to outdoor attractions and shorten the snowbird season by up to 36% by the end of the century (Yañez et al., 2020). This could significantly affect the tourism-dependent economy of the inland desert region, as well as tourist destination hotspots in parts of Central and Northern California that face increasing risks of extreme heat.

12.2 State and National Parks

State Parks

California's outdoor recreation economy contributes over $80 billion annually, or about 2.1% of state GDP, and supports nearly 550,000 jobs (US BEA, 2023). California's state parks are a large part of the state's recreation economy: state park visitors generate an estimated $6.8 billion in park-related expenditures each year, supporting local lodging, restaurants, retail, transportation, and other visitor-serving businesses (California State Parks Foundation, 2026). California has the largest state park system in the US, with over 280 parks that host 70–80 million visitors and bring in over $110 million in revenue annually (CA State Parks, 2024). State beaches, which are especially vulnerable to coastal erosion from sea level rise and storm surges, are especially popular: they drew nearly 36 million visitors in 2023 and earning consistently earn higher revenues than state parks (CA State Parks, 2024).

Climate hazards can disrupt this economic activity through park closures, damaged infrastructure, reduced access, and lower visitation. During the 2022–2023 winter storm event, nearly 50 state parks were forced to close temporarily, with five sustaining significant damage (Brooks, 2023). The initial damage estimate was $190 million to restore the damaged facilities and reopen the affected parks (CDOF, 2024). These storms caused widespread landslides, sinkholes, coastal erosion, and facility damage, limiting visitor access and affecting nearby tourism-dependent businesses. Wildfires have also caused extensive and long-lasting damage to park landscapes, infrastructure, and visitation. In 2020, the CZU Lightning Complex Fire swept through Big Basin Redwoods State Park, burning 97% of its 18,000 acres, destroying more than 100 structures including visitor facilities, and toppling an estimated 15,000 trees; damage was so extensive that the park did not reopen to visitors until July 2022 (CA State Parks, 2025). Early estimates placed basic wildfire repair needs for Big Basin alone at approximately $186 million, illustrating how wildfire impacts can create both immediate revenue losses from closures and large long-term rebuilding costs (Cart, 2021).

National Parks

California's 28 national park units receive more than 36 million visits annually (Flyr & Koontz, 2024). In 2023, national park visitors spent an estimated $3.2 billion in the state, supporting nearly

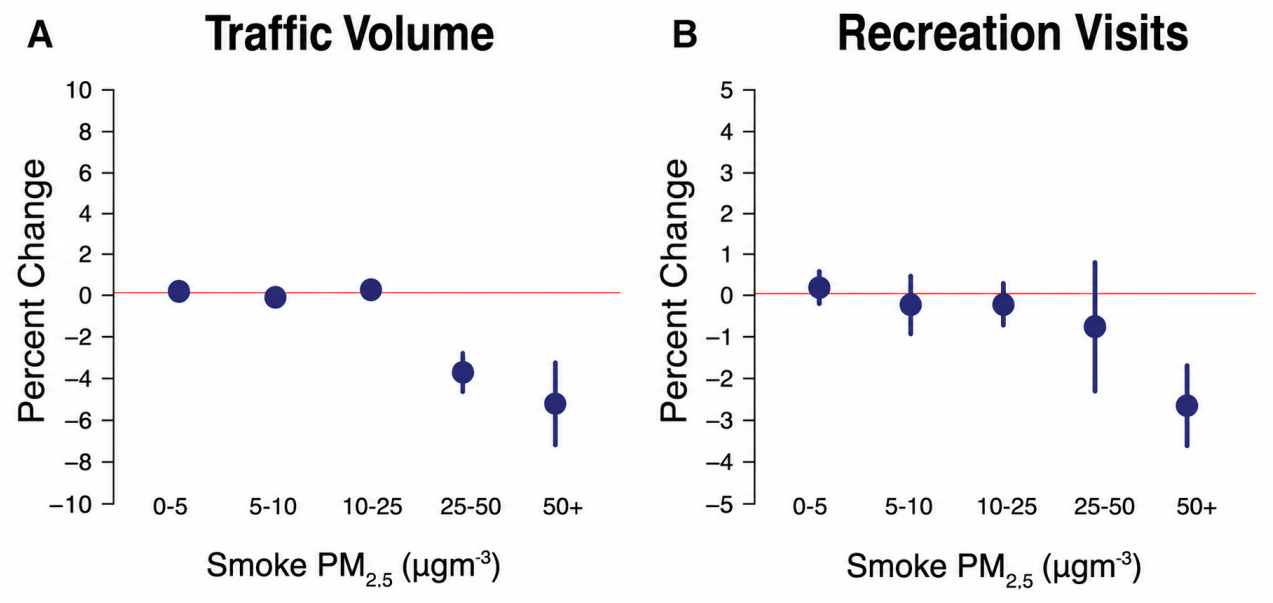
40,000 jobs, primarily in the lodging and restaurant industry (Flyr & Koontz, 2024; NPS, 2024). Because more than 40% of national park jobs are seasonal, climate-driven changes in visitation patterns could affect employment opportunities in nearby communities (Fisichelli et al., 2015).

National parks also face growing exposure to climate-related hazards. The National Park Service manages approximately 397 national parks, 57% of which face a high risk from at least one major hazard—wildfire, drought, sea level rise, or invasive species (NPCA, 2024). Wildfire is the second most prevalent climate-related threat to national park units after invasive species, with 95 parks nationwide classified as high-risk (NPCA, 2024). In California, Lava Beds National Monument, Lassen Volcanic National Park, Yosemite National Park, and Sequoia and Kings Canyon National Parks face high risk from three overlapping threats: wildfire, drought, and invasive species (NPCA, 2024).

Research on national park visitation trends from 1980–2019 found that the impacts of extreme drought and wet years on park visitation vary by location and recreational offerings (Jenkins et al., 2023). For example, Yosemite and Sequoia and Kings Canyon experienced notable declines in visitation during extreme drought years (−8.6% and −8.2%, respectively), largely due to reduced attendance in peak summer and fall (Jenkins et al., 2023). During extreme wet years, visitations dropped an average of 8.5% in Sequoia and Kings Canyon, 13.9% in Lassen Volcanic, and 16.6% in Pinnacles (Jenkins et al., 2023).

Lassen Volcanic National Park was closed temporarily in 2021 after the record-setting Dixie Fire burned 73,240 acres within park boundaries (NPS, 2024). Three major wildfires in 2020 and 2021—the Castle Fire, KNP Complex Fire, and Windy Fire—killed an estimated 14,000 mature giant sequoias in the Sierra Nevada, representing roughly 19% of the world's population of these trees (US DOI, 2023). This unprecedented loss threatens the long-term regeneration of old-growth giant sequoia groves, with implications for ecosystem function, biodiversity, cultural and recreational value, and the visitor economies associated with these landscapes.

Wildfire smoke exposure is also associated with reduced mobility and recreation visits, as people may cancel trips, reduce outdoor activity, or remain indoors during high-smoke periods. A study of sites managed by the California National Park Service found that visitation from 2006 to 2017 did not meaningfully change at low or moderate smoke concentrations, but monthly recreation visits declined by about 2.7% when wildfire-smoke PM2.5 exceeded 50 μg/m³ (Heft-Neal et al., 2023). This level is near the EPA's "Unhealthy" AQI threshold for 24-hour PM2.5, as shown in **Figure 20**. These findings illustrate how climate hazards can reshape behavior in ways that reduce recreation demand and affect tourism-dependent economies.



Exposure Avoidance at High Smoke PM2.5 Concentrations

Figure 20: *Traffic volume (A) and national park recreation visits (B) decline at higher smoke PM2.5 levels, suggesting behavioral avoidance during severe smoke events. Points show estimated percent changes by smoke PM2.5 bin; vertical bars indicate uncertainty intervals. Source: (Heft-Neal et al., 2023)*

Chapter 4.

Economy-Wide Impacts



Key Takeaways

1. **Economy-wide estimates of climate impacts are informative but inherently imprecise.** Estimates should be interpreted alongside sector-specific evidence of California's economic vulnerability to climate change. Estimating overall economic damages due to climate change is complicated by multiple interacting sources of uncertainty, including how long damages persist, the difficulty of isolating climate impacts from other factors, uneven and hard-to-measure spillover effects across sectors, limited but growing evidence on the effectiveness of adaptation, and uncertainty about future socioeconomic and climatic conditions. Although there have been efforts to estimate the effects of climate change on GDP growth, additional peer-reviewed research focused specifically on California is needed to provide policymakers with more precise estimates. However, a lower bound impact on individual sectors or pathways of damage can be provided even in the absence of precise, certain estimates.

2. **Human health and workforce impacts are the largest economic damages from climate change.** Air quality impacts ($190.6 per capita) and reduced labor productivity ($103.3 per capita) indicate that human health and workforce impacts constitute a significant portion of total estimated climate damages. Increased heat-related deaths may also represent a large economic cost, with mortality damages alone estimated by some studies at $725.7 per capita annually under a scenario of 3°F (1.67°C) warming (Barreca et al., 2016; Deschênes & Greenstone, 2011; Hsiang et al., 2017). The overall effects of climate change on mortality in California are an area of active research.

3. **Climate impacts vary regionally across California, with inland areas facing heightened risks.** If local patterns of economic damages follow national and global nonlinear effects of temperature on economic activity, Inland Desert and Central Valley counties—where baseline temperatures are already high and warming is projected to be greatest—are likely to experience disproportionately large economic impacts. These risks to the economy are compounded by wildfires and heat-sensitive labor, agriculture, and energy demand.

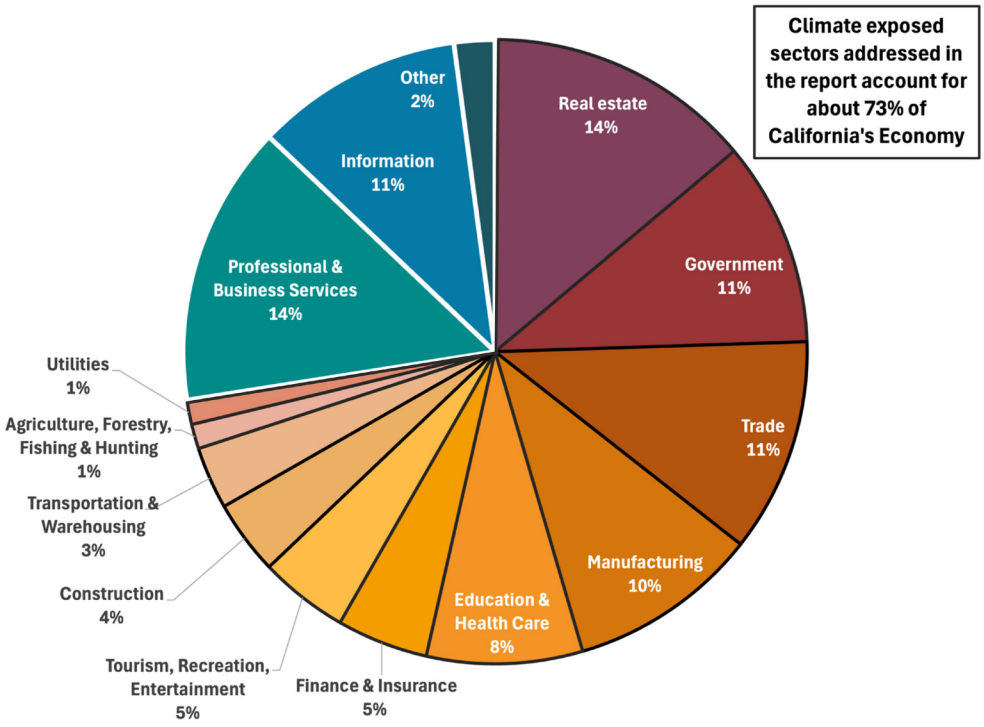
4. **Climate change will likely reduce California's long-term economic growth trajectory.** Temperature increases are projected to reduce the size of state and local economies in the future (Colacito et al., 2019; Kahn et al., 2021). While the magnitude remains uncertain, the direction of the effect is consistently negative across studies, and additional California-specific research would improve precision.

13.1 Damage Estimates in California by Sector

While previous sections of the report have focused on sector-specific economic impacts, this section describes economy-wide impacts by bringing sector-specific damages together and by discussing impacts to the market economy as measured through gross domestic product (GDP). GDP is the conventional measure of economic activity but only an estimate, based on incomplete information, that captures only one dimension of human welfare (Chang & Li, 2015).

California's economic output reached over $4 trillion in 2024 (US BEA, 2024). The sectors described in this report—including real estate, government, healthcare, education, insurance, tourism, agriculture, forestry, fishing, and utilities—account for over 73% of the state's economy, as evidenced in **Figure 21**. Climate damages discussed in the transportation, energy, or the labor force sections of this report can negatively impact multiple economic sectors including trade, manufacturing, construction, transportation, and warehousing. Other sectors, such as information and professional business services, are indoor, less-exposed sectors, though the highly interconnected nature of infrastructure and the economy means that climate impacts in one area can cascade across others, compounding risks and amplifying economic and social consequences statewide (Bedsworth et al., 2018). Additionally, there are critical economy-wide impacts that span all sectors, such as human health and labor, which do not match specific sectors in **Figure 21**.

Professional, scientific, and technical services sectors are largely resilient to climate disruptions as they provide goods and services that can be delivered digitally, jobs are primarily indoors, and they can resume operations after disruptions more easily since they are more reliant on human capital than physical capital (CVL Economics, 2024; Li & Yu, 2025).



California's Economy by Major Sector, 2024 ($4 trillion total)

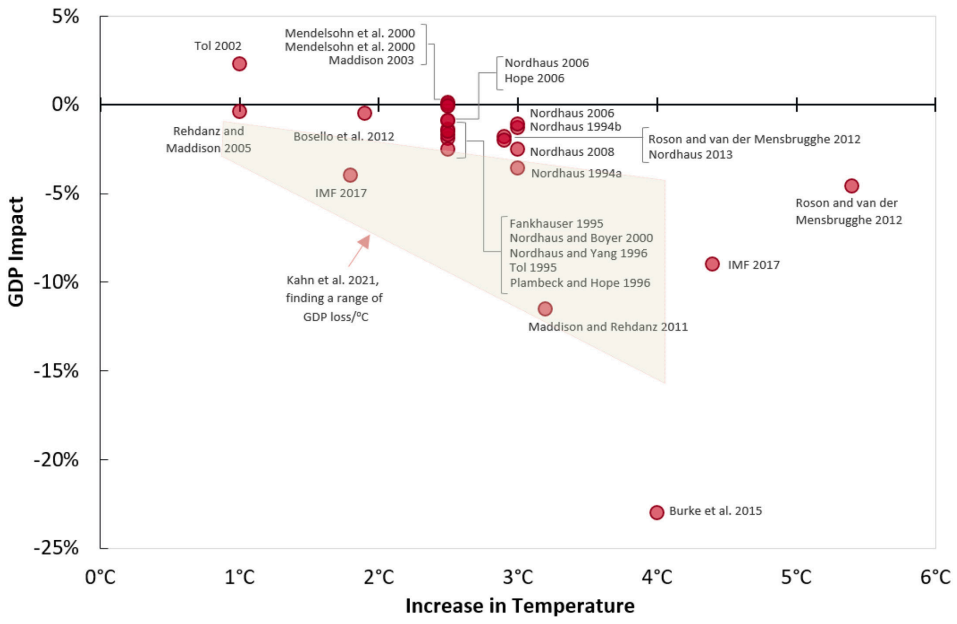
Figure 21: *Sectors of California's economy that are most exposed to climate change impacts include real estate, government, trade, manufacturing, insurance, tourism and recreation, agriculture, and utilities. In addition, cross-sector impacts, such as those on human health and labor productivity, also have significant economic consequences. Data sources: (US BEA, 2024), (GO, 2024b)*

13.2 The Effect of Temperatures on Economic Activity

There is strong evidence that rising global temperatures have a negative impact on GDP. The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report concludes with high confidence that increases in global temperatures are directly linked to higher frequency and intensity of extreme weather events (IPCC, 2021). These climate-related disruptions can stifle investment, reduce output, and slow economic growth across developing and advanced economies. As Earth's average temperature rises, damages are expected to be nonlinear, with each degree of warming generating larger negative impacts on the economy (Burke et al., 2015; Waidelich et al., 2024).

Existing research has focused on quantifying the relationship between rising temperature and economic output through empirical damage functions. These functions typically apply statistical or structural economic models to historical and projected temperature data to estimate how temperature fluctuations impact productivity, labor supply, and sector-specific revenues, thereby affecting overall GDP (Burke et al., 2015). Analyses of US counties find that income declines with increasing heat exposure; each additional weekday with a daily average temperature above 86°F (30°C) has been associated with significant declines in annual county income per person (Deryugina & Hsiang, 2014). US national GDP is projected to be approximately 4% lower by 2100, compared to a scenario in which temperatures remain unchanged from 2024 (Congressional Budget Office, 2024b).

The magnitude and persistence of these negative economic impacts are areas active scholarly debate. To exemplify the range of estimates, **Figure 22** draws from a subset of the literature to show projected impacts of increasing temperature on global GDP, with estimates ranging from small changes (around -0.2%) to substantial losses of up to 20% by 2100, depending on the method and assumptions used. One study finds that a persistent increase in average global temperature by 0.04°C per year would result in GDP per capita across the globe more than 7% lower in 2100 than it would otherwise be without warming (Kahn et al., 2021). If the temperature increase is limited to 0.01°C per year, the GDP losses are kept to about 1% (Kahn et al., 2021).

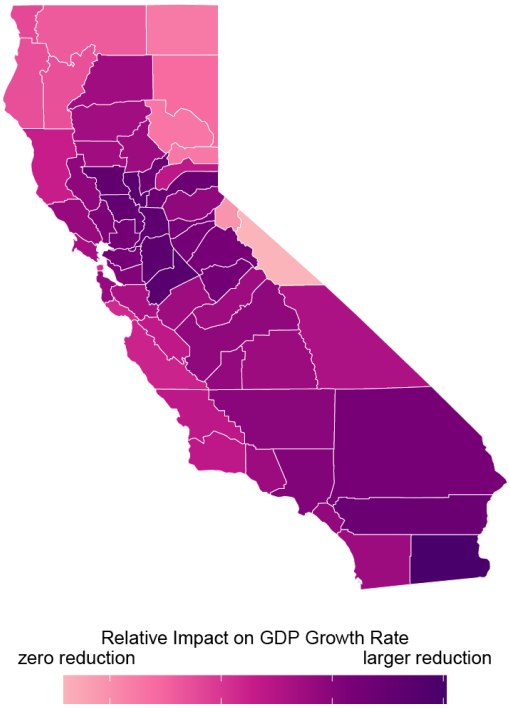


A Range of Estimates of Global GDP Losses Due to Higher Temperature

Figure 22: *Estimates on how much global GDP may decrease as temperatures rise, drawing on a subset of studies in the literature. Each red point represents the findings of a published economic study, estimating the expected economic losses for various levels of global warming. The shaded area represents the range of possible GDP per capita losses in Kahn et al. 2021, depending on both future warming and climate variability. Source: (Kahn et al., 2021)*

Looking within countries, it is reasonable to predict that economies will be affected differently across states and counties. However, the academic literature estimating economy-wide effects does not yet include a robust number of studies on climate change impacts at state and county scale. The economic and population linkages across states and counties are much stronger than those across countries, such that impacts of climate change on state- and especially county-level economic activity may not match the estimated country-level impacts more prevalent in the literature. One study on US states finds that each 1°F (0.56°C) increase in average summer temperature is associated with a reduction in the annual growth rate of state output by about 0.15–0.25 percentage points, and the study projects that climate change could lower US output growth by as much as one-third over the next century (Colacito et al., 2019). Looking at US data at county level, a single day above 90°F (32°C) can reduce average county-level income by approximately 0.04%, with the largest impacts observed in labor-intensive sectors such as agriculture, construction, and manufacturing (Behrer et al., 2021).

Although the academic literature has not precisely estimated the magnitude of economic impacts at county level in California, it is possible nevertheless to characterize which counties are likely to be more vulnerable to climate effects. Much of the literature on climate change impacts on GDP finds that places with higher baseline temperatures and larger temperature increases suffer greater economic impact (Burke et al., 2015). California counties with larger predicted increases in temperature and higher baseline temperatures, such as the inland desert counties and those in the Central Valley, are therefore likely to experience greater reduction in economic activity, as shown in **Figure 23**.



Relative Scale of Climate Change Impact on GDP Across Counties

Figure 23: *Relative county-level changes in average annual GDP per capita growth rates at mid-century. Inland desert counties and counties along the Central Valley show larger relative growth slowdowns than many northern and coastal counties.*

Data Source: *These illustrative estimates are based on econometric estimates of temperature effects on GDP per capita growth to LOCA2 climate projections for 2041–2070 under SSP3–7.0. (Burke & Tanutama, 2019; Pierce et al., 2023).*

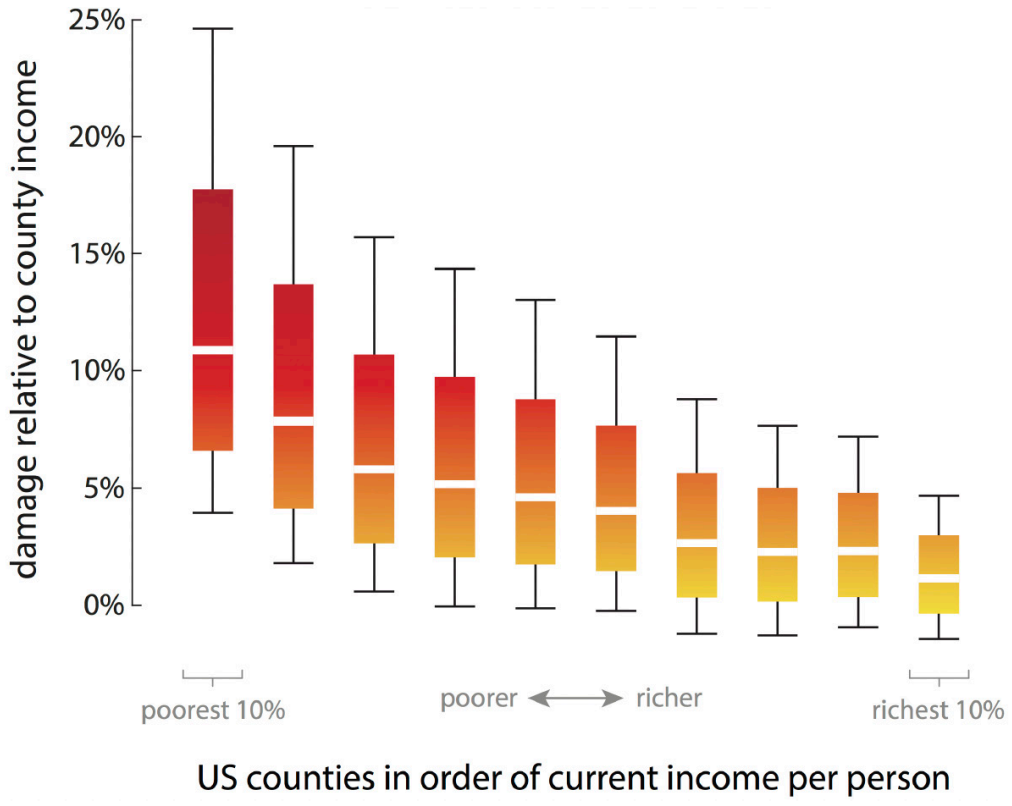
13.3 Unequal Impacts Across Communities

Climate change impacts are distributed unevenly across income groups, geographic areas, and demographic populations, with low-income communities, communities of color, Tribes, rural residents, and outdoor workers in California often bearing disproportionate climate-related health and economic burdens (Ehlers, 2022; OEHHA, 2022). The unequal burden of climate change stems from both differential *exposure* and differential *vulnerability*. Exposure refers to the physical presence of people, infrastructure, or assets in harm's way, such as homes located in floodplains or workers laboring outdoors in extreme heat. Vulnerability, in contrast, reflects the capacity to respond, cope, or adapt to these risks, shaped by factors such as income, access to cooling and healthcare, and institutional support (Carleton et al., 2022a). In this way, climate change not only affects vulnerable populations more severely, but it also amplifies existing economic inequalities.

Across the US, counties with lower average incomes are projected to experience significantly greater economic damage from climate change relative to their income levels, as shown in **Figure 24** (Hsiang et al., 2017). Low-income households are less likely to have access to air conditioning systems, reducing their ability to adapt to rising temperatures and increasing health

and productivity risks during extreme heat events (Brockway et al., 2021; DNV GL Energy Insights, 2020). These heightened exposures translate directly into workplace harms, with workers in the lowest 20% of income facing heat-related injury risks that are five times higher than those in the highest 20% of income (Park et al., 2021).

Additionally, homeowners in rural mountainous areas face increasing exposure to wildfires, as well as rising insurance costs or the loss of coverage entirely through non-renewals (Morales et al., 2022). Smaller and rural cities are more vulnerable to climate impacts than larger and more urban cities due to smaller tax bases and fewer administrative resources to manage disaster recovery (Liao & Kousky, 2022). Furthermore, people experiencing homelessness face even greater exposure to climate hazards and are highly vulnerable due to limited shelter, medical care, and social support. Over one-third of the nation's unhoused population lives in California, and these populations are consistently overrepresented in heat-related fatalities (Sturm et al., 2024).



Projected Economic Damage from Climate Change in United States Counties

Figure 24: *How climate change is expected to have unequal economic impacts across the US, with poorer counties projected to experience disproportionately higher damages relative to their income. Counties in the poorest 10% could face median income losses exceeding 10%, while the richest counties are projected to see far smaller relative damages. These projections underscore how rising temperatures are likely to amplify existing income inequalities, as the most economically vulnerable communities bear the brunt of climate-related losses. Source: (Hsiang et al., 2017)*

Box 31: *Unquantified Impacts on Tribal Communities*

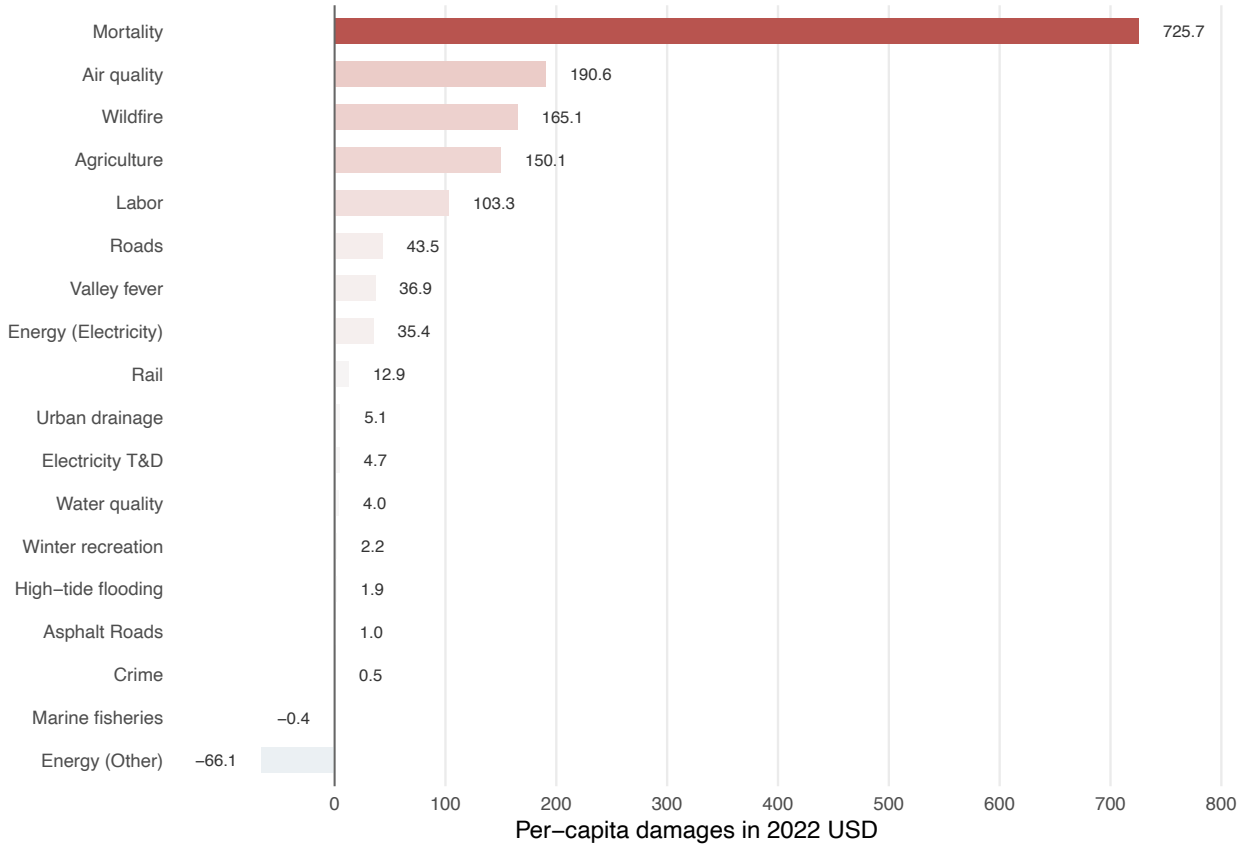
There is a need for more Tribal-specific research that captures how climate impacts affect Tribal subsistence practices, timber revenue, tourism, and culturally important species and resources (Whyte et al., 2023). Disruptions to subsistence lifeways can reduce adaptive capacity, while economic insecurity across both subsistence activities and business operations can deepen existing economic vulnerabilities (Allard & Brundage, 2019; McMillen et al., 2017). For some Tribal communities, exposure to sea level rise, extreme heat, drought, and wildfire can threaten the long-term viability of Tribal homelands and can undermine cultural lifeways, sovereignty, and community stability (Maldonado et al., 2013; Norton-Smith et al., 2016). Additionally, Tribal governments may also face unique administrative and financial barriers in accessing post-disaster assistance, including limited staff capacity, which can delay funding and recovery (GAO, 2024).

Box 32: *Projected Climate Damage Estimates from FrEDI*

The Framework for Evaluating Damages and Impacts (FrEDI) was developed by EPA as a peer-reviewed, open-source model that combined climate damage estimates from multiple studies to estimate the annual economic impacts of climate change in the US (EPA, 2024). FrEDI reports economic impacts by degree of warming, rather than for a single emissions scenario, with impacts binned by global temperature. Using a common metric of 3°F (1.67°C) of global warming by 2100 relative to the 1986–2005 baseline, FrEDI allows one to compare the relative magnitude of climate-driven economic damages across sectors and regions. For context, 3°F (1.67°C) of warming by 2100 is most comparable to the low-emissions pathway RCP 2.6, which projects roughly 2.7–3.6°F (1.5-2.0°C) of global warming by 2100. As with most models, the damage estimates in FrEDI do not fully capture cross-sector interactions or include all sectors potentially affected by climate change. Thus, while the FrEDI framework provides a systematic way to estimate and compare climate damages, the reported values should be interpreted as conservative estimates.

Figure 25 presents projected damages for California across key FrEDI categories by 2100 under 3°F (1.67°C) of global warming. Positive changes indicate harm (economic loss), while negative damages reflect projected benefits (economic gain). FrEDI presents mortality as representing the largest category of impact, which is consistent with the preponderance of evidence but nevertheless remains an area where some disagreement in estimated impact remains (Gould et al., 2025). Four other categories with relatively large climate damages are adverse air quality, wildfire-related property and health losses, crop yield impacts, and reductions in worker productivity and hours worked. Modest cost savings are projected for non-electric heating fuels in milder winters, although these gains are relatively minor compared to the broader damages from rising temperatures. See **Appendix A** for more information on the damage inputs for each sector.

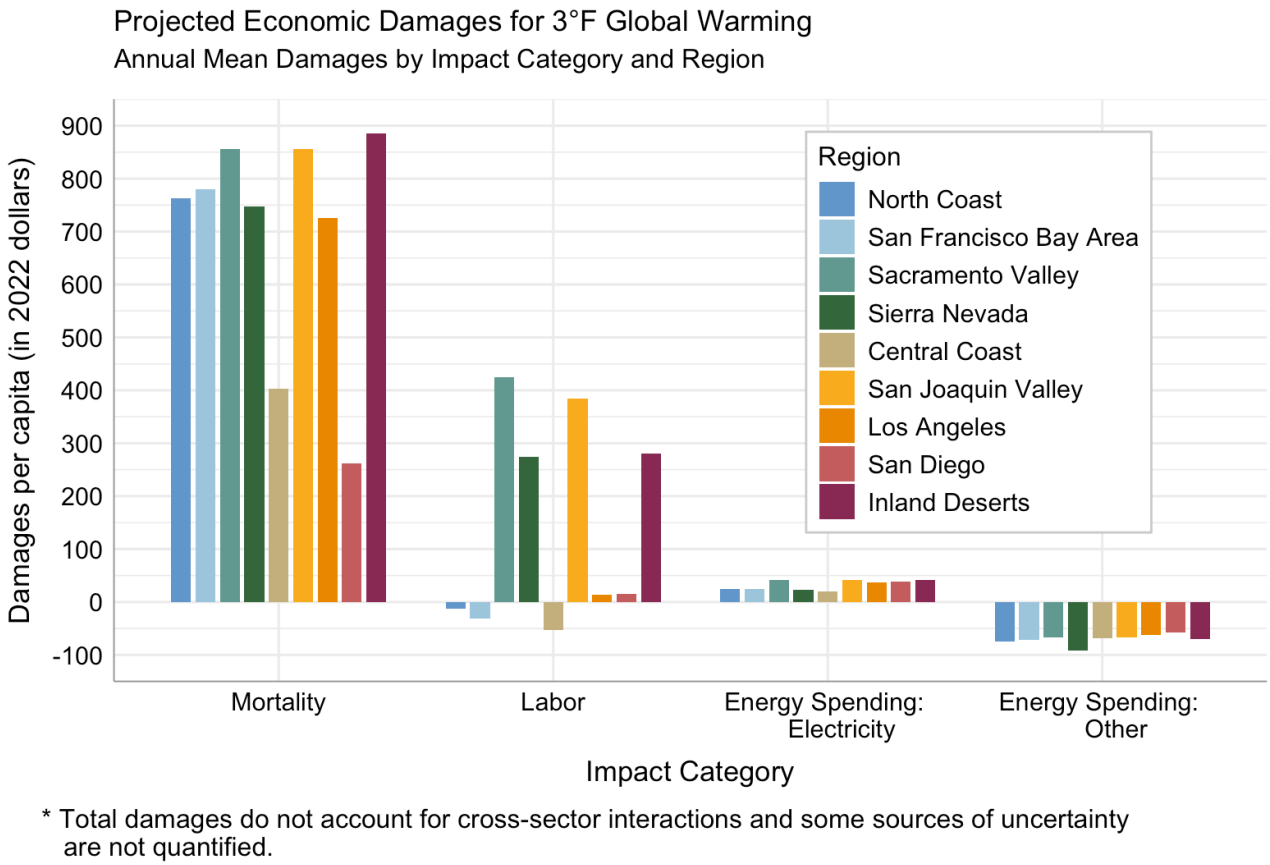
The economic effects of climate change will vary across California, with different regions facing unique challenges because of their climate and economic composition. **Figure 26** displays the climate damages by region in California by 2100 across mortality, labor, and energy categories of impact. Mortality and labor impacts contribute the largest estimated damages across regions, with labor impacts concentrated in regions with 'high-risk' industries, such as agriculture and forestry. Across regions, warmer winters are expected to reduce heating demand and lower use of non-electric energy sources, primarily natural gas. The regions shown in **Figure 26** correspond to the nine regional geographies used across California's Fifth Climate Change Assessment reports.



Projected Per Capita Economic Damages for 3°F of Warming in California

Figure 25: *Projected climate damages across different sectors in California by 2100. FrEDI estimates the yearly economic harm from climate change by calculating the average cost per person for each impact. These dollar values are intended to give a sense of how much climate change could cost an individual, every year, across different types of damages in California. Because these values are statewide per-capita averages, they do not capture how damages may vary across regions, populations, or communities with different levels of exposure, vulnerability, and adaptive capacity.*

Data Source: *This figure leverages data from the Fifth National Climate Assessment and the U.S. EPA's Framework for Evaluating Damages and Impacts (EPA, 2024; Hsiang et al., 2023).*



Projected Per Capita Economic Damages for 3°F of Warming by Region

Figure 26: *Population-weighted average climate damages across nine California regions, broken down by sector for which county-level damages data are available in FrEDI. Values are shown under a future warming scenario consistent with global temperature increases of 3°F (1.67°C) by 2100, comparable to RCP 2.6, a low radiative-forcing pathway.*

Data Source: *This figure leverages data from the Fifth National Climate Assessment and US EPA's Framework for Evaluating Damages and Impacts (EPA, 2024; Hsiang et al., 2023)*

Conclusion



Across the state, rising temperatures, wildfire, drought, flooding, and sea level rise are already affecting workers, households, businesses, governments, infrastructure systems, and natural resources. The evidence synthesized throughout this report documents how climate change is imposing growing economic costs across California's economy and that these costs are expected to increase as climate hazards intensify throughout the century.

The findings of this assessment underscore three central conclusions. First, climate change is already imposing measurable costs on California's economy, with recent decades marked by larger wildfire losses, more costly droughts, more damaging floods, and increasingly severe heat events across the state. Second, climate impacts rarely occur in isolation; disruptions to one sector often generate consequences across many others, amplifying economic damages through interconnected social and economic systems. Third, climate risks and economic losses are distributed unevenly, with some regions, industries, and populations facing substantially greater exposure and fewer resources for adaptation and recovery.

Interconnected Economic Impacts and Cascading Risks

Across California's $4 trillion economy, climate-related damages manifest through multiple interconnected pathways. Climate damages cascade across sectors, creating economic consequences that extend far beyond the initial hazard. Health impacts from extreme temperature and wildfire smoke exposure are among the largest categories of damages, generating substantial costs through premature mortality, illness, hospitalizations, lost productivity, and adverse birth outcomes. Extreme heat can also increase electricity demand, negatively impact agricultural yields, increase risk of wildfires, and reduce the reliability and performance of critical infrastructure systems. Wildfires can damage homes and businesses, increase insurance costs, disrupt outdoor industries and recreational economies, and create long-term fiscal pressures for local governments. Flooding can damage infrastructure, interrupt supply chains, displace residents, and reduce economic activity across entire regions. Because California's economy functions as an interconnected system, disruptions in one sector often generate consequences across many others, amplifying total economic losses.

Magnitude and Distribution of Economic Damages

The economic impacts of climate change vary considerably across California's regions. Inland counties in the Central Valley, Inland Empire, and southeastern desert regions face disproportionate burdens from extreme heat. In contrast, some northern regions may experience reduced cold-related mortality and lower winter heating costs. Wildfire risks are concentrated in wildland-urban interface communities, while flood risks are particularly significant in low-lying coastal areas, river corridors, and parts of the Central Valley. As a result, the economic impacts of climate change are shaped not only by the magnitude of climate hazards but also by where those hazards occur and the people, industries, and infrastructure they affect.

Climate-related economic damages are also unevenly distributed across California's population. Low-income households, outdoor workers, Tribal communities, rural communities, older adults, young children, and people with pre-existing conditions often face disproportionate climate-related risks due to higher exposure and sensitivity to hazards, as well as fewer resources

available for adaptation and recovery. Economic losses extend beyond aggregate measures of damage and include important questions of equity, opportunity, and resilience. Access to resources, infrastructure, insurance, and health protections influences a community's ability to withstand and recover from shocks.

Economic resilience depends not only on people, businesses, and infrastructure, but also on the health of California's natural systems. Forests, watersheds, fisheries, and agricultural lands support food production, water supplies, recreation and tourism, and other economic activities that contribute to livelihoods across the state. Disruptions in these systems create economic consequences that can extend from rural communities to nationwide supply chains and consumer markets. As climate risks intensify, protecting these systems will become increasingly important for reducing future losses while sustaining the industries, livelihoods, and communities that depend on them.

Research Gaps and Information Needs

Despite substantial advances in understanding climate change impacts on the economy, important knowledge gaps remain. A fundamental uncertainty is the magnitude and duration of long-term economic impacts at state, regional, and county scales, including how climate change will affect overall economic growth and how damages will differ across places and populations. While this is an active area of research at global and national scale, California-specific research could further improve the understanding of impacts on economic output at state and local scales. More research can better measure impact pathways, with important gaps in understanding of climate-driven displacement, long-term educational and health outcomes after disasters, wildfire-related drinking-water contamination, nonmarket forest and ecosystem-service losses, and the balance of heat- and cold-related mortality under future warming. More longitudinal research would help clarify how climate shocks affect households, renters, students, workers, businesses, and local governments over time, including through cascading impacts across housing, labor, health, education, infrastructure, and public finance systems. Further, Tribal-specific research could contribute to a clearer understanding of how climate impacts affect Tribal livelihoods, subsistence practices, timber revenue, and culturally important resources. Finally, decision-making would benefit from continued research on the effectiveness, costs, and limits of adaptation strategies, including resilient infrastructure, public health protections, ecosystem restoration, building standards, and technologies that could expand feasible adaptation options across sectors. Addressing these information gaps would improve damage estimates, strengthen benefit-cost analysis, and help decision-makers identify and target adaptation strategies that improve economic resilience across California’s diverse regions and communities.

Implications for California's Future

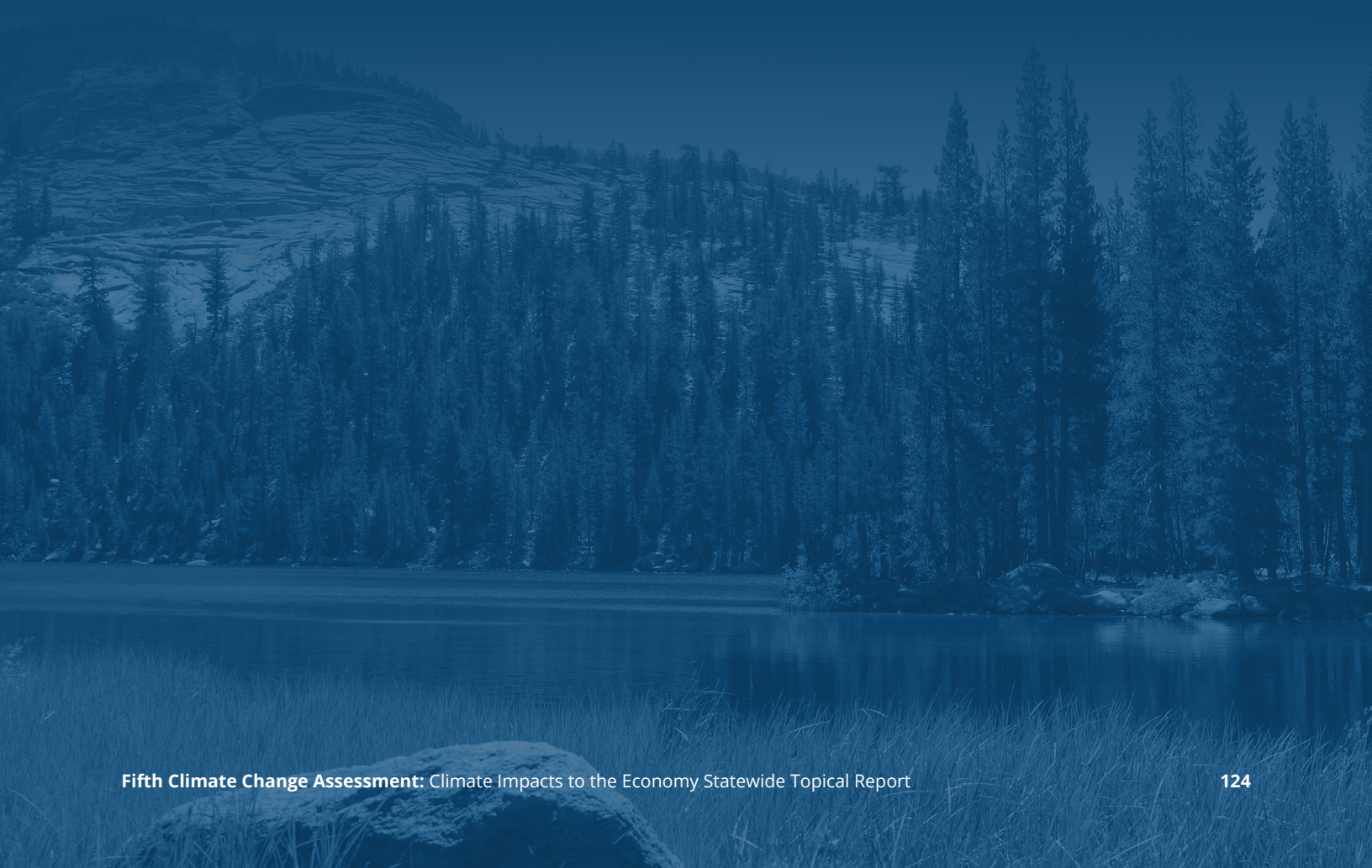
California's economy faces a critical juncture as climate change proceeds and impacts accelerate. The state's trajectory depends fundamentally on two factors: the pace of global emissions reductions that will determine the magnitude of future warming, and the effectiveness of local and state adaptation measures deployed to protect vulnerable populations, critical infrastructure, essential services, and economic sectors. The magnitude of economic damages California ultimately experiences is not predetermined. Adaptation investments offer opportunities to

reduce damages substantially below unmitigated scenarios, though costs and benefits distribute unevenly across communities and sectors.

Adaptation is most effective when approached as a long-term strategy rather than a series of responses to individual disasters. Increasing resilience requires integrating climate risk into planning, investment, governance, and decision-making across sectors. It also requires recognizing the interconnected nature of climate impacts and designing solutions that address multiple risks simultaneously. Investments that strengthen communities, modernize infrastructure, protect natural systems, and reduce underlying vulnerabilities can help California avoid larger economic losses in the future.

California has long demonstrated an ability to adapt, innovate, and respond to emerging challenges. The state's economic strength, research institutions, technological capacity, and leadership in climate policy provide important advantages as climate risks continue to grow. However, the scale of projected impacts underscores the need for increased and sustained action. The magnitude of future economic losses will depend not only on the trajectory of climate hazards, but also on investments made today in adaptation, resilience, and risk reduction. These investments will shape the costs Californians face in the decades ahead. By anticipating climate risks and integrating resilience into economic decision-making, California can reduce future losses while building a stronger, more adaptable, and more prosperous society.

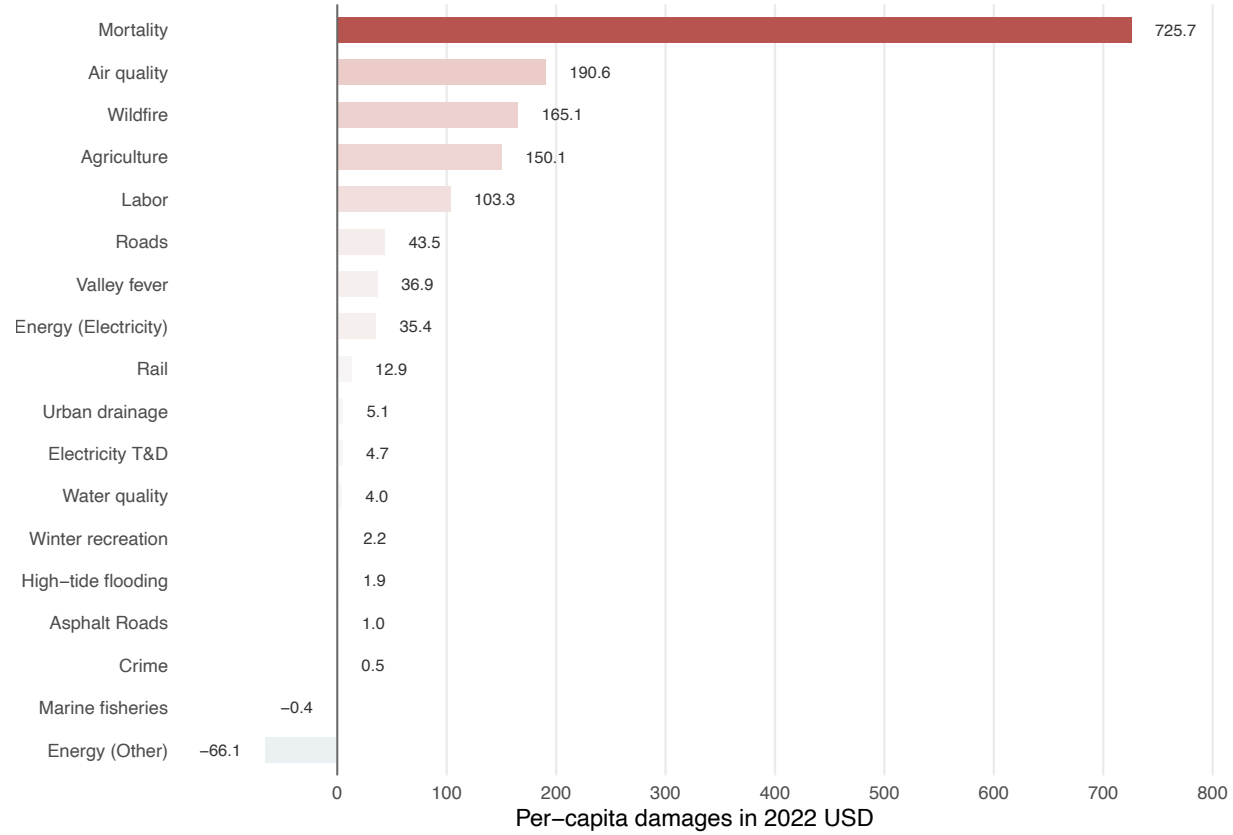
Appendices



Appendix A: Sector Specific Estimates based on EPA's Framework for Evaluating Damage and Impacts (FrEDI)

Figure 27 shows estimated sector-specific damages featured at national and regional levels in the Fifth National Climate Assessment's Chapter 19 on Economics (Hsiang et al., 2023). These, in turn, come from the Environmental Protection Agency's Framework for Evaluating Damage and Impacts (FrEDI), a peer-reviewed model that unified climate damage estimates into a single framework for analysis (EPA, 2024). As of December 2025, the EPA removed the webpage disseminating the FrEDI model and technical documentation, and in April 2026 stated that the Agency was no longer disseminating FrEDI or relying on it to formulate or support regulations (EPA, 2026). The estimates presented here should therefore be interpreted as previously published FrEDI outputs used in the Fifth National Climate Assessment, reported here at the California state level.

Specifically, FrEDI estimates correspond to a scenario where, by 2100, global surface temperature increases by 3°F (1.67°C) relative to the 1986–2005 baseline, which is comparable to RCP 2.6, a low radiative-forcing and strong-mitigation pathway. By estimating multiple impact categories under the same 3°F (1.67°C) global warming level and reporting damages in per-capita dollar terms, FrEDI provides a common metric for comparing the relative magnitude of projected economic damages across sectors. FrEDI draws on a synthesis of sector-specific impact models and damage functions for the US, so the results should be interpreted as partial estimates rather than a comprehensive accounting of all climate impacts. These estimates assume a constant population over time, do not account for cross-sector interactions or cascading effects, and treat adaptation differently across categories: some sectors include no-additional, reactive, or proactive adaptation scenarios, while others reflect adaptation already embedded in the underlying damage functions.



Sector Impacts: Projected Economic Damages for 3°F (1.67°C) of Warming in California

Figure 27: *Projected annual per-capita climate damages across 18 impact categories in California under 3°F (1.67°C) of Warming by 2100. This figure utilizes information from the Fifth National Climate Assessment and the US EPA Framework for Evaluating Damages and Impacts (FrEDI) analysis to compare across impact categories.*

Note: *"Electricity T&D" refers to Electricity Transmission and Distribution Infrastructure. "Energy (Other)" refers to energy costs other than electricity, mostly natural gas. Positive changes indicate harm and negative damages indicate benefits.*

The largest contributors to these estimated per-capita damages are impacts to health and livelihoods. These include the economic cost of heat- and cold-related mortality, climate-driven changes in air quality via ozone and particulate matter mortality, wildfire-related mortality and morbidity damages, and reductions in hours worked and lost wages. Agriculture is also among the larger FrEDI damage categories, but the estimate is limited to US-level crop damage relationships for wheat, maize, soybeans, and cotton. Because these crops do not reflect California's agricultural composition, the FrEDI Agriculture category should be interpreted as a partial indicator rather than a representative estimate of agricultural damages in the state. The main offsetting benefit appears in the "Energy (Other)" category, where negative damages reflect projected savings from reduced demand for non-electric heating fuels, primarily natural gas, as winters warm. Overall, the FrEDI data underscores that California is projected to experience significant net economic harm from climate change, with human health and labor impacts representing a majority of total damages.

Sector-specific estimates cannot be easily aggregated, as many damages are double-counted across categories. To give a sense of the magnitudes, the sector damages can be compared to California's GDP per capita in 2024 of around $102,700.[1] In other words, the estimated air-quality damages from 3°F (1.67°C) of warming in California, using the $190.6 per-capita damage estimate, is equivalent to approximately $7.5 billion statewide, or approximately 0.2% of today's GDP, per year. Summing across categories, these damages would total 1.5% of today's GDP under 3°F (1.67°C) of warming by 2100. Again, this sum is only illustrative, since (a) some damages appear in multiple categories, (b) not all damages are accounted for (leading to the underestimation of costs) and (c) cross-sector interactions may imply that adding across categories does not give the true total cost.

Broadly speaking, each of these damage estimates comes from first using statistical methods on historical data to estimate a damage function relating temperature changes to an outcome (mortality, labor productivity, crop yields, etc.). Climate projections are then pushed through these damage functions to estimate the change in the outcome variables as temperatures change into the future. Further information on how these numbers are calculated is available from the FrEDI technical documentation (EPA, 2024). Here we provide more details for the categories representing larger damage magnitudes.

As described in the *Health* chapter, hotter temperatures are expected to cause a substantial rise in heat-related deaths. Data for the Fifth National Climate Assessment indicates a $725.7 per-capita damage estimate from excess mortality due to extreme temperatures in California (Barreca et al., 2016; Deschênes & Greenstone, 2011; EPA, 2024; Hsiang et al., 2017). In the US, each additional day with average temperatures above 90°F (32.2°C) raises the US annual mortality rate by about 0.11 percent—or nearly 1 extra death for every 100,000 people (Barreca et al., 2016; Deschênes & Greenstone, 2011). By 2100, higher temperatures could increase the age-adjusted US mortality rate by around 3% (Deschênes & Greenstone, 2011). While significant evidence suggests mortality damages from climate change will be large at global and national levels, active research continues on whether such damages will occur in California. Specifically, California's unique temperature distribution and high-income level may mean that increases in heat-related deaths from climate change may be smaller than previously estimated, and the decrease in cold-related deaths may result in a net decline in temperature-related mortality (Gould et al., 2025). Nonetheless, even while the net effects are an area of active research, the consensus is that heat related mortalities are going to increase.

The $190.6 per capita damage estimate for air quality reflects the economic valuation of additional mortality attributable to climate-driven changes in ground-level ozone and fine particulate matter (Fann et al., 2021). For context, the ozone-only analysis in the EPA's earlier *Climate Change Impacts and Risk Analysis* (CIRA) estimated that climate-driven changes in ozone under RCP4.5 would result in 300–810 additional premature deaths per year nationally in 2050, rising to 630–1,700 additional premature deaths per year in 2090 (EPA, 2017). The associated annual costs of premature deaths were projected to be $6.9 billion in 2050 and $18 billion in 2090 (EPA, 2017). Those ozone-only estimates should be interpreted as contextual evidence rather than a direct decomposition of

1 California GDP per capita is calculated using 2024 California GDP in current dollars from the US Bureau of Economic Analysis and 2024 state population from the US Census Bureau. California 2024 GDP was approximately $4.048 trillion (current dollars) and population was 39.431 million residents, yielding GDP per capita of approximately $102,700 in 2024 dollars. (BEA, 2026; US Census Bureau, 2026).

the FrEDI air quality estimate, which also includes mortality from PM2.5 (particulate matter with a diameter of 2.5 μm or less).

The $165.1 per capita damage estimate for wildfires reflects economic losses from both property destruction and smoke-related impacts on reduced earnings (Buechi et al., 2020; Borgschulte et al., 2024; Neumann et al., 2021). The average annual structural losses from wildfires rose from about $0.03 billion per year in the 1979–1988 decade to nearly $1.0 billion per year in 2009–2018, as more structures in the wildland-urban interface are burned (Buechi et al., 2020). Additionally, smoke exposure has been shown to reduce earnings by an estimated $125 billion per year across the US (Borgschulte et al., 2024). Each day of wildfire smoke lowers quarterly employment by about 80 workers per million adult residents (Borgschulte et al., 2024).

The $150.1 per-capita agriculture damage reflects projected losses from reduced yields in major staple crops (cotton, maize, soybean, wheat) under warming. These projections are based on Climate Impact Lab agricultural damage functions incorporated into FrEDI, which estimate how changes in temperature, precipitation, and CO2 fertilization affect crop yields and production values (Hsiang et al., 2017; McGrath & Lobell, 2013; Schlenker & Roberts, 2009). The underlying crop response functions draw on evidence that yields for major field crops increase with temperature up to crop-specific thresholds and then decline sharply above those thresholds, with estimated thresholds of roughly 29°C for maize, 30°C for soybeans, and 32°C for cotton (Schlenker & Roberts, 2009). CO2 fertilization effects are incorporated as a separate variant based on estimated crop yield responses to changes in atmospheric CO2 concentrations, rather than as an adaptation scenario (McGrath & Lobell, 2013).

The $103.3 per-capita labor damages reflect projected losses from heat-driven reductions in time worked and wages among workers in high-risk, heat-exposed occupations. Each additional 1°F above a 90°F (32.2°C) daily maximum temperature is estimated to reduce work time among high-risk workers by about 2.6 minutes relative to a 90°F day (Neidell et al., 2021). Using this relationship with future climate projections, the same study estimates that annual lost wages from reduced work on days above 90°F could reach approximately $36.7 billion nationally by 2090, in 2015 dollars, under an intermediate emissions scenario (RCP 4.5) (Neidell et al., 2021).

The $35.4 per-capita Energy (Electricity) damage reflects projected increases in power-sector costs associated with higher electricity demand for cooling as temperatures rise, including costs related to meeting additional demand and required capacity expansion (McFarland et al., 2015; Rode et al., 2021). The -$66.1 per capita Energy (Other) impact reflects projected savings from reduced direct consumption of non-electric fuels, such as natural gas, oil, and coal, as warmer winters reduce heating demands (Rode et al., 2021).

The $36.9 per-capita Valley fever damage estimate reflects projected hospitalization costs, lost wages, and mortality damages from climate-sensitive changes in coccidioidomycosis, or Valley fever. The underlying study estimates future Valley fever incidence based on climate suitability and projected disease incidence in counties where Coccidioides may become endemic, then monetizes cases using medical costs, lost productivity, and the value of a statistical life (Gorris et al., 2021). This category is especially relevant for California because Valley fever is already endemic in parts of the state, particularly the Central Valley and Central Coast (CDPH, 2025). Research

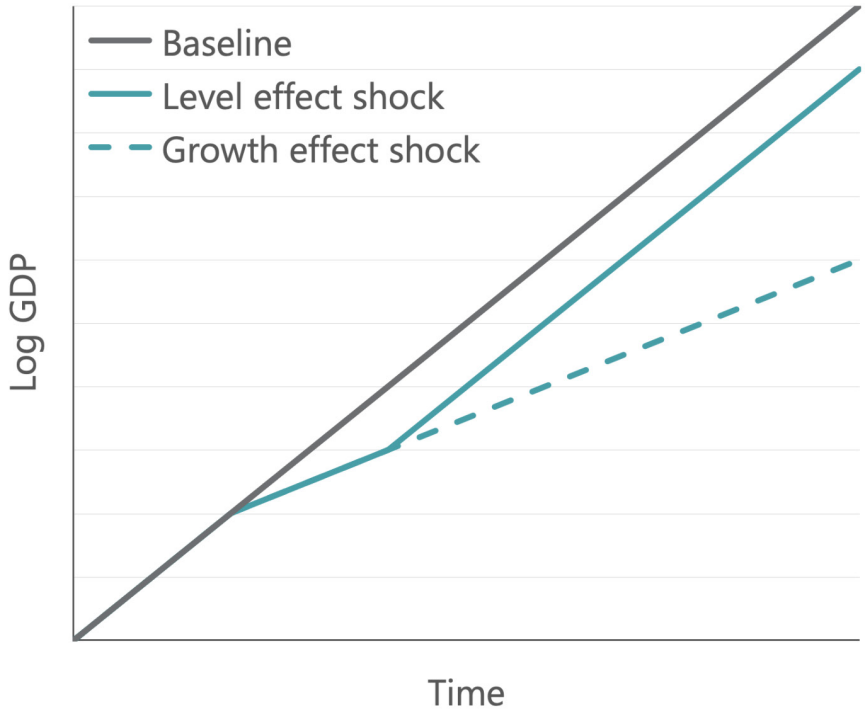
suggests that the rise and spread of Valley fever is linked to changes in climate; as climate change alters aridity, drought, dust, and precipitation patterns, California's existing high-incidence regions may face greater localized risks than statewide per-capita averages suggest (Gorris et al., 2019).

Appendix B: Economic Uncertainties: The Challenge of Estimating Economy-Wide Impacts of Climate Change

Given that climate change will have economic impacts that are valued in markets (e.g., changes in agricultural profitability) as well as non-market damages (e.g., changes in mortality risk), estimating damages through sector-specific analysis is considered more informative (NASEM, 2017). Examining these sectors individually can better capture the variation of climate impacts across sectors, geographies and communities, and provide insights that are directly relevant to policy design, investment decisions, and resilience planning.

Given the salience of market measures of economic activity, however, it is nevertheless worthwhile to consider estimates of damages to economic activity as measured through GDP. Estimating the exact magnitude of the impacts of climate change on California's future GDP remains complex even as most research points to negative effects. The following five factors illustrate why precise measurement is difficult:

1. **The duration of damages is uncertain.** A central uncertainty in projecting the economic impacts of temperature increases is whether effects are primarily short-lived shocks to economic output or persistent influences on long-term economic growth (**Figure 28**) (Colacito et al., 2019; Council of Economic Advisers & Office of Management and Budget, 2024; Howard & Sterner, 2017; Kopits et al., 2025). These two potential impacts—a level effect and a growth effect—have major implications on the size of the future economy in a warmer climate. Under *a level effect*, temperature increases cause a temporary reduction in economic growth that may be followed by recovery in the growth rate. In contrast, a *growth effect* implies that climate damages reduce the economy's growth year after year, so even modest short-term disruptions compound over time and result in substantially lower GDP over the long term. While evidence increasingly shows that increased temperature and extreme weather reduce economic performance, the magnitude of the economic effect in the long run is an area of active academic debate.



Level and Growth Adjustments Following a Permanent Climate Shock

Figure 28: *Source: (Aerts et al., 2024) Losses from a one-time, permanent change in climate depend on whether the shock affects output levels or growth rates. Under a level effect, GDP declines immediately but then resumes its pre-shock growth trajectory. Under a growth effect, the shock permanently lowers the rate of growth, leading to widening losses over time.*

2. **It is challenging to isolate the impact of climate versus other factors on the economy.** State economic trends are shaped by multiple factors—policies, technological innovation, population shifts, and global and national market cycles—making it difficult to identify the causal effect of climate from all the other factors that influence economic performance. Isolating the influence of temperature, drought, or extreme events requires careful statistical methods and robust assumptions.

3. **Climate change impacts are highly uneven and hard-to-measure.** Climate extremes affect California's industries and communities differently. Some areas, such as the Central Valley, bear heavy losses from heatwaves or drought impacts on agriculture, while others are less affected. These nonlinearities and sectoral differences make it hard to generalize a single "climate effect" on growth (Howard & Sterner, 2017; Burke et al., 2015). Many studies rely on average annual temperature or precipitation, but much of the real damage comes from extremes—heatwaves, wildfires, floods—that GDP statistics may not fully capture.

4. **There is limited evidence on how adaptation can lessen damages.** People and businesses are already responding to climate risks, for example farmers can switch to more drought tolerant crop varieties, homeowners can invest in smart cooling infrastructure; and businesses can adjust work schedules to protect outdoor laborers from extreme heat. Although these measures could cushion the economy from climate shocks, their costs, effectiveness, and distribution are not yet fully documented.

5. **There are forecasting limitations due to unknown futures and incomplete or inconsistent data.** GDP data are measured with error, especially when broken down to the county or sectoral level, at least in part because of cross-county and cross-sector economic linkages. Climate models also carry uncertainty when scaled down to the local level, making the quality of projections more variable. Finally, long-run forecasts involve unknowns about future emissions, climate sensitivity, technological change, and policy responses. Economists must also contend with rare, low-probability, but highly catastrophic climate change-induced events that have the potential to reshape the economy far more dramatically than smaller changes might suggest.

Appendix C: Example Economic Damages from Climate Change in California

Table 2: Sample Current Impact Estimates of Climate Hazards on California-Specific Economic Outcomes

Section	Sector	Climate Hazard	Impact Type	Region	Economic Estimate	Source
Social Systems	Health	Temperature	Mortality	California	A single hot day (35°C/95°F) increases annual mortality rates by 4 deaths per 1 million people relative to a moderate (20°C/68°F) day, or ~$54 million in economic damages per million people per hot day using a $13.6 million value of a statistical life (VSL).	Carleton et al., 2022
Social Systems	Multiple	Temperature	Multiple	California	Seven major heat events between 2013 and 2022 resulted in $7.7 billion in combined damages to health, infrastructure, energy, and economic activity, with mortality representing the largest share.	(CDI, 2024
Social Systems	Health	Wildfire	Wildfire smoke	California	Wildfire smoke exposure is associated with 6,974 excess preterm births in California 2007–2012), implying ~$452 million in lifetime economic costs, using an average cost of $64,815 per preterm birth.	Heft-Neal et al., 2022; Waitzman et al., 2021
Social Systems	Health	Temperature	Mortality	US	0.11% increase in annual age-adjusted mortality rate per additional >90°F day (relative to 50–60°F day). Monetizing heat-related mortality and increased air-conditioning costs yields > $1.95 trillion in present discounted economic losses over the 21st century.	Colacito et al., 2019; Deschênes & Greenstone, 2011; Hsiang et al., 2017
Social Systems	Health	Wildfire Smoke	Mortality	California	Wildfire smoke exposure from 2008 to 2018 is estimated to have caused up to 55,710 premature deaths with associated costs of $456 billion in 2015 dollars)	Connolly et al., 2024)
Social Systems	Health	Wildfire Smoke	Mortality	US	Wildfire smoke exposure among Medicare beneficiaries 65+ years of age exceeds $6 billion annually in mortality costs.	Miller et al., 2021

Section	Sector	Climate Hazard	Impact Type	Region	Economic Estimate	Source
Social Systems	Health	Wildfire Smoke	Hospital Bonds	US	A one standard deviation increase in wildfire smoke pollution is associated with a 0.064% increase in hospital borrowing costs and a 0.121% increase in nursing homes borrowing costs. These effects are 50% to 100% higher in high-poverty and high-minority communities. Over the next decade, smoke-related financing impacts could increase healthcare interest expenses by ~$570 million and raise per-patient care costs by ~$250 in the most affected areas.	Lopez et al., 2024
Social Systems	Labor	Wildfire smoke	Earnings	US	Loss of $125 billion per year, or about 1.96% of annual earnings, per year of smoke exposure.	Borgschulte et al., 2024
Social Systems	Labor	Wildfire smoke	Earnings	US	Each additional day of smoke exposure reduces quarterly earnings by approximately 0.1%.	Borgschulte et al., 2024
Social Systems	Labor	Extreme Heat	Decreased Productivity	California	Across extreme heat events, labor productivity losses have ranged from $7.7 million to $210 million per event, primarily due to decreased work capacity and increased absenteeism.	CDI, 2024
Social Systems	Labor	Temperature	Work Hours	US	Each degree of warming above 90°F (32.2°C) can reduce daily work by 2.6 minutes for high-risk workers.	Neidell et al., 2021
Social Systems	Education	Temperature	Earnings	US	Air conditioning in schools offsets ~73% of heat-related learning losses, equivalent to ~$212 per student per 1°F in recovered future earnings.	Park et al., 2020
Social Systems	Education	Wildfire Smoke	Earnings	US	Severe wildfire smoke years are associated with ~$111 per student in reduced future earnings, totaling about $1.7 billion nationwide.	Wen & Burke, 2022
Social Systems	Government	Wildfire	Municipal Budgets	California	In response to wildfires in 1995–2010, municipalities experienced a $97 per capita decline in excess revenues and were 25 percentage points more likely to run a budget deficit over the next five years.	Liao & Kousky, 2022
Built Systems	Real Estate	Flooding	Property Damages	California	More than $1.7 billion in expected flood damage per year.	First Street Foundation, 2021
Economy Wide	Cross Cutting	Wildfire	Multiple	California	Wildfire damage averaged over $117.4 billion annually between 2017 and 2021 across property damage, labor market disruptions, loss of life, and indirect losses.	Paci et al., 2023
Built Systems	Real Estate	Wildfire	Property Damage	California	CAL FIRE calculated the cost of damage to properties caused by wildfires from 2017 to 2021 at $9.9 billion annually, regardless of ownership.	Paci et al., 2023
Built Systems	Real Estate	Wildfire	Property Damage	California	The average annual structural losses from wildfires rose from about $0.03 billion per year in the 1979–1988 decade to nearly $1.0 billion per year in 2009–2018.	Buechi et al., 2020

Section	Sector	Climate Hazard	Impact Type	Region	Economic Estimate	Source
Built Systems	Real Estate	Wildfire	Property Insurance	California	The 2020 wildfire season generated $5–$9 billion in insured losses, while the 2017 and 2018 wildfire seasons each produced over $10 billion in insured losses.	Bellisario et al., 2021
Built Systems	Real Estate	Wildfire	Property Insurance	California	Los Angeles wildfires generated overall losses of approximately US $53 billion, with insured losses of roughly US $40 billion.	Munich Re, 2025
Built Systems	Energy	Temperature	Energy Infrastructure	US	A 1°C increase in temperature reduces transformer lifespans by ~10% (4 years).	CDI, 2024
Built Systems	Energy	Extreme Heat	Service Disruption / Power Outage	California	Public Safety Power Shutoffs in the 2019 wildfire season generated ~$10 billion in lost customer value.	Feo et al., 2020
Built Systems	Energy	Multiple	Service Disruption / Power Outage	California	In California, 61% of major power outages from 2000 to 2023 were attributed to extreme weather.	Chen & Freedman, 2024; Climate Central, 2024
Built Systems	Energy	Wildfire	Consumer Bill	California	For residential customers, wildfire-related utility costs led to a monthly $24 increase on the average 2023 bill for PG&E, an $18 increase for SCE, and a $13 increase for SDG&E; comprising between 7-12% of total monthly bills.	CPUC, 2024
Built Systems	Water	Drought and Extreme Heat	Well Drilling	California	In response to the 2021 drought, farmers in the Central Valley invested $24 million to drill 321 new wells due to surface water curtailments and $22 million to construct 294 additional wells due to extreme heat.	Hadachek et al., 2025
Natural Systems	Agriculture	Drought	Crop Revenue Losses	California	The 2020–2022 drought caused crop revenue losses of $1.3 billion (2021), $1.7 billion (2022), and 14,600 jobs.	Medellín-Azuara et al., 2022
Natural Systems	Agriculture	Salinity	Damaged Crops	California	Salinity can lead to statewide revenue losses of $3.7 billion annually ($1.7-$7 billion range).	Welle & Mauter, 2017
Natural Systems	Forestry	Wildfire	Timber	California, Oregon, Washington	Private timberland values have fallen by 10% between 2000 and 2020, with $6.2 billion attributed to increasing wildfire and drought risks.	Wang & Lewis, 2024
Natural Systems	Tourism / Recreation	Temperature / Reduced Snowpack	Revenue Loss / Jobs	Pacific Region	Snowmaking requirements in the Pacific region (California and the Pacific Northwest) increased by 16–22% in the 2000–2019 period due to warming, relative to 1960–1979. In the Pacific region, average ski seasons have shortened by 7.1 days (6.0%), the largest regional loss in the US, with annual direct economic losses estimated at $52.8 million ($4.8M additional snowmaking + $48.0M revenue losses).	Scott & Steiger, 2024
Economy Wide	Economy Wide	Temperature	GDP	US	A 1°F increase in the average summer temperature is associated with a reduction in the annual growth rate of state-level output of 0.15–0.25 percentage points.	Colacito et al., 2019

Section	Sector	Climate Hazard	Impact Type	Region	Economic Estimate	Source
Economy Wide	Economy Wide	Temperature	Inflation	US	Higher temperatures are pushing up inflation by 0.32 to 1.18 percentage points per year.	Kotz et al., 2024
Natural Systems	Agriculture	Extreme Heat	Crop indemnity claim	California	In 2021, heat was cited as the cause of more than $25 million in crop indemnity claims in Napa and Sonoma counties, two leading California wine-producing regions.	Parker et al., 2024; Reyes & Elias, 2019

Table 3: Sample Future Impact Estimates of Climate Hazards on California-Specific Economic Outcomes

Section	Sector	Climate Hazard	Impact Type	Region	Economic Estimate	Source
Social Systems	Health	Wildfire	Mortality	US	A 50% increase in wildfire smoke exposure is associated with an additional 9–20 deaths per 100,000 adults aged 65 and older. Using a $13.7 million VSL, this corresponds to approximately $123–274 million in mortality damages per 100,000 older adults exposed.	Burke et al., 2021
Social Systems	Health	Temperature	Mortality	US	By 2100, higher temperatures are projected to increase the US age-adjusted mortality rate by approximately 3%.	Hsiang et al., 2017
Social Systems	Health	Temperature	Mortality	US	By 2100, excess mortality will account for about 70% of climate damages.	Hsiang et al., 2017
Social Systems	Health	Temperature + Ozone	Mortality	US	By 2050, climate-driven air-quality changes could cause 300–1,200 premature deaths per year ($6.9–$9.8 billion in damages); by 2090, 630–2,500 deaths ($18–$26 billion).	Fann et al., 2021
Social Systems	Health	Temperature	Mortality	California	By 2050, climate change is projected to cause 560 additional heat-related deaths per year in California. However, reductions in cold-related deaths are projected to more than offset these additional heat-related deaths, resulting in an estimated cumulative net decline of about 53,500 temperature-related deaths in California through 2050.	Gould et al., 2025
Social Systems	Health	Wildfire Smoke	Mortality and Morbidity	US	By 2090, wildfire-related PM2.5 mortality and morbidity is estimated to rise from ~$7 billion per year to ~$36 billion per year under a moderate emissions scenario (RCP4.5).	Neumann et al., 2021
Social Systems	Health	Wildfire Smoke	Mortality	California	California is projected to experience ~5,060 additional smoke-attributable deaths per year by 2050 under the high-warming scenario (SSP3-7.0), relative to the 2011–2020 baseline, or $68.8 billion using a VSL of $13.6 million.	Qiu et al., 2025

Section	Sector	Climate Hazard	Impact Type	Region	Economic Estimate	Source
Social Systems	Government	Multiple Hazards	Government Spending	Los Angeles	Between 2024 and 2040, climate change damages in Los Angeles County will cost over $12.5 billion; over $9 billion will be incurred by municipal governments (or ~$780 million per year).	CCI, 2024
Social Systems	Government	Multiple Hazards	Municipal Bonds	US	A 1% increase in coastal climate risk is associated with about $1.7 million in higher municipal bond issuance costs.	Painter, 2020
Social Systems	Labor	Temperature	Labor Hours	Southwest US	Extreme heat is projected to cut labor hours in the Southwest by ~17–34 hours per exposed worker as warming rises from 2°C to 4°C.	EPA, 2021
Social Systems	Labor	Temperature	Lost Wages / Work Hours	US	By 2090, reduced work on days over 90°F (32.3°C) is projected to cut national annual wages by $36.7 billion under a moderate emissions scenario (RCP 4.5).	Neidell et al., 2021
Built Systems	Real Estate	Sea Level Rise	Property Damages	California	By 2050, $17.9 billion in losses projected from inundation of residential and commercial buildings under 50 cm (19.2 in) of sea level rise.	Grenier et al., 2024
Built Systems	Real Estate	Sea Level Rise	Property Damages	California	Sea level rise of 1, 2, and 4 feet along the California coast is projected to put approximately 10,900, 19,000, and 66,600 homes, respectively, at risk of chronic inundation, with associated property value losses of about $11 billion, $20 billion, and $68 billion, respectively.	Yu, 2020
Built Systems	Real Estate	Flooding	Property Damages	US	By 2050, annual flood losses are projected to rise by more than 61%, increasing from ~$20 billion to ~$32–32.3 billion per year.	First Street Foundation, 2021
Built Systems	Real Estate	Coastal Flooding	Property Damages	California	By 2100, $150+ billion of property and 600,000 people could be impacted by dynamic flooding.	Barnard et al., 2019
Built Systems	Real Estate	Wildfire	Property Damages	California	Under SSP2-4.5, California's current property value exposed to elevated wildfire risk rises from roughly $2–3 billion during 2000–2018 to approximately $5 billion during 2020–2049.	Anderegg et al., 2023
Built Systems	Real Estate	Wildfire	Property Insurance and Damages	California	By the 2040s, the Sierra Nevada is projected to have an increase in the number of summer fires of 51% and burned area of 59% compared to the 2010s.	Gutierrez et al., 2021
Built Systems	Energy	Temperature	Other	US	At the national level, total energy spending per capita will decrease by 4.1% in 2090 under RCP 8.5.	Rode et al., 2021
Built Systems	Energy	Sea Level Rise	Flooding	San Francisco Bay Area	By 2100, an estimated 90 to 290 kilometers of natural gas pipelines in the San Francisco Bay Area could be inundated.	Ju et al., 2019
Built Systems	Transportation	Temperature	Roadways	US	Higher temperatures are predicted to add approximately 3–9% to annual pavement building and maintenance costs across the next 30 years.	Underwood et al., 2017

Section	Sector	Climate Hazard	Impact Type	Region	Economic Estimate	Source
Built Systems	Transportation	Sea Level Rise and Storm Surge	Ports	California	By 2100, California ports would need to spend between an estimated $9 billion–$12 billion on storm surge protections under 6.5 feet of sea level rise.	Margaronis, 2019
Natural Systems	Agriculture	Temperature	Crop yields	California	By 2050, heat-driven yield losses (−11%) could correspond to roughly a ~$196 million reduction in the export value of California-grown vegetables, using the 2023 vegetable export value ($1,782 million) as a baseline (exports only, assuming export value changes proportionally with yields).	Medellín-Azuara et al., 2018
Natural Systems	Agriculture	Drought	Water Shortages	California	By the early 2040s, drought conditions could contribute to statewide water shortages of ~5-9.5 million acre-feet, or direct agricultural losses of ~$2.7-$5.1 billion annually.	Lund et al., 2025
Natural Systems	Forestry	Wildfire	Timber	California	High-severity wildfires are projected to reduce California timber harvest by $12.7 billion over the next 50 years, eliminating the equivalent of 7 years' worth of harvest and 4,300–5,900 jobs.	MBG Inc., 2023
Natural Systems	Tourism / Recreation	Temperature / Reduced Snowpack	Revenue Loss / Jobs	Pacific Region	In the Pacific region (California and the Pacific Northwest), ski seasons are projected to shorten by 46 days under moderate emissions (RCP4.5) by the 2050s. Associated annual direct economic losses in the Pacific region are projected at $307 million (RCP4.5) in the 2050s, rising to $426 million (RCP4.5) by the 2080s.	Scott & Steiger, 2024
Natural Systems	Tourism	Sea Level Rise	Tourism Revenue	Venice Beach	By 2100, Venice beach, a tourist destination in Los Angeles, could lose $450 million in tourism revenue under a 1.4 meter sea level rise scenario.	King et al., 2016
Economy Wide	Economy Wide	Multiple	Cost per Individual	US	Projected climate-related costs for an American born in 2024 are between $500,000 and $1 million in their lifetime.	ICF, 2024

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