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RICARDO LARA
INSURANCE COMMISSIONER
California Department of Insurance

Impacts of extreme heat to California's people, infrastructure, and economy

Pioneering analysis measuring uninsured and insured costs of extreme heat events

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June 28, 2024

Prepared for:

California Department of Insurance
300 Capitol Mall,
13th Floor
Sacramento, CA 95814

Prepared by:

Industrial Economics, Incorporated
2067 Massachusetts Avenue
Cambridge, MA 0214
617/354-0074

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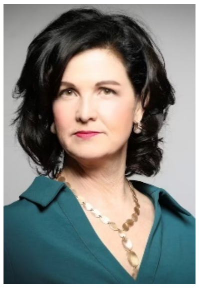
FOREWORD



As climate change drives record-breaking temperatures around the world more of us are feeling the burn, or soon will. Extreme temperatures are here to stay - even if we manage aggressive action to reduce our emissions of heat-trapping greenhouse gases.

Hotter times are bringing growing human and financial losses around the world. The data, information, and tools we need to understand such impacts across all of society are improving but the field is still in its infancy compared with the speed and size of the growing extreme heat threat. In particular, we are just scraping the surface in understanding the disproportionate impacts of heat on marginalized and low-income communities.

Access to data that makes clear the economic risks of a threat that is invisible and silent – and so too often overlooked – is crucial for decision-makers everywhere, especially with extreme heat now taking more lives, on average annually, than any other climate hazard.

The analysis and recommendations you will read in these pages are the result of years of work and commitment by the California Department of Insurance's (CDI's) Climate Insurance Working Group, the CDI Climate and Sustainability Branch, and the leadership of Insurance Commissioner Ricardo Lara. Understanding and communicating the economic implications of - and solutions for - extreme heat is a critical and timely accomplishment, especially set against the backdrop of a state facing mounting climate risks and impacts.

I hope this is the first of many such efforts, and that it can be replicated for cities, states, and national governments everywhere, to better understand the human and financial toll of extreme heat and, crucially, how to protect people and livelihoods from it.

The data presented in this report - on insured and uninsured costs of extreme heat - will inform government preparations and responses to the threat. It could also motivate financing – including for things like forecast-based insurance products – by governments, businesses, and the philanthropic community, to help accelerate equitable adaptation to extreme heat.

Read on – and share!

Kathy Baughman McLeod
CEO, Climate Resilience for All
Member, CA Climate Insurance Working Group

Having lived through scorching summers in New Orleans while growing up, I have firsthand knowledge of the profound impact of heatwaves on our daily lives. Now, living in California, I've witnessed similar impacts on communities—rising temperatures that endanger health, strain infrastructure, and worsen existing socioeconomic inequities, particularly in low income communities of color. The urgency to protect people from these escalating risks has never been clearer.

This report on the extreme heat protection gap is not just a collection of data; it is a powerful tool for action. By providing -- for the first time -- the economic and social costs resulting from recent extreme heat events, it equips policymakers, insurance companies and healthcare providers with tangible evidence to drive meaningful change. This data is pivotal in shaping policies that can make insurance more equitable and enhance community resilience against extreme heat.

More than ever, as climate change intensifies, there is a pressing need for proactive measures. Each recommendation in the report -- from enhancing investments in extreme heat to expanding insurance coverage for vulnerable populations -- is rooted in real-world data and designed to protect public health, support economic stability and improve the resilience of infrastructure. The Greenlining Institute commends the California Department of Insurance for their commitment to building our understanding of the true costs of extreme heat that are often invisible and Industrial Economics, Incorporated for their rigorous analysis of these costs. By harnessing the data-driven insights from this report, we can build toward a future where our communities are prepared and protected in the face of escalating temperatures.

Sona Mohnot
Director of Climate Resilience
The Greenlining Institute

LETTER FROM THE COMMISSIONER

Dear Readers,

The challenges presented by extreme heat are no longer a distant concern; they are an immediate and escalating threat to our health, infrastructure, economy, and overall well-being. Good data is essential for any strategy to be effective, and that's why I sponsored legislation in 2022 requiring this data to be collected and analyzed. This pioneering analysis, "Impacts of Extreme Heat to California's People, Infrastructure, and Economy," underscores the urgency of California's efforts to create a groundbreaking heat wave ranking and early warning system. It's a call for comprehensive strategies to address the previously unseen impacts of extreme heat.

Our Department has established itself as a global leader by continuing to be innovative in our approach to solutions for the climate risks we face. We want to assess the risks, encourage preparedness and risk mitigation, and establish cross-cutting partnerships with federal, state, and local governments, healthcare providers, businesses, and insurance companies to enhance resilience against extreme heat events. We also create a framework to measure the true costs of seven significant extreme heat events over the past decade, providing a detailed analysis of the financial and human tolls they exacted on our communities. The full spectrum of costs is likely much deeper than our preliminary estimates. From increased mortality rates and adverse health outcomes to significant economic losses across various sectors, the data presented is undeniable proof that we must act.

One of the major challenges we face is the disproportionate impact of extreme heat on vulnerable populations, including low-income communities, older adults, and outdoor workers. The findings underscore the urgency of developing targeted interventions and policies that mitigate the immediate effects of extreme heat and build long-term resilience. These strategies should be developed through conducting thorough risk assessments, involving local communities in planning, considering long-term sustainability, and ensuring that adaptation measures are equitable and environmentally sound to avoid making policy decisions that leave people behind or encourage adaptation measures that are more harmful than helpful. We want this analysis to help spur innovative insurance solutions and pre-disaster adaptation measures that can enhance our preparedness and response to future heat events.

Opportunities exist for improving our resilience to extreme heat. By investing in adaptive infrastructure, such as urban tree planting to reduce the "heat island" effect, and implementing comprehensive heat action plans, we can significantly mitigate the impacts on our communities. We want to partner in the development and promotion of innovative insurance products that protect outdoor worders, cover business interruptions, infrastructure and agricultural damages, and emergency services during extreme heat events.

I encourage all stakeholders, from local governments to private enterprises, to make the most of the insights and recommendations provided in this analysis. Through coordinated efforts and proactive measures, we can protect our people, economy, and environment from the increasing threats posed by extreme heat.

Let us use this report as a catalyst to foster greater cross-sector collaboration and drive forward-thinking solutions that will safeguard our state for generations to come.

Sincerely,

Ricardo Lara
Insurance Commissioner
California

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Acknowledgements

This report has been completed by the California Department of Insurance (CDI) with the support of Industrial Economics, Incorporated (IEc), a consulting firm with expertise in assessing the multisectoral impacts of climate change, as well as cooperation from insurance company representatives and the California nonprofit community. The primary project team for CDI was led by Rabab A. Charafeddine, PhD with contributions from Kara Voss, PhD, Deborah Halberstadt, and Mike Peterson from the Climate and Sustainability Branch. The primary project team at IEc included Jacqueline Willwerth, William Raich, Megan Sheahan, Henry Roman, and James Neumann. Maps and certain data analysis were supported by EcoTech Resources, Inc. (Berkeley, CA).

This effort was also supported by an expert advisory panel consisting of Dr. Jisung Park, Dr. Patrick Kinney, Dr. Josh Graff Zivin, and Dr. Doug Leslie.

The report authors wish to acknowledge the helpful assistance of Lauren Parker of USDA's California Climate Hub and David Lobell of Stanford University, for insight and data references for the Agriculture sector; Tom Lorenz of the U.S. Energy Information Administration for the Electricity sector; and Yommy Chiu and Jackie Higgins of Swiss Re, Katie Sabo, Cole Mayer, and Scott Barhorst of AON, and Janet Ruiz of the Insurance Information Institute (III) for insurance coverage information.

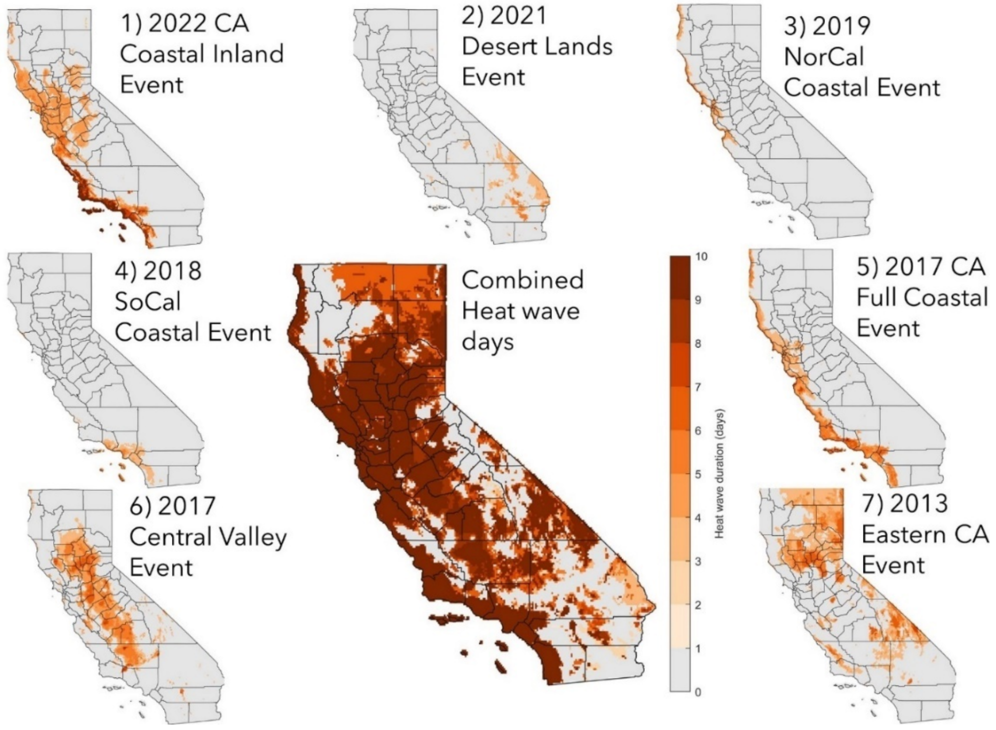
1 | Executive Summary

The overarching goal of this report is to generate an assessment of the impacts and costs of recent extreme heat events, particularly focusing on the disproportionate effects on vulnerable communities. It fulfills a recommendation from the Climate Insurance Report and a subsequent state law mandate, providing a foundational analysis to be used to focus policy initiatives aimed at reducing extreme heat impacts.

In response to the growing burden of extreme heat on California's people, economy, and governments, the California legislature passed Assembly Bill (AB) 2238, signed by the Governor on September 9, 2022, with the primary intent of establishing a statewide extreme heat ranking system. An important requirement of the bill is for the Department of Insurance (CDI) to conduct and publish a study on past extreme heat events and the effectiveness of insurance coverages. CDI will share the results of the study with the California Environmental Protection Agency, the Integrated Climate Adaptation and Resiliency Program, and legislative policy committees to inform California's extreme heat ranking system and support ongoing efforts in extreme heat resilience planning across the state.

The report uses a comprehensive, evidence-based approach to assess the economic costs of seven carefully chosen extreme heat events which impacted California during the period 2013 to 2022. These events differ in their geographic coverage, number of people living within the area of the extreme heat event, impacts on five specific sectors of interest (Health and Safety, Economy, Infrastructure, Energy, and Governance), and overall magnitude and intensity of impact. This report provides a rich understanding of the range of impacts experienced during these events, and the extent to which insurance provides compensation for these losses, but data and other limitations mean that the overall impacts are likely to be underestimated.

Figure 1. Spatial Extent of the Seven Historical Heat Events



The main objective of this report is to describe and assess the uninsured and insured costs of a set of historical extreme heat events in California on communities, local and tribal governments, the healthcare system, and economic productivity, among other potential costs at the state and local levels.

Selection criteria for the Extreme Heat Events in this study:

- Selected event occurred in the last 2-11 years;
- Was widespread and spatially representative in its effects;
- Caused or was associated with extreme heat effects of interest to the objectives of the present CDI study (including health, economy, infrastructure, governance);
- Reflected impacts both to the general population and vulnerable groups;
- Represented diverse geographic and socioeconomic locations.

The key findings of the study are summarized below, in four categories: estimated costs of extreme events; impacts on subpopulations of interest; insurance coverage and gaps addressing these costs; and preliminary estimates of benefits and costs of three interventions to lessen these impacts for California.

Costs of Extreme Heat

The total impacts across the Health and Safety, Economy, Infrastructure, Energy, and Governance sectors range from a high of over $3 billion for the widespread effects of the 2022 CA Coastal Inland event, affecting more than 34 million people over 14 days, to $230 million for the more spatially limited 2013 Eastern CA event, affecting about 3 million people over 9 days.

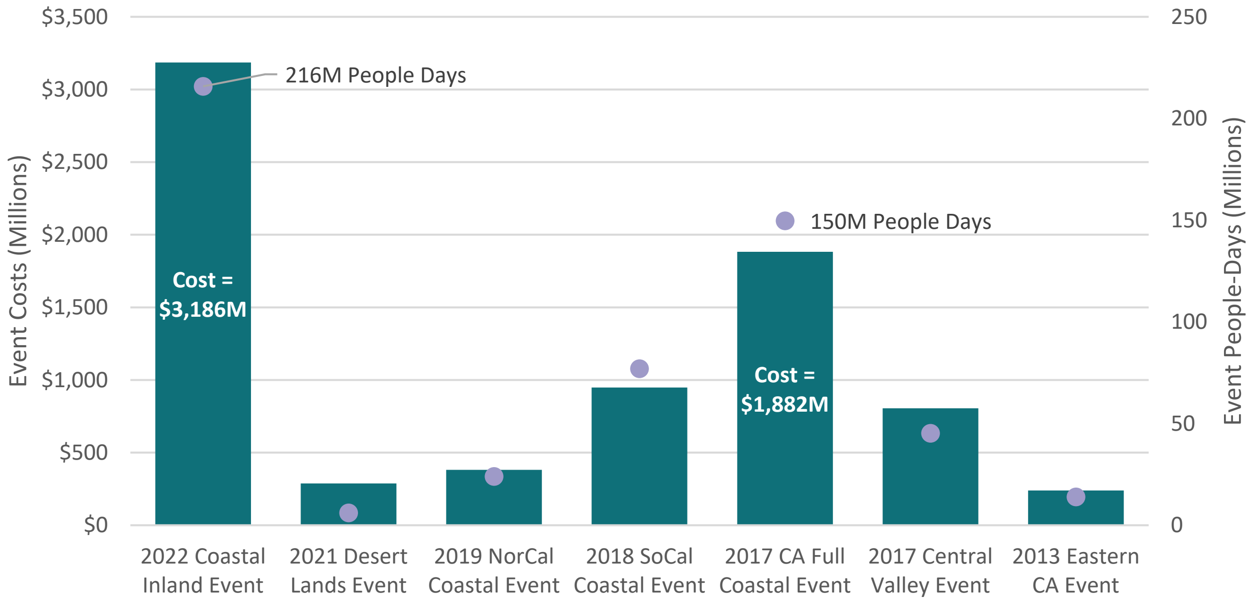
- The 2017 CA Full Coastal Event also had a big impact, with nearly $2 billion in total costs. The other five events each account for between $230 million and $1 billion in total costs, and between 10 million and 70 million people-days (see **Figure 2** below).
- Most of these impacts were experienced in the Health and Safety sector. For the 2022 CA Coastal Inland event alone, this included nearly 200 deaths, more than 140 adverse birth outcomes, over 2000 hospitalizations, and over 4.200 emergency department visits, all attributable to the extreme heat over 14 days in a single event, experienced by more than 34 million Californians.
- **Impacts in the Economy sector:** Including in agriculture, manufacturing, and weather-exposed industries, range from just under $100 million (for the 2019 NorCal Coastal event) to over $600 million for the 2022 Coastal Inland event. The largest effects are for lost manufacturing productivity.
- **Energy sector:** Documented power outages led to an estimated $580 million in combined damages across the seven events, with $230 million attributed to a single 2022 event. These losses were concentrated among commercial and industrial ratepayers, associated mainly with lost productivity but also with service sector losses.
- **Infrastructure:** Damages and delays associated with rail and road infrastructure added from $3 to $35 million in losses per event. Most of the losses in the roads sector translate into increased maintenance and rehabilitation costs for municipal and state government.
- **The estimates and metrics in this report are conservative.** While the estimates of total impact presented in this study are illuminating and startling, because the study is focused on a select set of past

events and because many impacts cannot be quantified or costs fully estimated, a full accounting of the annual historical costs and physical effect incidence is likely to be much higher than estimated here.

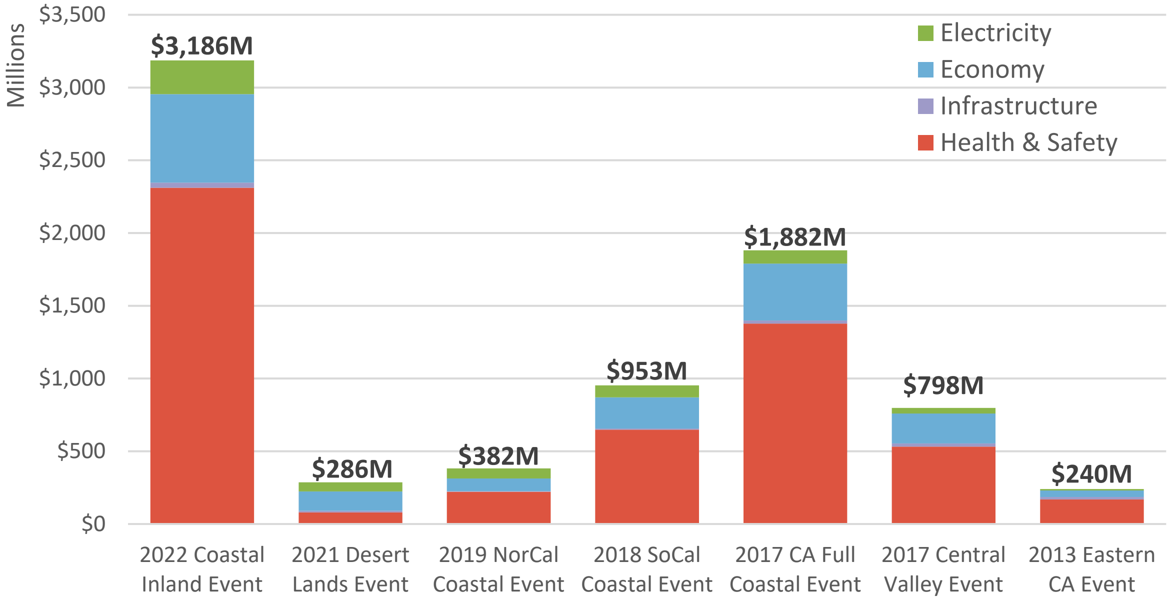
Figure 2. Calculated Costs Across Quantified Impacts

Panel A shows total costs (in 2022 dollars) across quantified outcomes (premature mortality, prenatal outcomes excluding stillbirths, Emergency Department visits and hospitalizations, as well as damages or losses for rail, roads, crops, dairy production, dairy mortality, lost wages, manufacturing productivity, and power outages) for all events. Purple dots show the number of persons and number of days exposed to extreme heat (the product of persons exposed and days of exposure yields "people days"). People days are calculated as Census tract populations multiplied by days that tract is in the event. Panel B shows total costs by event and costs by sector, for each event.

Panel A: Total Cost and People Day Exposure Metrics



Panel B: Total Cost and Cost by Sector



Impacts on Populations of Concern

- Many of the quantified costs of extreme heat during the selected events in this study fall disproportionately on already overburdened racial and ethnic sub-populations. For example, Black, Native American, and White Hispanic estimated mortality rates from extreme heat are higher than for Asian and White Non-Hispanic populations, and in some cases, the rates for overburdened groups are twice as high as for Asian and White Non-Hispanic groups.

- This report also investigated costs to disadvantaged communities identified by the California Office of Environmental Health Hazard Assessment under the environmental justice criteria established in California's Senate Bill (SB) 535 criteria (California Health and Safety Code, Section 39713), and most recently updated in 2022. For example, six of the heat events showed mortality rates for disadvantaged community tracts between 14 and to 30 percent higher than non-disadvantaged community tracts.

- Hospitalization and emergency department visit rates connected to extreme heat also fall disproportionately on overburdened populations, with over 50 percent of hospitalizations and nearly two thirds of emergency department visits falling on Black, Native American, White Hispanic, and Asian populations, well in excess of their representation in the state population.

- Among age-related impacts, elderly individuals experienced worse health outcomes from exposure to extreme heat compared to other age groups. However, our findings suggest that these events also have specific health impacts on other age populations, including impacts on maternal and child health. Available literature also points to disparities in impacts on weather-exposed industry workers (with particular effects among low-income populations); for mobility associated with impacts to roads and passenger/transit rail; and for workplace injuries (with five times larger rates of workplace injury associated with heat for low income compared to high income workers).

Insurance Coverage and Gaps

- Only a relatively small portion of these costs are covered by insurance, in all sectors. The largest share of the costs of extreme heat, in the Health and Safety sector, are accounted for by premature mortality associated with exposure to extreme heat. Premature deaths may be covered by life insurance, but only just over half of individuals nationwide are covered by life insurance, and the average life insurance payout of roughly $160,000 falls far short of the total expected costs of this loss of life.

- The most robust insurance coverages are for nonfatal health effects and workplace injuries, the direct costs of which are covered by private or publicly supported medical insurance. However, the indirect costs (loss of income during illness or injury) are frequently not covered by insurance.

- For the Economy, Infrastructure, Energy, and Governance sectors, insurance coverage is mixed. Often coverages exist for the type of impact (e.g., business interruption) but extreme heat is not a covered peril at this time under these policies.

- The most robust insurance coverage in the Economy sector is likely Federally supported crop insurance – but many specialty crops prevalent in California are incompletely covered or excluded from coverage by Federal crop insurance. Private crop insurance for specialty crops can be procured, but uptake is low. New coverages for the Governance sector directly address the impacts assessed in this report, and include extreme heat as a peril, but uptake is extremely low, and coverages are documented only for non-heat perils (e.g., floods and storms).

2 | Introduction

California has experienced record heat in recent years, including nationally notable incidents such as:

- Extreme heat causing power outages in Los Angeles as long as one week in July 2018;[*]
- Record high temperatures in Death Valley and Los Angeles County in August and September of 2020, which also fueled new and existing wildfires;[†]
- Heat in the Central Valley and nearby areas in July 2021, exacerbated by an ongoing drought;[‡] and
- A widespread heat event in September 2022 which eventually affected most of California's coastal areas and many inland regions from the Bay Area to Southern California and combined with hurricane force winds to worsen wildfires.[§]

In response to the growing burden of extreme heat on California's people, economy, and governments, the California legislature passed AB 2238, signed by the Governor on September 9, 2022, with the primary intent of establishing a statewide extreme heat ranking system and an associated public communication plan, and to partner with local and tribal governments to better prepare and plan for these events. An important additional requirement of the bill is for the Department of Insurance (CDI) to publish a study on past extreme heat events and the effectiveness of insurance coverages, with the goal of better understanding the extent to which insurance mitigates these impacts and can facilitate effective adaptation to extreme heat. This report addresses the CDI reporting component of AB 2238.

The main objective of this report is to describe and assess the uninsured and insured costs of a set of historical extreme heat events in California on communities, local and tribal governments, the healthcare system, and economic productivity, among other potential costs at the state and local levels. This report takes a broad, multi-sectoral, and evidence-based approach to estimating the overall losses from seven historical extreme heat events from the period 2013 to 2022. In addition to quantifying costs, the report also estimates the component of those losses or costs covered or potentially covered by insurance, summarizing available information on applicability and limitations of existing insurance products for each category of loss, and on the prevalence of those coverages among the affected entities.

A secondary objective is to examine the economic benefits and costs of three extreme heat interventions which might be adopted by government or private entities in the state. The three interventions are: 1) Adoption by local governments of comprehensive extreme heat response plans; 2) Implementation of more extensive tree planting efforts, to increase shade and directly reduce temperatures, as well as provide other benefits; and 3) Adoption of cooling systems for the shelter of dairy cows, to reduce livestock mortality and increase milk production during extreme heat events.

The remainder of this report consists of five chapters. Chapter 3 provides information on the seven selected historical events, how they were chosen for closer examination and analysis in this report, and other information about the prevalence of extreme heat events in California over the last decade. Chapter 4 presents the in-depth analysis of the physical and economic costs of these events for a range of impacts on health and safety;

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[*] See reporting on a series of events in 2018 throughout North America and globally, here: https://en.wikipedia.org/wiki/List_of_heat_waves#2018

[†] See NASA's reporting on this event here: https://earthobservatory.nasa.gov/images/147256/california-heatwave-fits-a-trend

[‡] See NPR's reporting on this event here: https://www.npr.org/2021/07/10/1014914833/californias-central-valley-residents-try-to-stay-cool-in-record-heat

[§] See CNN's reporting on this event here: https://www.cnn.com/2022/09/08/us/western-us-heat-wave-thursday/index.html

California’s economy; infrastructure; electricity supply, demand, and transmission; and California’s state and local governance. Each of these five sectors addresses multiple categories of impacts – for example, health and safety examines heat-induced premature mortality, a range of non-fatal but serious health outcomes, and workplace injuries, at varying levels of detail. This chapter also provides quantitative and qualitative assessments of the extent to which insurance coverages are available, and the prevalence of coverages, for each impact category. Chapter 5 provides additional information on relevant insurance coverages for the impact of extreme heat. Chapter 6 presents analysis of the economic benefits and costs of three interventions that could be adopted to prevent, prepare for, or respond more effectively to some of the impacts examined in Chapter 3. Chapter 7 provides a short list of areas for further research. As stated in the report, a full accounting of the annual historical costs and physical effect incidence is likely to be much higher than estimated here, owing to data, methods, and time and resource limitations. Pursuing the recommendations for further research in this chapter could provide a better understanding of the full costs of extreme heat to California, the incidence of these costs on populations of concern, the extent to which insurance can play a role in mitigating these effects, how these impacts might evolve in the future as climate changes, and the efficacy of actions to reduce these costs.

3 | Extreme Heat Events in California

The first report objective was to select seven past extreme events to evaluate in more detail. There are multiple available methods to identify relevant heat and related weather thresholds that could signal a period of concern for extreme heat impacts. After careful consideration, the project team selected one of these methods; used available data to identify candidate events in California's recent past to be considered for inclusion; and then evaluated candidate events against five criteria to choose seven specific past events for use in this study. This chapter provides a summary of heat events methods considered, the event selection criteria used and the seven events selected using these criteria, and characteristics of the people and places affected by these seven events.

3.1 Defining Extreme Heat Events

Heat events can be objectively defined using a threshold approach – that is, when heat and potentially other important weather variables, such as humidity are measured to be above a threshold of concern, the places and time periods where these conditions apply can be determined to be in a "heat wave." These threshold methods differ in their formula for using weather data, and whether they use absolute or relative measure of heat severity. An absolute measure might classify a heat event using a definition of "all days with maximum temperature above 95ºF," for example. A relative measure, on the other hand, might consider all the daily maximum temperatures in a typical summer and identify a heat wave by choosing the top 1 percent of those days in the recent past. With a relative measure, the definition is used to identify an anomaly from typically experienced heat, so areas that are typically cooler, and therefore also not well acclimated to extreme heat, may have a lower absolute threshold for a heat event than areas that are typically hotter. Some definitions also require a certain number of consecutive days above the threshold. Examples of available definitions of extreme heat events that the Project Team considered are described in Appendix A. Such metrics and tools include measures adopted by Cal-Adapt (a web-based climate adaptation planning tool supported by the California Energy Commission's Public Interest Energy Research program), the California Office of Environmental Health Hazard Assessment (OEHHA), and other California agencies.

The definition ultimately chosen to define the dates and locations of heat events was the Excess Heat Factor approach,[*] a relative measure that accounts for both severity (i.e., heat burden above a place-specific threshold) and acclimatization (i.e., deviation from typical conditions in the area), and driven by daily high apparent temperature, which considers both temperature and humidity conditions.[†] The Excess Heat Factor was chosen because it considers temperature, humidity, and acclimatization, all important factors in the impact of extreme heat, and because it is a measure favored by the Extreme Heat Resilience Alliance, an initiative launched in August 2020 with the California Department of Insurance as a founding member, for many of the same reasons.[‡]

In the period 2013 to 2022, there were more than 100 multi-day instances across the state that met the definition of an Excess Heat Factor event.[§] This report focuses on six events that met this definition, and that ranked high in terms of overall event length and number of people impacted, while also providing some geographic diversity in impact area across California. A seventh event was chosen based on the Cal-Adapt 98th percentile

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[*] Based on Nairn, John R., and Robert J B Fawcett. The excess heat factor: a metric for heatwave intensity and its use in classifying heatwave severity. Int J Environ Res Public Health. 2014 Dec 23;12(1):227-53. doi: 10.3390/ijerph120100227. PMID: 25546282; PMCID: PMC4306859.

[†] Using data from the PRISM Climate Group, Oregon State University, https://prism.oregonstate.edu

[‡] More information on the Adrienne Arsht-Rockefeller Foundation Resilience Center and the Extreme Heat Resilience Alliance and its activities can be found at their website: https://onebillionresilient.org/project/extreme-heat/

[§] Numerous sources of historical temperature data exist, but this study used data from Oregon State's PRISM model, which produces daily temperature and humidity data at a four kilometer resolution, re-gridded from NOAA's network of monitoring stations. The fine spatial scale of this data source is ideal for capturing the variability in conditions across California, and it provides comprehensive spatial coverage, a key advantage over station data.

temperature-based definition, to ensure additional spatial coverage in parts of Southeast California, where events rarely meet the Excess Heat Factor definition because of the typically low humidity conditions.

3.2 Selected Events

The set of seven selected events meet the following criteria:

- Occurred in the last 2-11 years;
- Was widespread and spatially representative in its effects;
- Caused or was associated with extreme heat effects of interest to CDI (including health, economy, infrastructure, governance);
- Reflected impacts both to the general population and vulnerable groups;
- Represented diverse geographic and socioeconomic settings.

The following seven events, in **Table 1**, all occurred recently (between 2013 and 2022), affected many people, considered together cover most of the state, and/or have other noteworthy characteristics such as a high share of census tracks in the areas designed for environmental justice consideration through the California SB535 List of Disadvantaged Communities [*], or coincided with occurrence of major power outages.

Table 1. Characteristics of Selected Heat Events

Selected characteristics of the seven selected events including the dates over which any location met the criteria for extreme heat during the event, the population affected (based on residence), and person-days, a measure of event exposure.

#	Heat Event	Dates	Population Affected	Person-Days[a]
1	2022 CA Coastal Inland Event	8/31 - 9/13 (14 days)	34,225,941	215,814,930
2	2021 Desert Lands Event[b]	6/15 - 6/22 (8 days)	1,453,124	6,106,653
3	2019 NorCal Coastal Event	6/8 - 6/14 (7 days)	5,776,417	24,042,309
4	2018 SoCal Coastal Event	7/6 - 7/12 (7 days)	18,705,368	77,009,571
5	2017 CA Full Coastal Event	8/27 - 9/8 (13 days)	28,835,057	149,691,445
6	2017 Central Valley Event	6/17 - 6/27 (11 days)	8,611,346	45,222,323
7	2013 Eastern CA Event	6/27 - 7/5 (9 days)	3,023,645	13,949,510

Notes:

a. Person-days are a measure of the scale of the event, calculated as the sum of people affected multiplied by the days each person was in the event (for example, an event that affects 10 people on the first day and 20 people on the second day would have 30 person-days).

b. Identified as heat event using the temperature-based approach used by the Cal-Adapt tool (https://cal-dapt.org/tools/extreme-heat), more effective for arid regions.

The spatial extent and duration of each event are shown in **Figure 3**. The defined heat events often covered large areas of the state; however, the severity of the events was not uniform across the affected area. As the heat event progressed, certain areas moved in and out of the defined event. For example, the 2022 Coastal Inland Event covered parts of the San Joaquin Valley but persisted longer along the southern coast. Also, because the events are identified in part based on deviations from typical summer temperatures, the absolute temperature threshold for an event varied by location. For example, despite experiencing some of the highest temperatures in the state,

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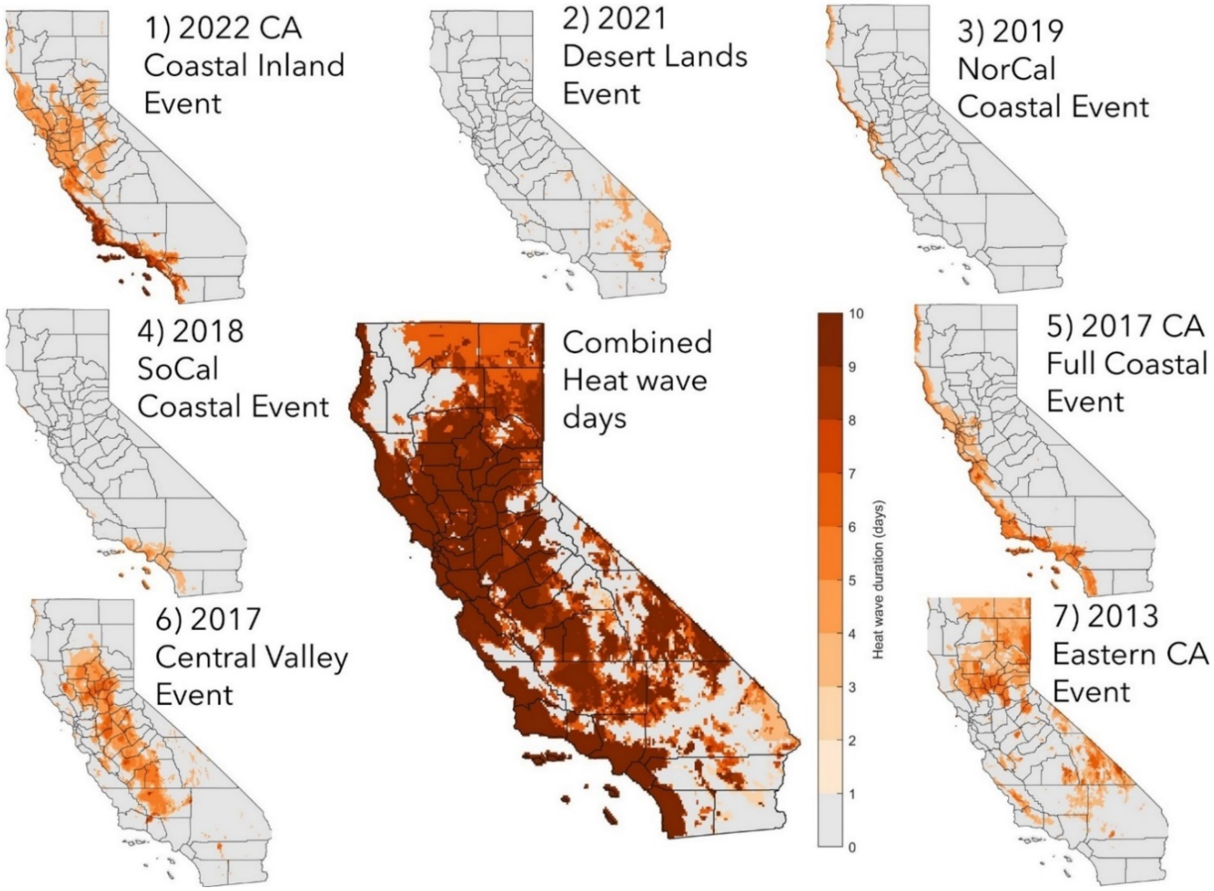
[*] SB 535 List of Disadvantaged Communities (2022), https://oehha.ca.gov/calenviroscreen/sb535

the Death Valley region only appeared in one of the seven events because typical summer temperatures are already quite high – this outcome is a feature of the relative temperature approach used to identify events of consequence in this study.

Figure 3. Spatial Extent of the Seven Historical Heat Events



4 | Costs of Extreme Heat Events

The focus of this study is quantifying and estimating the economic cost to California for a broad range of impacts of extreme heat, across multiple categories, while also assessing the extent to which these costs may be covered by existing insurance products. **Table 2** lists the impacts evaluated in this study. The five cost categories are useful for organizing impacts however they are not entirely distinct. Some impacts may span categories; for example, the power outage costs considered under the electricity category could also be included in the economy category.

Table 2. Evaluated Impacts of Extreme Heat

Category	Impact	Measure of Economic Cost to California Used in this Study	Potential Insurance Coverages Considered in this Study
Health and Safety	Mortality	Willingness-to-pay to avoid fatal risks	Life insurance
	Hospitalizations and Emergency Department Visits	Cost of medical treatment and lost income	Medical insurance
	Outpatient visits	Cost of medical treatment	Medical insurance
	Birth-related outcomes	Lifetime cost of medical treatment	Medical insurance
	Workplace injuries	Number of injuries*	Worker's compensation
Economy	Dairy productivity	Lost dairy farm revenue	Limited parametric insurance options
	Dairy cow mortality	Replacement costs for herd	Cow health/life insurance
	Crop agriculture productivity	Lost crop revenue	Crop insurance
	Manufacturing productivity	Lost manufacturing GDP	Business interruption insurance
	Reduced work time in weather-exposed industries	Lost wages to workers	No coverages identified
	Business closures and other lost revenue	Business interruption costs*	Business interruption insurance
Infrastructure	Rail costs	Repair and delay costs	Limited coverages identified
	Road costs	Repair and delay costs	Parametric policies for local governments
	Airports	Delay costs for travelers, lost airline revenue*	Travel insurance, some business interruption policies
Electricity	Costs of power outages	Customer interruption cost	Business interruption insurance
	Residential energy costs	Costs to residential consumers*	No coverages identified
	Distribution and transmission infrastructure repairs	Repair and replacement cots to utilities*	No coverages identified
Governance	Event response costs	Direct costs to governments during heat events*	Some parametric insurance options available to governments cover all three categories of Governance costs
	Tax revenue losses	Lost local and state tax revenue*	
	Increased demand for government services	Costs to local and state governments during and after events	

Note: For impacts indicated with a "*" in the table above, data and methods do not support fully quantifying costs for California, or attributing costs to specific events. These impacts are described qualitatively in the report.

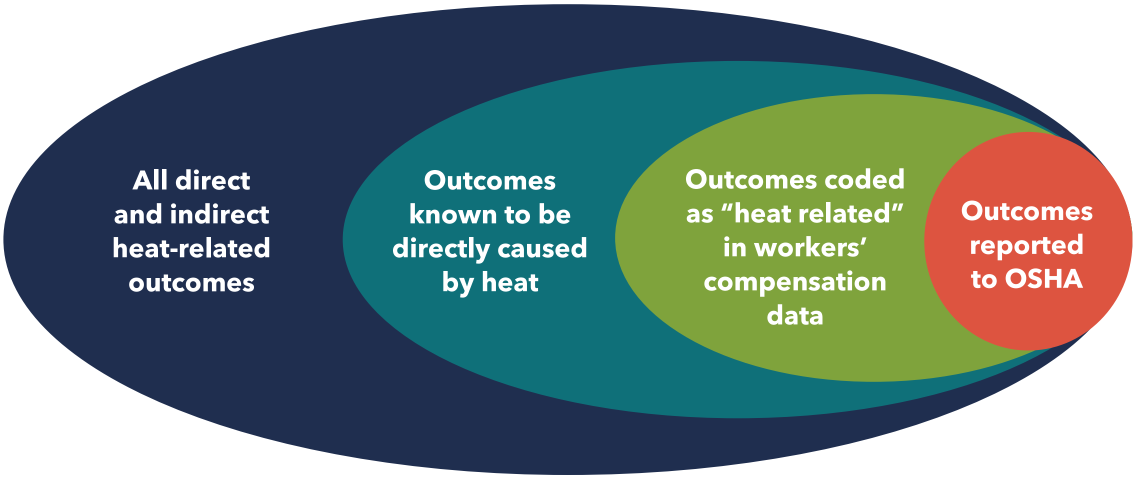
4.1 Cost Estimation Methods

Specific methods for each impact analysis are summarized in subsequent sections and detailed in Appendix B, however we follow a similar generalized approach for all impacts:

1. We attempt to capture all impacts of the event, not just the impacts officially documented as extreme heat related. In many cases, this means we rely on peer-reviewed extreme heat impacts literature rather than a direct accounting approach. We use the impact literature due to the systematic undercounting of costs in available data that would be used in an accounting approach. Examples of undercounted costs include uninsured costs that are not captured in claims data, unreported occupational injuries, and any outcomes that are not coded as "heat related" in official data sources but are theoretically and conceptually tied to heat stress. **Figure 4** below illustrates this comprehensive, "attribution" approach to capturing a broad range of direct and indirect effects, using workplace injuries as an example.

Figure 4. Attribution-Based Approach Used in this Study versus Other Measures of Heat Impacts

This study adopts the broad, "attribution-based" approach to estimating the impacts of extreme heat. The attribution approach is designed to identify all impacts of heat, whether they are explicitly documented in contemporaneous records or not, by comparing outcomes during heat events to a baseline of outcomes during non-event periods of time (such as in adjacent but milder summer season days).



2. We measure impacts above a "no event" baseline, meaning above what might be expected during "normal" conditions in absence of an extreme heat event. For many impacts, adverse outcomes still occur at a non-zero rate during warm months outside of extreme events. This analysis captures the impacts above those expected under normal conditions.[*]

3. The scope of measured impacts is confined just to the geographies and days over which the event occurred. Heat-driven impacts may occur before or after a defined event and may occur in neighboring areas not defined within the event area. Events are generally defined at the Census tract-day or county-day level.[†]

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[*] Specifically, we subtract impacts calculated for a constructed counterfactual scenario from each impact event. The counterfactual scenario is the median apparent temperature day from a 31-day window around the day of the event using all days in 2013-2022. For instance, if a heat event included June 1, 2021, then the counterfactual scenario would be the median temperature and humidity conditions from May 16 – June 15 in all years between 2013-2022. Note that the year of the event, 2022 in this example, is included.

[†] The climate data is processed at the Census tract-day level. If any tract within a county is identified as experiencing a heat event on a given day, the County is included in the analysis.

4. Each impact estimate is subject to a number of uncertainties. We discuss some of these uncertainties and limitations in the discussions below. To ensure we do not convey false precision, we present estimates using two significant digits.[*] In cases where the methods and/or data do not support quantitative cost estimates, we describe impacts qualitatively.

A key purpose of this study is to analyze the insurance gaps faced by vulnerable populations. We identify the subset of costs covered by insurance for all categories of impact based on available information. For some categories of cost, namely the health and safety category, data are available to quantitatively identify insured costs. For many of the other cost categories, information is not publicly available to quantitatively break out costs by insured status. In these cases, we rely on qualitative information and expert judgement regarding the proportion of costs likely to be covered. This information was collected through a series of conversations with representatives from the insurance industry familiar with the availability of insurance mechanisms to cover extreme heat impacts.[†] The results of our discussions are described in more detail in Chapter 5, and in Appendix C.

This study focuses on the analysis of the distribution of costs across vulnerable groups to the health and safety category given greater data availability for these topics. The distribution of costs by race, ethnicity, insurance status, and for outdoor workers is provided for the premature mortality category and for hospitalizations and birth outcome. Where medical insurance is the primary coverage addressing the impact, available information also supports differentiating by insurance type (e.g., Medi-Cal, Medicare, private insurance). These estimates provide a greater understanding of the populations most adversely impacted by extreme heat – especially for the health category, which represents the largest quantified impact in this study.

4.2 Summary of Cost Estimation Results

This section provides some of the highlights of the results presented in more detail in the sections that follow. Reviewing results across these seven events can be useful to understand patterns in costs of extreme heat at a more granular spatial and sectoral scale than is accessible if we were to aggregate costs across all historical events. Nonetheless, it is important to remember these events were chosen as significant historical events with varying characteristics and therefore are not representative of all "typical" events experienced in California. They do, however, represent large-scale heat events that are likely to become more common in the future under a changing climate.[‡]

Figure 5 presents the share of quantified costs by category for the seven events.[§] Health (premature mortality, as well as a range of nonfatal health impacts) and economy sector impacts represent the largest categories of quantified costs for all events. Economy and electricity impacts are proportionally larger in the 2021 Desert Lands Event; this event ranks lowest in terms of person-days affected, but affects several agriculture areas, showing the largest effects on crop productivity and among the largest effects on dairy productivity. Infrastructure impacts are relatively smaller across all events. Note that governance sector impacts are largely

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[*] Note we also continue to perform quality control checks on all analyses. Results may change prior to finalization as a result of these checks.

[†] See the Acknowledgements section at the end of this document for a list of experts contacted through this process.

[‡] For historical perspective on heat events, including data on 2023 being the warmest year on record, see https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature. For information on projected changes in climate, including extreme heat, that is specific to California, see the California Climate Change Assessment, including here: https://www.climateassessment.ca.gov/techreports/projections-datasets.html

[§] Power outage data for the electricity category are not available for earlier events therefore we only present the most recent four events. The relative share of the remaining three categories is similar to those shown for the earlier events.

made up of impacts from other sectors (e.g., road maintenance costs), but have incidence for the state or local government sector, so they are not shown here.

Figure 5. Share of Costs by Category

Share of quantified costs by category for the seven events. Totals may not sum to 100% due to rounding.

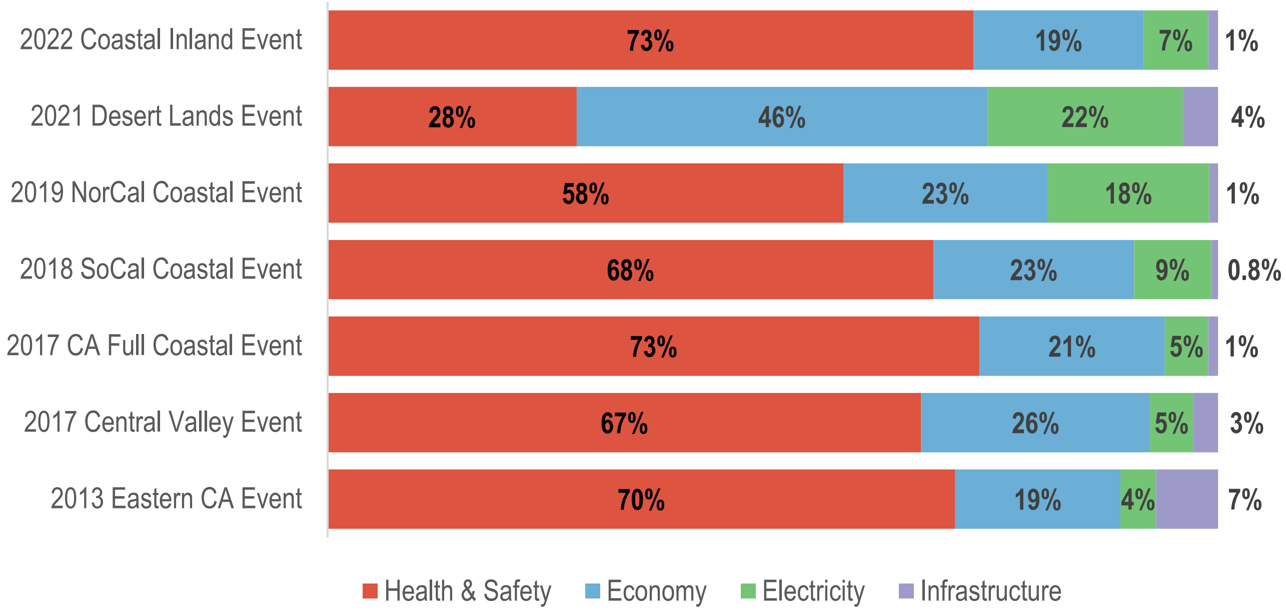

Figure 6 presents the total calculated costs per event, and the number people days per event, for the quantified impacts. People-days are calculated as Census tract populations multiplied by the number of days that tract is in the event. The 2022 Coastal Inland Event had the largest cost impact, over $3 billion dollars, much of which is attributed to premature mortality impacts. This event was widespread in its effects, accounting for more than 200 million people-days. The event also coincided with high humidity associated with a tropical storm (Hurricane Kay), exacerbating the effect of high heat. The high winds were also blamed for worsening wildfires this event. [*]The 2017 CA Full Coastal Event also had significant costs, with nearly $2 billion in total costs and 150 million people-days. The other five events each account for between $230 million and $1 billion in total costs, and between 10 million and 70 million people-days.

Only a relatively small portion of these costs are covered by insurance, in all sectors. The largest share of the costs of extreme heat, in the Health and Safety sector, are accounted for by premature mortality associated with exposure to extreme heat. These premature deaths may be covered by life insurance, but only just over half of individuals nationwide are covered by life insurance, and the average payout of roughly $160,000 falls far short of the total expected costs of this loss of life. The most robust coverages are for nonfatal health effects and workplace injuries, the direct costs of which are covered by private or publicly supported medical insurance – however the indirect costs (loss of income during illness or injury) are frequently not covered by insurance.

For the Economy, infrastructure, energy, and governance sectors, insurance coverage is mixed. Often coverages exist for the type of impact (e.g., business interruption) but extreme heat is not a covered peril under these policies. The most robust insurance coverage in these sectors is likely Federally supported crop insurance – but

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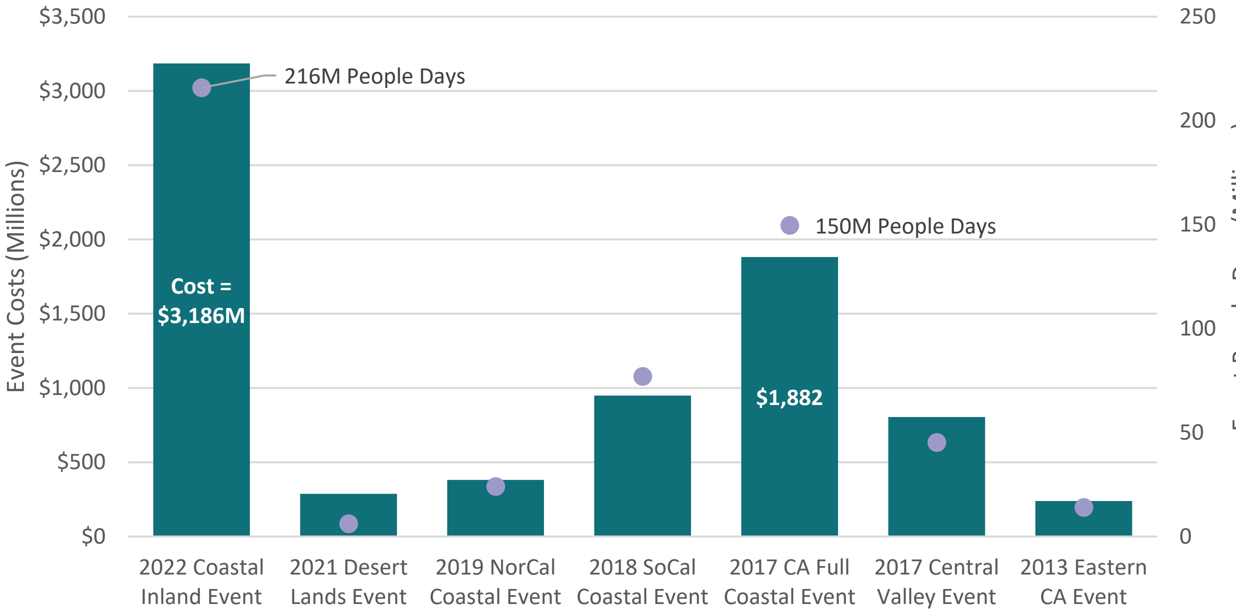
[*] The wildfire costs for this event were extensive but are not part of the scope of this report so are not included here.

many specialty crops prevalent in California are incompletely covered or excluded from coverage by Federal crop insurance. Private crop insurance for specialty crops can be procured, but uptake is low, probably less than 50 percent. New coverages for the Governance sector directly address the impacts assessed in this report, and include extreme heat as a peril, but uptake is extremely low, probably less than five percent.

Figure 6. Calculated Costs Across Quantified Impacts

Total costs (in 2022 dollars) across quantified outcomes (premature mortality, prenatal outcomes excluding stillbirths, Emergency Department visits and hospitalizations, as well as damages or losses for rail, roads, crops, dairy production, dairy mortality, lost wages, manufacturing productivity, and power outages) for all events. Purple dots show the number of persons and number of days exposed to extreme heat (the product of persons exposed and days of exposure yields "people days"). People days are calculated as Census tract populations multiplied by days that tract is in the event.



The remaining text in this chapter provides more details on costs, incidence among sensitive or vulnerable populations, and insurance protection gaps, for the Health and Safety, Economy, Infrastructure, Energy, and Governance sectors.

4.3 Health and Safety Impacts

Human health and safety are major concerns during extreme heat events. High temperatures can result in many adverse health effects, including premature death and non-fatal illness and injury. In this section, we quantify the costs of extreme heat on premature mortality, hospitalizations and emergency department visits, outpatient visits, birth-related outcomes, and workplace injuries. These topics, particularly premature mortality, are areas of significant research, allowing us to leverage recent and high-quality impacts literature to study the seven heat events of interest. Because the impacts in this sector relate to human health, we can further leverage rich datasets on health insurance coverage, demographics, and other population-based metrics to understand who is bearing the costs of these events. Where possible, we present estimates by health insurance status (i.e., insured and uninsured populations); however, we note that the full social costs of some outcomes, such as stillbirth and premature death, are far greater than any medical expenditures incurred for these cases.

The three types of insurance coverage most relevant for the health sector are life insurance (partially covering the full costs associated with premature mortality); health insurance (for non-fatal outcomes); and workers compensation (for workplace injuries). Life insurance uptake rates are less than 60 percent; health insurance coverage is near universal in California but varies by payer; and worker's compensation coverage is required for all employees but excludes contract workers or those working through informal arrangements.

Health and Safety Key Findings

- Premature mortality represents the most significant cost for the seven extreme heat events. The total social welfare losses associated with premature death range from $77 million to $2.2 billion per event, reflecting attributed premature deaths of 7 to 200 people per event.
- Extreme heat events also heighten the incidence of non-fatal health outcomes, including those pertaining to childbirth, such as low birth weight for newborns, pre-term births, stillbirths, and gestational diabetes for expectant mothers.
- Adverse health outcomes impact Black, Hispanic, and Native American communities disproportionately. In addition, information available from existing literature concludes that the bulk of premature deaths are concentrated among older populations.
- The majority of Californians are covered by a mix of public and private health insurance options, but a notable portion remain uninsured (6.3% in 2021). Out-of-pocket expenses, including copays, deductibles, and out-of-network costs, are further borne by patients. Roughly half of the population is covered by life insurance.

Table 3 provides a summary of the quantified components of Health impacts, for each event. The Premature Mortality impacts are largest, but heat-induced hospitalizations are also large relative to other impacts.

Table 3. Summary of Health Impacts (millions 2022$)

Total losses across economic impact categories for seven extreme heat events.

Heat Event	Premature Mortality	Hospitalization	Emergency Department Visits	Outpatient Visits	Birth Outcomes
1. 2022 CA Coastal Inland	$2,200	$75	$8.0	$19	$6.7
2. 2021 Desert Lands	$77	$2.1	$0.2	$0.8	$0.20
3. 2019 NorCal Coastal	$210	$7.7	$1.1	$2.0	$0.75
4. 2018 SoCal Coastal	$610	$22	$2.7	$6.5	$2.1
5. 2017 CA Full Coastal	$1,300	$49	$5.2	$12	$4.5
6. 2017 Central Valley	$510	$18	$2.0	$5.5	$1.7
7. 2013 Eastern CA	$160	$5.4	$0.58	$1.7	$0.43

4.3.1 Premature Mortality

Key Findings

- Epidemiological literature provides strong evidence that extreme heat can result in premature death. Associated social costs can be in the billions of dollars per event.
- Health impacts are most pronounced in population centers.
- CDPH analysis of 2022 CA Coastal Inland event illustrates how results could be higher when considering statewide impacts (i.e., not only the areas deemed to be in a heat wave).
- The risks for workplace injury also larger for men versus women; for younger versus older workers; and are five times larger for workers at the lower end of the income distribution compared to highest income workers.

High ambient temperatures can interfere with the human body's ability to cool itself and maintain a reasonable internal temperature for short and long-term health. When these temperatures become extreme, severe acute and chronic health effects can result, including death. Humans can physiologically adapt over time to better tolerate higher temperatures within certain constraints and can also reduce risks through behavioral changes such as using cooling centers and increasing the availability of air conditioning. A review by Kinney (2018) finds that reported estimates of the effect of extreme heat on death in high-income countries have been declining over time; such a trend suggests that these adaptations may be having an effect. Nonetheless, studies that include California and quantify acclimatization, such as Lay et al. (2021)[1] and Rahman et al. (2022)[2], still find significant associations between extreme high temperatures and premature death, suggesting that these trends have not yet eliminated the risk. We report in this section costs of avoided mortality associated with our suite of extreme heat events, using a risk estimate from the Rahman et al. study that estimates the risks of all-cause mortality due to extreme heat in California from 2014 to 2019.

Table 4 below provides a summary of the overall premature mortality impacts and costs by event. The largest impacts are generally found in population centers, and the costs per event are mostly proportional to the person-days of exposure to extreme heat metric presented in Chapter 2 above.

A Note on Valuation of Health Effects

- Valuation of mortality is based on a value of statistical life (VSL) approach that is commonly used in environmental and health risk analyses, including those conducted by the California Air Resources Board and the South Coast Air Quality Management District. The VSL used in this study is $11.2 million (citation provided in main text).
- The VSL is not the value of any one individual's life; it is a population-wide estimate aggregated from the value individuals place on small changes in their risk of death, such as the incremental increases in all individuals' risk of death during an extreme heat event. By comparison, the average individual life insurance payout is about $150,000.
- Cost estimates for non-fatal outcomes are conservative. Beyond the immediate work loss associated with hospitalizations, these estimates do not consider impacts to worker productivity or quality of life, or long-term follow up costs for emergency department visits and hospitalizations.

Table 4. Premature Mortality Costs by Event

Total costs of attributable premature mortality (ages 0-99) for seven historical heat events, based on analysis derived from Rahman et al. (2022), including counts of attributable premature mortality for each event. Costs shown in 2022 dollars, representing willingness to pay to avoid premature death based on Robinson and Hammitt (2015).[3] See Table B2 for a detailed description of methods and data sources.

Heat Event	Total Costs	Number of Deaths
1. 2022 CA Coastal Inland	$2,200,000,000	200[*]
2. 2021 Desert Lands	$77,000,000	7
3. 2019 NorCal Coastal	$210,000,000	19
4. 2018 SoCal Coastal	$610,000,000	55
5. 2017 CA Full Coastal	$1,300,000,000	120
6. 2017 Central Valley	$510,000,000	45
7. 2013 Eastern CA	$160,000,000	14

In addition to estimating the population-wide costs of extreme heat events, this report considers how these adverse outcomes are experienced by different racial and ethnic groups and vulnerable populations. These impacts are influenced by three factors:

- Differences in exposure experienced by a population subgroup; for example, if a subpopulation tends to reside in areas with higher numbers of extreme heat days, that group will experience larger health impacts. There may be other factors as well that affect exposure, such as behavioral factors, but this analysis focuses on differences based on geographic location.

- Baseline health status; health risks of extreme heat are proportional to the baseline rates of mortality and morbidity in a population. All else equal, a subpopulation with higher rates of disease and death will experience larger impacts of extreme heat. Estimated rates of mortality by age, for example, is primarily driven by the increased baseline mortality rates of people 65 and older, since the heat impacts fall heavier on those with increased frailty. This analysis captures these differences by using race-and ethnicity-specific baseline health rates where available.

- Other subgroup-specific vulnerabilities; membership in a population subgroup may be associated with increased or decreased vulnerability to extreme heat relative to the average population risk. For example, elderly individuals tend to experience worse health outcomes from exposure to extreme heat than those of other age groups due to cardiac strain created by exposure to heat, while babies and young children sweat less than older people, limiting their body's ability to naturally cool.[4,5] Studies also examine the relationship between extreme temperature mortality and residence in an urban environment, poverty, identifying as a member of racial and ethnic groups including Black and African American and Hispanic and Latino individuals, suffering from social isolation, or working outdoors.[6,7,8,9,10] These differential sensitivities by age, race and ethnicity, and environment are apparent only in a small number of existing studies, most of which focus on localized events. While those studies add to our knowledge

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[*] The California Department of Public Health (CDPH) separately evaluated the mortality impacts of the 2022 Coastal Inland heat event in an August 2023 study and found a total mortality estimate approximately twice as large as the value we report here. Comparing CDPH's analytic methods with those of this report, we found that the two studies generally agree regarding the rate and risk of premature death resulting from high temperatures, but that the quantified mortality estimates were generated using different study designs. While the analytic choices made in each study are reasonable for its design, these differences contribute to the discrepancy in premature deaths. For example, when IEc conducted a sensitivity analysis to modify its geographic and temporal scope to better match the CDPH analysis, we were able to reduce the difference by half. We believe the remaining discrepancies relate to other methodological differences that we were unable to emulate, such as differences in the assumed baseline mortality rate. These differences help to illustrate the potential magnitude of uncertainty in our mortality estimates.

of differential sensitivity, they are less appropriate for the statewide analyses in this study. As a result, this analysis is not able to address the influence of this factor when presenting impact rates by subgroup.

Detailed population data by census tract and baseline incidence rates stratified by race and ethnicity allow us to assess premature mortality rates by demographic group, even without data on differential variability, as shown in **Table 5** below. Race- and ethnicity-specific mortality rates focus on differential exposures by census tract and differences in baseline health status only; combining these factors with data on differential vulnerability to extreme heat by population subgroup would further refine these differences; if initial findings in the literature are confirmed, we could expect differences across racial and ethnic groups to be even wider than shown. Table 5 also includes information on mortality rates by age for two groups, Age 0-64 and Age 65+. As noted above, differences in rates by age are primarily driven by the increased baseline mortality rates of people 65 and older, since the heat impacts fall heavier on those with increased frailty.

Table 5. Premature Mortality Rates Attributable to Extreme Heat per 1,000,000 by Race, Ethnicity, and Age

Rates of premature mortality per 1,000,000 (ages 0-99) for five race and ethnicity subpopulations, age-standardized to the total state population, and for two age groupings, for seven historical heat events. Based on analysis derived from Rahman et al. (2022). See Table B2 for a detailed description of methods and data sources.

Heat Event	Black	Asian	Native American	White Non-Hispanic	White Hispanic	Age 0-64	Age 65+
1. 2022 CA Coastal Inland	7.1	3.8	7.8	4.7	6.2	1.5	28.8
2. 2021 Desert Lands	5.3	2.5	4.9	3.4	5.0	1.4	21.5
3. 2019 NorCal Coastal	6.1	2.4	4.7	2.5	3.7	0.9	16.9
4. 2018 SoCal Coastal	5.2	2.1	4.5	2.6	3.6	0.8	16.3
5. 2017 CA Full Coastal	6.9	2.9	5.8	3.7	4.9	1.2	22.5
6. 2017 Central Valley	6.6	3.2	6.5	4.6	6.1	1.6	27.1
7. 2013 Eastern CA	5.8	3.0	4.8	3.7	5.6	1.4	24.7

Notes: For the Age 0-64 and Age 65+ results, differences across events are primarily driven by the event duration, with higher total mortality rates resulting from longer duration events. Differences in mortality rates by age group are primarily driven by the increased baseline mortality rates of people 65 and older, as heat impacts fall heavier on those with increased frailty.

The standardized mortality rates in **Table 5** show a consistent result across events – that Black, Native American, and White Hispanic mortality rates from extreme heat are higher than for Asian and White Non-Hispanic populations.[*] In some cases, the rates for overburdened groups are twice as high as for Asian and White Non-Hispanic groups, for example in the 2018 SoCal Coastal event, where the most intense heat was concentrated in the Southwest corner of the state (see **Figure 7** below, the fourth panel is the 2018 SoCal Coastal event).

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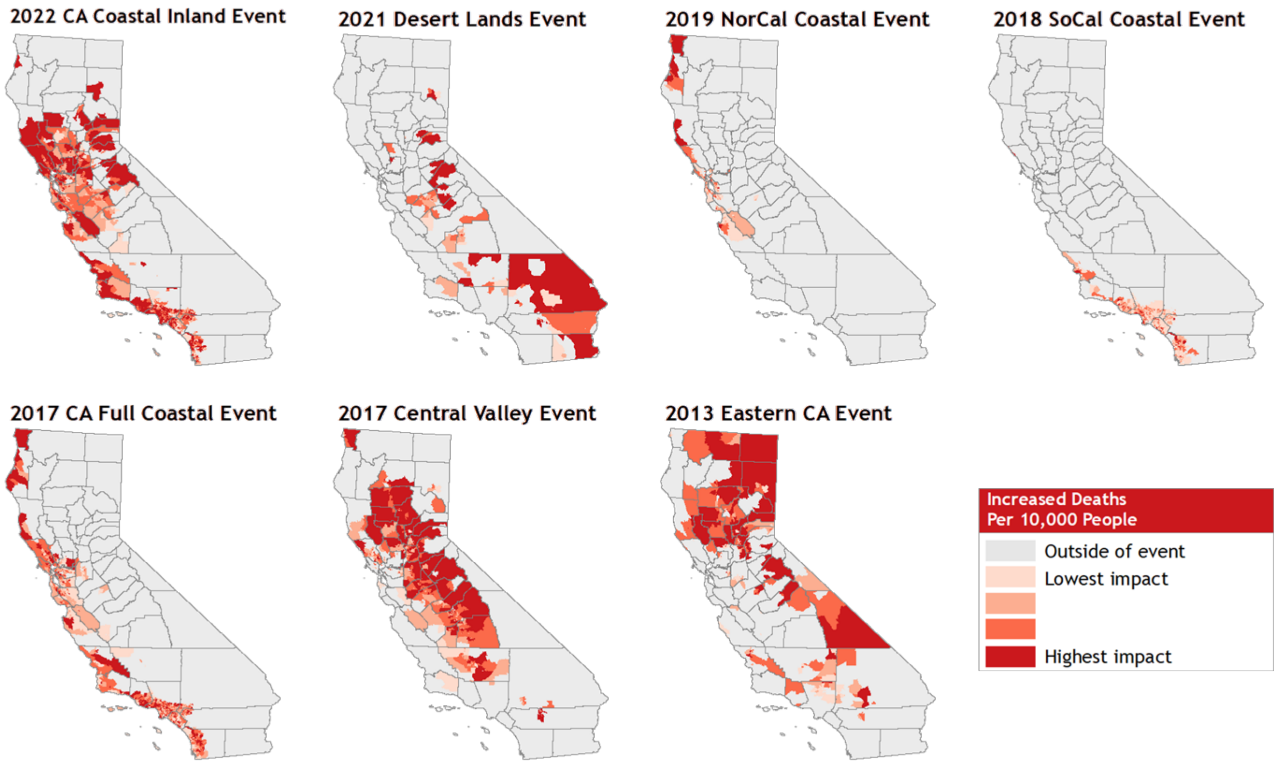
[*] Rates are standardized to remove the effect of differences in age distribution across groups on mortality rates. The standardized rates show that for an exposed population with the same age distribution the effects on certain subgroups would be expected to be greater given their higher levels of exposure to extreme heat and their worse baseline health status.

Figure 7. Premature Mortality Impacts Attributable to Extreme Heat by Census Tract and Event

Mortality impacts from Rahman et al. (2022) by Census tract for each event. All maps use the same legend to allow for comparison across events.



This type of differential exposure analysis can also be applied to assess differences in mortality incidence across other groups. For example, **Table 6** below provides a summary of differences in mortality rates for populations within and outside of California's SB535 environmental justice Census tracts. Because this analysis uses Census tract-specific mortality rates, the results reflect both differences in exposure to extreme heat across these two groups as well as differences in the baseline health of SB535 and non-SB535 communities.

Table 6. Premature Mortality rates per 1,000,000 by SB535 Designation

Rates of premature mortality per 1,000,000 (ages 0-99), age-standardized to the total state population, for seven historical heat events. Based on analysis derived from Rahman et al. (2022). See Table A1 for a detailed description of methods and data sources.

Heat Event	SB535 Census Tracts	Non-SB535 Census Tracts
1. 2022 CA Coastal Inland	7.1	5.5
2. 2021 Desert Lands	4.7	4.6
3. 2019 NorCal Coastal	4.0	3.4
4. 2018 SoCal Coastal	3.7	3.1
5. 2017 CA Full Coastal	5.4	4.3
6. 2017 Central Valley	6.7	5.3
7. 2013 Eastern CA	5.8	5.1

The results shown in **Table 6** show higher extreme heat mortality rates for populations in SB535 tracts for all events evaluated. Six of the events showed rates for SB535 tracts between 14 and to 30 percent higher, with most in the 20 to 30 percent range. The difference in rates is greatest for the events with the largest mortality impact. The event with the smallest difference between these groups is the Desert Lands event centered in Southeastern CA, where the population is much smaller and SB535 tracts are fewer in number.

The costs of mortality impacts stratified by population groups reflect both differences in exposure to extreme heat events across groups and differences in the baseline health of each group. The costs do not reflect evidence from the literature suggesting that different population subgroups may have higher or lower vulnerability to heat. Several published literature reviews highlight that studies of heat-related mortality tend to show higher risks for women than men.[11,12,13] Of particular note, a 2019 study by Son et al. found that out of 74 studies reviewed, half reported higher vulnerability of women to heat-related mortality compared to 12 that reported higher risks to men.[14] Future analyses of mortality impacts of extreme heat events should incorporate these findings and explore the impact across genders when reporting costs stratified by population subgroup.

4.3.2 Hospitalizations and Emergency Department Visits

Key Findings

- Extreme heat events lead to increased hospitalizations and emergency department (ED) visits for a variety of heat-related conditions, including kidney failure, respiratory ailments, mental health, and stroke. Increases have been observed for both adults and children during these events.
- In total, over 5,000 hospitalizations and nearly 10,600 ED visits are associated with the episodes of extreme heat evaluated in this study, with hospitalizations ranging from 60 to 2,132 across events and ED visits ranging from 126 to 4,280.
- For the largest extreme heat event the majority of both hospitalizations and ED visits involved non-white, non-Hispanic residents. Fewer than 30 percent of those affected had private insurance (less than 17 percent for hospitalizations) and Medi-cal and Medicare comprise between 60 and 79 percent of these patients.

Extreme heat events also result in increases in hospitalizations and emergency department (ED) visits, as dehydration and other heat-induced changes to the body's systems can result in significant illness. For example, Schwarz et al. (2021) and found that respiratory hospitalizations in California increased with extreme heat, and Sherbakov et al., (2018) found extreme heat led to significant increases in hospitalizations of Californians for stroke, renal failure, and mental health issues.[15] Heat can make it more difficult to breathe by constricting airways in people with asthma, contributes to inflammation and other changes that increase stroke risk, and puts strain on the kidneys due to dehydration.[16,17,18] Patients with existing mental illness may have difficulty recognizing dangerous conditions posed by heat conditions.

Heat's effects on children can also lead to health emergencies; for example, Bernstein et al. (2022) identified a relationship between historical daily maximum temperature and children's hospital emergency department visits.[19] Authors found that emergency department visits for all diagnoses increased in response to increased temperatures.

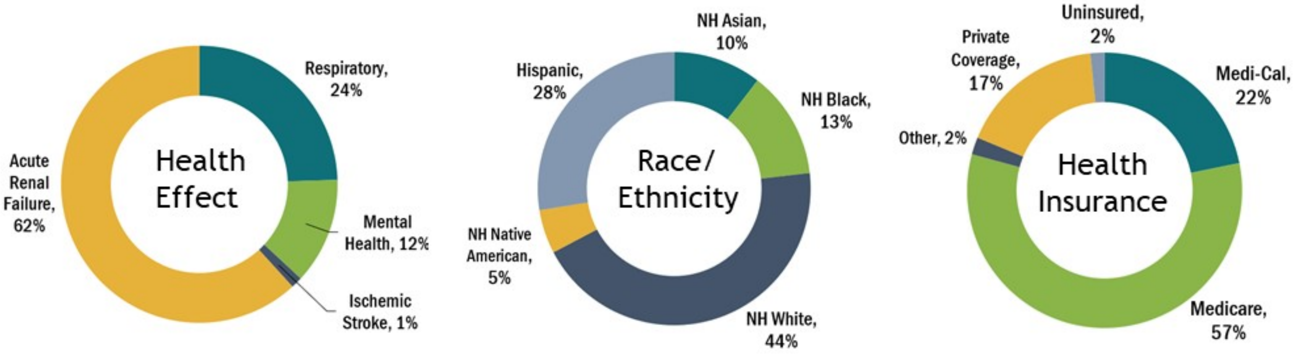
We report in this section the costs of non-fatal health effects associated with our suite of extreme heat events, using risk estimates from the Sherbakov et al, Schwarz et al., and Bernstein et al. studies. We estimate the costs of these avoided hospitalizations and ED visits using California-specific data on the costs of these services for the associated diagnoses, as well as the work loss associated with the duration of inpatient admissions. The bulk of these costs are insured through an array of health insurance options, including public and private plans.

According to the California Health Interview Survey, 93.7 percent of Californians were insured in 2021.[*] Insurance rates vary by county and important demographic characteristics, such as age, income, and employment status. Health insurance plans include private coverage (54.3 percent) and public options such as Medicare (16.4 percent) and Medi-Cal (22.3 percent). Importantly, insured individuals may still experience out-of-pocket expenses associated with medical care, such as copays, deductibles, and services not covered by insurance. Separate insurance products are available for work loss, including short- and long-term disability.

Figure 8 below summarizes three dimensions of the overall hospitalization cost impacts for the event with the largest impacts - the 2022 CA Coastal Inland event (other events have mostly similar patterns). The left panel shows relative numbers of hospitalizations for each of the heat-attributable effects evaluated in this analysis - most of the hospitalization and ED visits are for acute renal failure.

Figure 8. Distribution of Hospitalization Outcomes by Effect Type, Race and Ethnicity, and Health Insurance Coverage for the 2022 CA Coastal Inland Event

Estimates of the distribution of impact estimates, in cases, based on three studies of different types of hospitalizations associated with extreme heat. Race/ethnicity and health insurance status are based on county-specific incidence data. Results are for the 2022 CA Coastal Inland Event, which has the highest impact. See Table B3 for a detailed description of methods and data sources.



The center and right panels make use of specific individual incidence data, so reflect the combined effect of sensitivity and exposure on racial and ethnic groups, and for insurance types. The center panel shows incidence among subpopulations – more than half the incidence occurred for over-burdened groups, that is, Native American, Hispanic, Asian, and Black populations, combined. The right panel shows the distribution of incidence among insurance types. Only a small portion of the total hospitalized (17 percent) had private insurance coverage, much lower than the overall private insurance rates throughout the state; most of those hospitalized had either Medicare (57 percent) or Medi-Cal (22 percent).

Figure 9 below shows similar distributional data for emergency department visits for the heat-attributable health effects evaluated in this analysis, also for the 2022 CA Coastal Inland event. The costs of ED visits are roughly equally distributed among adult mental health and child all-cause ED visit categories. The race and ethnicity and health insurance distributions show similar results as seen for hospitalizations, but with a greater tilt toward Medi-Cal vs Medicare public insurance – likely because of incidence among young populations captures by the 0-18 years ED visit study.

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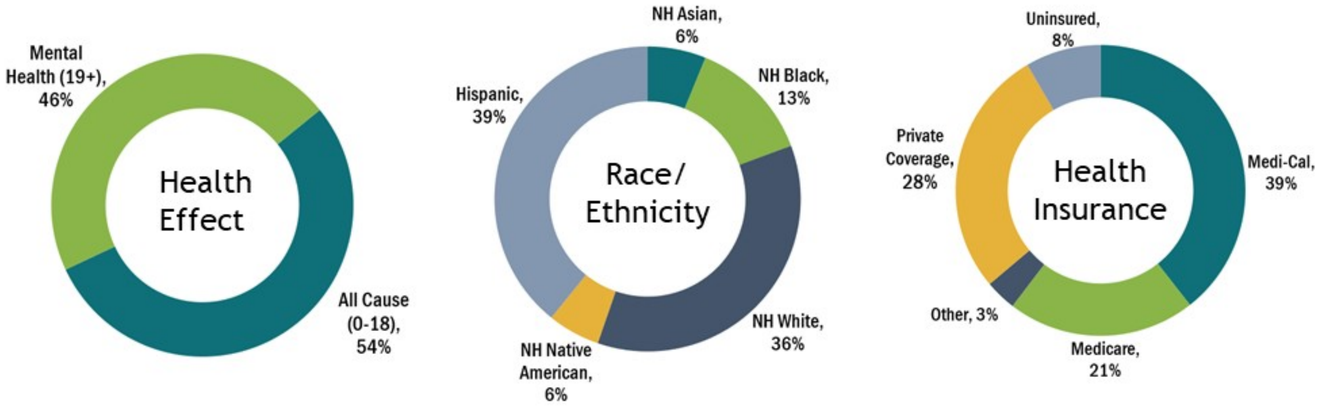
[*] See https://healthpolicy.ucla.edu/our-work/california-health-interview-survey-chis

Figure 9. Distribution of Emergency Department Visit Outcomes by Effect Type, Race and Ethnicity, and Health Insurance Coverage for the 2022 CA Coastal Inland Event

Estimates of the distribution of impact estimates, in cases, based on three studies of different types of emergency department visits associated with extreme heat. Race/ethnicity and health insurance status are based on county-specific incidence data. Results are for the 2022 CA Coastal Inland Event, which has the highest impact. See Table B4 for a detailed description of methods and data sources.



4.3.3 Outpatient Visits

Key Findings

- In total, over 138,000 outpatient visits are associated with the episodes of extreme heat evaluated in this study based on Medi-Cal and MediCare claims, ranging from 2,400 to 55,000 visits across events.
- The largest number of visits and costs are associated with the 2022 CA Coastal Inland and the 2017 CA Full Coastal events, each of which resulted in tens of thousands of excess outpatient visits, over and above the baseline number of visits, and more than $10 million in excess medical costs.
- Across all seven events there is a disproportionate share of outpatient visits for Black, non-Hispanic residents compared to the share in the state population, between less than 1 percent higher to nearly 10 percent higher.

Some people may suffer from heat-related ailments for which they seek treatment in an outpatient setting, such as a doctor’s office or health clinic, rather than a hospital. We expect that the impact on these types of health consultations would mirror that of hospitalizations and emergency department visits; however, studies of the effect of extreme heat events on these outpatient visits are extremely limited. One study of heat event-related outpatient visits that analyzed four years of data in the University of California, San Diego family medicine clinic system found that outpatient visits occurring during a heat wave could be over 30 percent more likely to feature a heat-related diagnosis.[20] However, the authors noted that these results are uncertain and could not confirm an association. More work is needed across broader geographic areas to confirm this association; nonetheless we conducted an exploratory calculation of the potential number of outpatient visits in our events that would be associated with an effect of this magnitude to illustrate the potential costs. **Table 7** below summarizes the results for outpatient visits by event. The largest number of visits and costs are associated with the 2022 CA Coastal Inland and the 2017 CA Full Coastal events, each of which resulted in tens of thousands of excess outpatient visits, over and above the baseline number of visits, and more than $10 million in excess medical costs. Because the data used to estimate these costs are from Medi-Cal and MediCare claims, and therefore omit outpatient visits among individuals with private or no health insurance, the estimated number of visits and costs likely underestimate the total incurred during those events. The total incidence of these visits, reflecting less serious heat-related illness and injuries than the hospital admissions and emergency department visits reported in the previous section of this chapter, is nonetheless approximately 10 times higher than the per-event incidence of emergency department visits, and 20 times larger than the incidence of hospitalizations. The cost per visit is much lower, however, at about $350 per outpatient visit. Combined, the total heat-related incidence of illness and injury during these events affected many thousands of Californians.

Table 7. Outpatient Visits by Event

Total costs of attributable outpatient visits for seven historical heat events, including counts of attributable visits for each event. Costs shown in 2022$, representing cost of illness estimates derived from published literature. See Table B5 for a detailed description of methods and data sources.

Heat Event	Total Costs	Total Number of Outpatient Visits
1. 2022 CA Coastal Inland	$19,000,000	55,000
2. 2021 Desert Lands	$810,000	2,400
3. 2019 NorCal Coastal	$2,000,000	5,900
4. 2018 SoCal Coastal	$6,500,000	19,000
5. 2017 CA Full Coastal	$12,000,000	35,000
6. 2017 Central Valley	$5,500,000	16,000
7. 2013 Eastern CA	$1,700,000	4,900

The incidence of outpatient visits among racial and ethnic groups varies substantially by event. As shown in **Table 8** for all seven events there is a disproportionate share of outpatient visits for Black, non-Hispanic residents compared to the share in the state population, between less than 1 percent higher to nearly 10 percent higher. The 2019 NorCal Coastal event shows the highest disproportionate impact for Black and Asian groups. Across all events, impacts are lower than the state average share of population for Hispanic residents. For other groups, the results vary considerably by event, compared to the representation of those groups in the overall state population.

Table 8. Incidence Shares for Outpatient Visits Among Racial and Ethnic Groups

Share of outpatient visit incidence among five sub-populations for seven historical heat events, compared to the percent of 2022 statewide population shares. Dots to the right of the center line show a higher share of incidence for that subpopulation than the group's representation in the state population, suggesting a disproportionately high impact for that group, for the event. Dots to the left of the center line show less than proportionate impacts for that group, in that event. See Table B5 for a detailed description of methods and data sources.

Heat Event	Black	Asian	Native American	White Non-Hispanic	All Hispanic
1. 2022 CA Coastal Inland	12%	18%	0.5%	31%	38%
2. 2021 Desert Lands	6%	5%	0.9%	45%	43%
3. 2019 NorCal Coastal	16%	30%	0.7%	31%	22%
4. 2018 SoCal Coastal	12%	17%	0.3%	30%	41%
5. 2017 CA Full Coastal	12%	19%	0.5%	32%	37%
6. 2017 Central Valley	9%	11%	1.2%	46%	33%
7. 2013 Eastern CA	7%	7%	2.1%	67%	17%
Percent of 2022 Statewide Population	6%	16%	0.4%	36%	42%

4.3.4 Birth-Related Outcomes

Key Findings

- Extreme heat is linked with several adverse birth-related outcomes, including gestational diabetes for expectant mothers, preterm births and cases of low birth weight for newborns, and stillbirths.
- In total, 344 cases of adverse pregnancy- or birth related outcomes are associated with the extreme heat events studied, with roughly equal numbers of gestational diabetes cases and adverse birth outcomes.
- The associated medical expenditures for these additional birth-related outcomes range from $200,000 to $6,700,000 per event.
- These costs are paid for by a mix of private and public health insurance plans, as well as out-of-pocket expenditures.

Extreme heat events also increase the incidence of health effects related to pregnancy and childbirth. Cost of illness estimates are limited for this outcome, and we emphasize that the welfare losses—including significant physical and emotional pain—from this particular outcome are likely to far exceed any medical expenditures incurred as part of a stillbirth. Several studies of California health data show that extreme heat can result in increases in pre-term births (i.e., delivery before 37 weeks)[*,21,22,23] those pertaining to childbirth. A fourth study, also conducted in California found that the incidence of gestational diabetes during pregnancy was higher among mothers who experience extreme heat event, potentially related to heat induced changes in insulin sensitivity and changes in blood sugar levels.[24]

The unit costs employed for this analysis are cost of illness estimates that reflect the incremental cost of medical treatment beyond those anticipated for a baseline birth. At the present time, we do not incorporate estimates for the stillbirth cases quantified in **Table 9**.

Table 9. Birth-Related Outcomes by Event

Total costs of attributable birth-related outcomes (among women ages 16-49) for seven historical heat events, including counts of attributable cases of quantified birth-related outcomes for each event. Costs shown in 2022$, representing cost of illness estimates derived from published literature. Cases of stillbirths are not valued due to lack of information in the literature. See Table B6 for a detailed description of methods and data sources.

Heat Event	Total Costs	Cases of Low Birth Weight	Cases of Preterm Birth	Cases of Gestational Diabetes	Cases of Stillbirth
1. 2022 CA Coastal Inland	$6,700,000	24	41	70	6.1
2. 2021 Desert Lands	$200,000	0.5	1.6	2.0	0.1
3. 2019 NorCal Coastal	$750,000	3.3	3.6	9.1	0.8
4. 2018 SoCal Coastal	$2,100,000	7.8	12	20	2.0
5. 2017 CA Full Coastal	$4,500,000	16	28	46	4.0
6. 2017 Central Valley	$1,700,000	5.4	11	17	1.2
7. 2013 Eastern CA	$430,000	1.3	3.1	5.4	0.3

In total, we estimate hundreds of adverse birth-related outcomes attributable to the seven extreme heat events. The additional medical expenditures resulting from these events range from $200,000 to $6,700,000. Gestational diabetes cases were the most prevalent outcome resulting from extreme heat, with up to 70 cases attributable to one event (the 2022 CA Coastal Inland event). In addition, the event resulted in 41 preterm births, 24 cases of

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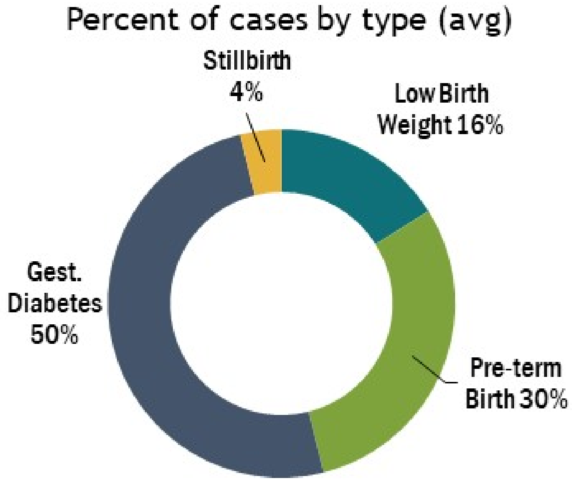
[*] We note that while low birth weight is more common among preterm deliveries, the definitions employed in this analysis do not overlap. Rather, low birth weight cases reflect full-term births in which the infant is born weighing less than 2,500 grams.

low birth weight, and 6 stillbirths. The distribution of birth-related outcomes by type, averaged across events, is shown in **Figure 10** below.

Figure 10. Distribution of Birth-Related Outcomes Averaged Across Events

Estimates of the distribution of impact estimates, in cases, based on studies of birth outcomes associated with extreme heat cited in main text. Results are averaged across the seven events studies. See Table A2 for a detailed description of methods and data sources.



4.3.5 Workplace Injuries

Key Findings

- ► Extreme heat events lead to workplace injuries that are directly attributable to heat, for example heat exhaustion, and indirectly associated injuries, such as incidents that result from heat-impaired cognitive function. Both types are captured by the approach used here – but data are not sufficient to attribute risks to individual events.
- ► Roughly 20,000 workplace injuries per year are associated with episodes of extreme heat above optimal workplace temperatures. This rate is 19 times higher than the number medically coded for heat exposure.
- ► The risks are also larger for men versus women; for younger versus older workers; and are five times larger for workers at the lower end of the income distribution compared to highest income workers.

Beyond health, safety is also an issue, especially in workplaces, where non-fatal injuries occur more frequently on hot days. California's Worker's Compensation System (CWPS) tracks workplace injuries, including those most commonly and directly associated with extreme heat, such as heat stroke. A recent study finds that approximately 360,000 injuries in California over the period 2001 to 2018, or roughly 20,000 per year relative to a hypothetical baseline of optimal workplace temperatures, are associated with episodes of extreme heat.[25] The rate estimated in this study is at least nineteen times larger than the number that are medically coded for heat exposure within the CWPS. The microdata used in this study is, unfortunately, not available for wider use, preventing a detailed quantitative analysis of workplace injuries for our selected seven events.[*]

These effects were noted in both outdoor and indoor settings (e.g., manufacturing, warehousing), and for injury types ostensibly unrelated to temperature (e.g., falling from heights) – the authors suggest that extreme

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[*] In general, publicly available measures of workplace safety tend to either be highly aggregated (e.g., by industry or state), and/or feature high reporting thresholds (e.g., only including very serious incidents such as the death of a worker or hospitalization of three or more workers) – data of that sort is not suitable for our analysis.

workplace heat may affect worker cognitive processes, leading to higher rates of injury. The risks are also larger for men versus women; for younger versus older workers (potentially because younger workers may work in riskier settings); and are five times larger for workers at the lower end of the income distribution compared to highest income workers, suggesting that workplace heat exposure has a disproportionately large effect on already overburdened populations.

The study also provides evidence of significant adaptation potential for this effect in the workplace. The effect of temperature on injuries was found to fall significantly during the 2001 to 2018 study period. For instance, the effect of a day above 90ºF falls by roughly a third between 2001 and 2018, and the effect of days above 100ºF is effectively zero after 2005. As a possible reason for this decline, the authors point to the impact of the nation's first heat safety mandate, the California Heat Illness Prevention Standard (Q3 2005), which applied to outdoor workplaces and required employers to invest in employee training, shade structures, and free water and paid rest breaks on days with temperatures above 95ºF.

The workplace injuries reported in the CWPS would, by definition, be covered events under Worker's Compensation law, so the insurance gap is likely small. While there is anecdotal and other information suggesting underreporting of workplace injuries in general, as well as underestimation and lack of recognition of heat-related illnesses, there currently is not a good estimate of the degree of under-reporting.[26] Some categories of workers, particularly undocumented persons or those working in informal settings, are likely omitted from these statistics and may represent an insurance gap.

4.4 Economy Impacts

Extreme heat events have the potential to reduce economic output across a broad range of sectors with exposure to high temperatures and humidity. This report estimates impacts to dairy and crop agriculture; industry productivity losses and dairy cow mortality; manufacturing productivity losses due to indoor places of work lacking air conditioning; reductions in time spent working in weather-exposed industries (monetized using lost wages); and business revenue losses due to consumers altering their behavior to avoid extreme heat conditions.

The Federal government is a primary insurer of losses in both dairy and crop agriculture, although gaps remain in coverage for extreme heat-driven losses, in particular for the specialty crops (e.g., grapes, almonds, and lettuce, among others) that make up the largest portion of California's agricultural economy.* For losses in other sectors, private insurers are the only option, although policies often do not cover heat as a peril except in certain instances (e.g., construction delay insurance). Data documenting private insurance coverage is typically unavailable, so we rely on guidance from experts in the insurance industry to illustrate the insurance gap for these cost measures.

The largest impacts in this sector occurred mostly for the most spatially extensive events, but there are some exceptions. For example, the crop productivity losses are highest for the 2021 Desert Lands event because the most intense effects were seen in areas of high agriculture productivity density.

Economy Key Findings

- Across all included measures, losses to the manufacturing sector are the largest in magnitude, although estimates are subject to measurement error and uncertainty.
- The 2022 Coastal Inland event has the largest cost across the combined included metrics. However, losses to dairy productivity and dairy cow mortality are highest during the 2017 Central Valley event given significant overlap in the area of impact with major agricultural regions.
- Revenue shortfalls resulting from changes in consumer behavior on high heat days are unquantified due to lack of statistical evidence on this topic.
- Impacts on sensitive or vulnerable subpopulations are not quantified – but available literature suggests that reductions in labor hours during extreme heat fall disproportionately among low-income populations.
- Insurance coverage for many crop losses is available through Federal crop insurance, but gaps exist for high-value specialty crops which dominate California agriculture, and for organic farmers. Coverage for losses in other categories of impact is largely unavailable.

Table 10. Summary of Economic Impacts

Total losses across economic impact categories for seven extreme heat events. See Tables B7 to B11 for details on methods and data used.

Heat Event	Dairy Productivity	Dairy Cow Mortality	Crop Productivity	Manufacturing Productivity	Reduced Work Time in Weather-Exposed Industries
1. 2022 CA Coastal Inland	$17,000,000	$330,000	$72,000,000	$310,000,000	$210,000,000
2. 2021 Desert Lands	$13,000,000	$280,000	$110,000,000	$2,600,000	$7,300,000
3. 2019 NorCal Coastal	$210,000	$4,100	$630,000	$74,000,000	$12,000,000
4. 2018 SoCal Coastal	$1,100,000	$61,000	$49,000,000	$84,000,000	$81,000,000
5. 2017 CA Full Coastal	$3,300,000	$1,100,000	$14,000,000	$230,000,000	$140,000,000
6. 2017 Central Valley	$52,000,000	$1,100,000	$58,000,000	$35,000,000	$59,000,000
7. 2013 Eastern CA	$2,500,000	$52,000	$17,000,000	$7,100,000	$18,000,000

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[*] See https://www.cdfa.ca.gov/Statistics/

4.4.1 Dairy Productivity

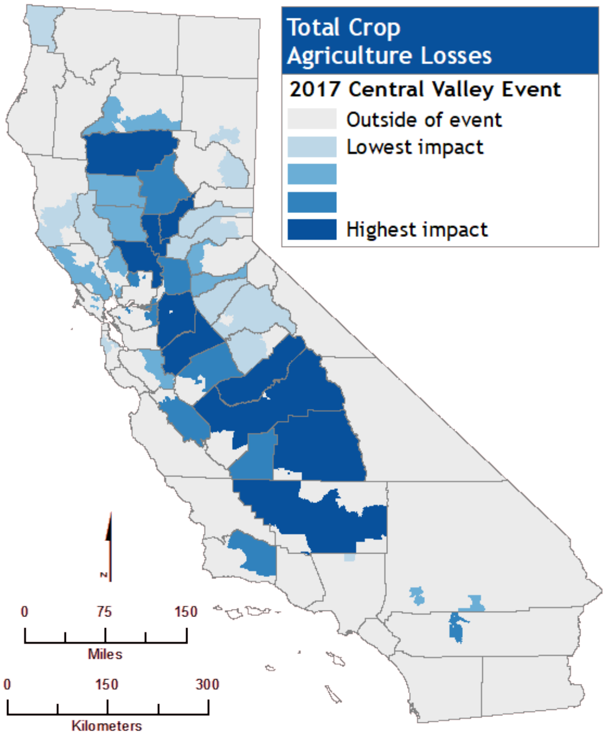
Key Findings

- Extreme heat events reduce dairy milk production beyond typical summer shortfalls, resulting in revenue losses to the dairy sector.
- The total lost dairy milk revenue ranges from $170,000 to $44 million across the seven events. The event with the highest losses was the 2017 Central Valley Event, given the concentration of dairy farmers affected.
- Since 2018, milk producers have the option of insuring against revenue losses (for heat and other causes) through the USDA's Dairy Revenue Protection Program. Private insurance options are limited, and uptake is thought to be low.

The dairy sector sees its lowest production in the summer months due to the biological response of lactating cows to warmer conditions. Extreme heat events exacerbate these shortages, resulting in revenue losses to the dairy sector. To estimate this effect, we employ a methodology from existing literature which offers a statistical relationship between air temperature, humidity, and dairy productivity losses.[27] Because production declines in typical summer conditions, we measure losses over and above shortfalls experienced on summer days with average temperatures. Production shortfalls are monetized using producer prices of milk.[*]

The heat event with the largest losses in milk production was the June 2017 Central Valley event, the worst event for this agricultural region, with milk production shortfalls around 130 million kg, equivalent to $44 million in producer revenue. Relative to the typical production volume across 11 days, this heat event resulted in losses of approximately 25 percent of total milk volume. The 2022 Coastal Inland event and 2021 Desert Lands events both resulted in losses above 5 percent of statewide volume during the event. All other heat events were concentrated in areas with fewer dairy farms and therefore lower estimated losses (see **Table 10** for a full reporting of costs by events).

Figure 11. Dairy Production Losses by County: 2017 Central Valley Event



California is the largest dairy producer in the U.S., and the broader dairy industry also includes producers of products that use milk as an input (e.g., yogurt companies). The estimates we present only consider primary milk producers, meaning losses to the downstream industry have the potential to increase the total estimated costs to industry reliant on milk as an input.

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[*] Restricted milk supply has the potential to drive up dairy prices. Our estimates do not account for price volatility, in part because the milk market is highly regulated, and it would be challenging to link individual heat events with changes in milk prices. Therefore, if prices increased during these events, then we under-estimate total revenue losses to milk producers. Increases in milk prices attributed to heat events may also harm milk consumers by reducing consumer surplus.

Since 2018, milk producers have the option of insuring against revenue losses (for heat and other causes) through the USDA's Dairy Revenue Protection Program. As with Federal crop insurance, premiums are subsidized. Private insurance options are limited, but do exist, and may be integrated with broader herd health monitoring and insurance systems[*] – but uptake is thought to be very low.[†]

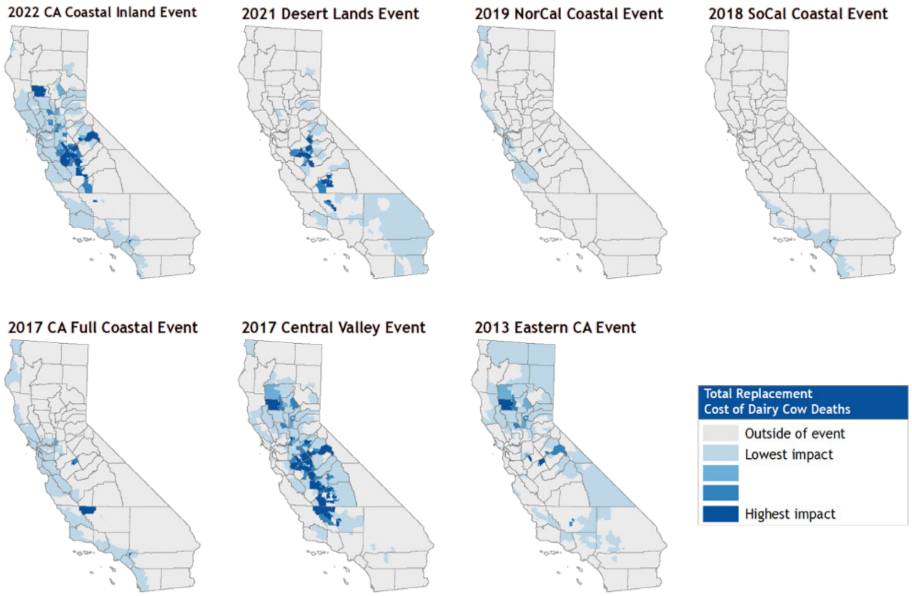
4.4.2 Dairy Cow Mortality

Key Findings

- Heat stress kills cows during the summer months, and even more so during the most extreme temperatures and humidity levels, particularly if current adaptation mechanisms are not calibrated to the hottest days.
- The total replacement cost of dairy cows lost due to extreme heat events ranges from $4,100 to $1.1 million across the seven events. The event with the highest losses was the 2017 Central Valley Event given the concentration of dairy farms in the areas affected during this event.
- Farmers have private options for insuring against dairy cow losses, although heat may not be listed as a covered peril on specific policies.

In addition to reduced dairy productivity, heat stress also kills dairy cows, reducing both immediate and long-term economic output. St.-Pierre et al. also offers a relationship between temperature, humidity, and excess dairy cow deaths.[28] We value these losses in terms of the replacement cost of the cow, a financial cost experienced by farmers.[‡] Other livestock are sensitive to heat as well, including pigs, poultry, and other common livestock. We, however, focus on cow mortality given the dominance of dairy production in California.

Figure 12. Total Cost of Dairy Cow Replacement by Event and County



As with productivity losses, the heat event with the highest dairy cow mortality was the 2017 Central Valley event, with an excess of 360 dairy cow deaths beyond typical summer levels.[§] Considering the cost to replace these lost cows, we estimate these financial losses to be about $1.1 million to farmers. Dairy cow mortality was significantly lower during the other heat events. Across all heat events, the number of cows lost was

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[*] https://www.scor.com/en/news/launch-heat-stress-protect-insurance-protect-dairy-income-climate-change#:~:text=SCOR%20has%20entered%20a%20partnership,losses%20due%20to%20heat%20waves

[†] Call with Janet Ruiz of the Insurance Information Institute (III) on November 14, 2023.

[‡] This monetization approach differs from our approach to human mortality, which relies on the value per statistical life to value lost human lives.

[§] News outlets described approximately 4,000 to 6,000 lost cows during this event (for example: https://www.cbsnews.com/news/cow-carcasses-pile-up-in-california-as-heat-wave-causes-mass-death/). If we add the baseline losses we estimate, meaning the number of cows lost on typical hot days, then our estimate is close to 6,000 for this event.

significantly less than 1 percent of the total statewide milk cow herd size (approximately 1.7 million in 2022), but the losses are nonetheless significant for a single event.

Livestock mortality is not covered by existing government insurance programs. Instead, farmers have two private options for insuring against dairy cow losses. One is to cover medical costs or mortality of cows specifically. A second option is to include cows like any other type of farm capital through liability coverage. An expert familiar with the industry estimates that approximately 75 percent of dairy cows in California may be covered by one of these options.[*] However, specific policies must include heat as a peril to compensate farmers for losses stemming from extreme heat. Data are not publicly available that document insurance coverage for these losses.

4.4.3 Crop Agriculture Productivity

Key Findings

- ► Heat affects all crops differently and has the potential to reduce yields and degrade crop quality. Quantitative studies linking extreme heat with production outcomes for crops dominant in California are not available.
- ► Using insurance claims data, we estimate that crop agriculture losses range from $630,000 to $110 million across the heat events, although the data underlying these estimates is imperfect for our purposes and do not subtract baseline expected losses.
- ► The FCIP covers farmer productivity losses stemming from heat and other causes, and approximately 50 percent of cropland in California is covered by the program.

Extreme heat exposure can also inhibit the productivity and quality of crop agriculture production by stressing plants and stunting development.[29] However, unlike dairy production, the effects may be less obvious in the short term given that crops mature over the course of a season and losses may not be realized until harvest time. Because many things may impact the quantity and quality of crop production over the course of a season, attributing agricultural losses to specific heat events is challenging. While researchers have documented the impacts of extreme heat on crops like corn, cotton, and soy grown in other parts of the United States,[30] related studies for crops more relevant to California – like horticulture and orchard crops – do not exist. Even if such a study was available for one dominant California crop, the vast heterogeneity in preferred growing conditions across crops would make transferability to other crops a challenge.

In the absence of these studies, we take a "bottom up" accounting approach to estimating total losses, starting with publicly available Federal Crop Insurance Program (FCIP) payout data through USDA's Ag Viewer. From all available claims, we select those with loss causes specific to "heat" and "irrigation failure" for county/month/year combinations matching the heat events in our study set.[†] We then use information on the percent of cropland insured by crop type to estimate losses on uninsured cropland not captured in the data.

Unlike the dairy categories, we find that the event with the largest estimated losses is the 2021 Desert Lands event, with $58 million in reported insured losses from which we estimate roughly $110 million in total losses across insured and uninsured cropland (see **Figure 13** for a map of the highest intensity of impacts). The 2017 Central Valley event, by contrast, is associated with $33 million in reported insured losses and $58 million in total losses. These somewhat counter-intuitive results underscore the challenges of relying on insurance claims

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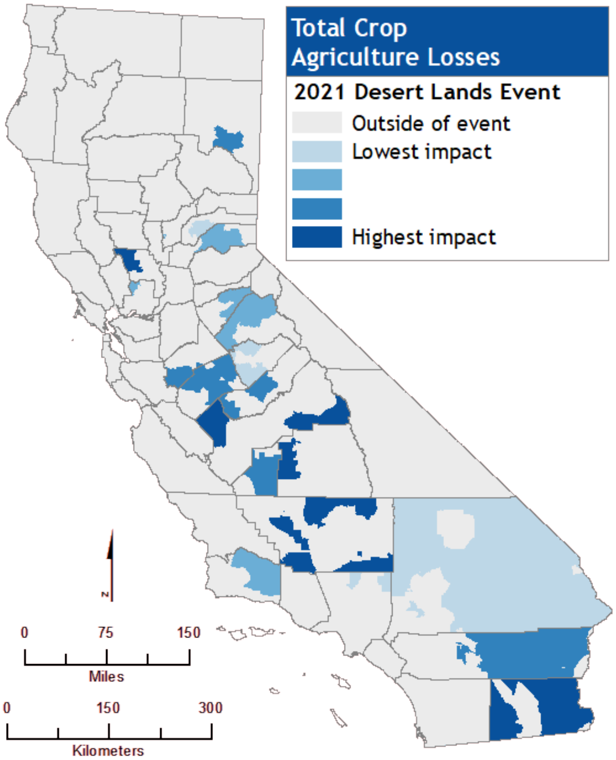
[*] Call with Scott Barhorst of AON on October 31, 2023.

[†] The effects of heat can be partially mitigated through irrigation. Lauren Parker of USDA's California Climate Hub suggested we include claims for "irrigation failure" because it typically signals heat would have been the driver of loss absent irrigation (call on September 5, 2023). Other research using USDA's Ag Viewer data for California shows that indemnity payments tagged as "heat" related are several times more common than those tagged with "irrigation failure" (Lobell, D. B., Torney, A., & Field, C. B. (2011). Climate extremes in California agriculture. *Climatic Change*, *109*, 355-363.)

data to estimate losses associated with specific heat events. First, the available FCIP data has limited temporal and spatial refinement, which is why we pull data by county and month, whereas there may be days within months and areas within counties not covered by our chosen heat events. Second, we are unable to accurately subtract "baseline" losses using insurance claims data given the substantial variability in losses across time and space. This is an important limitation because it is well documented that rising temperatures in general are associated with increases in U.S. crop agriculture losses,[31] and our approach is unable to separate general warming trends from the extreme heat events. Finally, existing evidence demonstrates that losses from extreme heat are higher on insured cropland than uninsured cropland,[32] suggesting that insured producers do not have adequate incentives to adapt to extreme heat conditions and that our approach may overestimate losses for uninsured cropland as a result. As described in Chapter 5 below, there also appears to be poor coverage and/or uptake for organically farmed croplands, because the Federal crop insurance system requires standardized farming practices, proven to achieve a threshold level of crop yield, to be implemented and documented in order to support coverage and claims.

Figure 13. Total Crop Losses: 2021 Desert Lands Event



We estimate that nearly half of all cropland in heat event-affected areas of California are insured through the FCIP. According to the 2017 Census of Agriculture, approximately 26 percent of all farms in the U.S. with cropland acres in that year were insured by FCIP, although the same statistic for California farms was not readily available.[*] Data from the USDA's Economic Research Service shows that some vegetable crops are not covered by FCIP – including watermelon, lettuce, and squash – in particular the types of crops more likely to be found in California than other states.[†] Agricultural producers are unlikely to seek private insurance options given the scale of FCIP.[‡]

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[*] Congressional Research Service. (2021). "Federal Crop Insurance: A Primer." February 18, 2021. Available at: https://crsreports.congress.gov/product/pdf/R/R46686

[†] USDA Economic Research Service. "Share of insured acres varies widely across vegetable and pulse crops." Last updated March 6, 2023. Available at: https://www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=105971

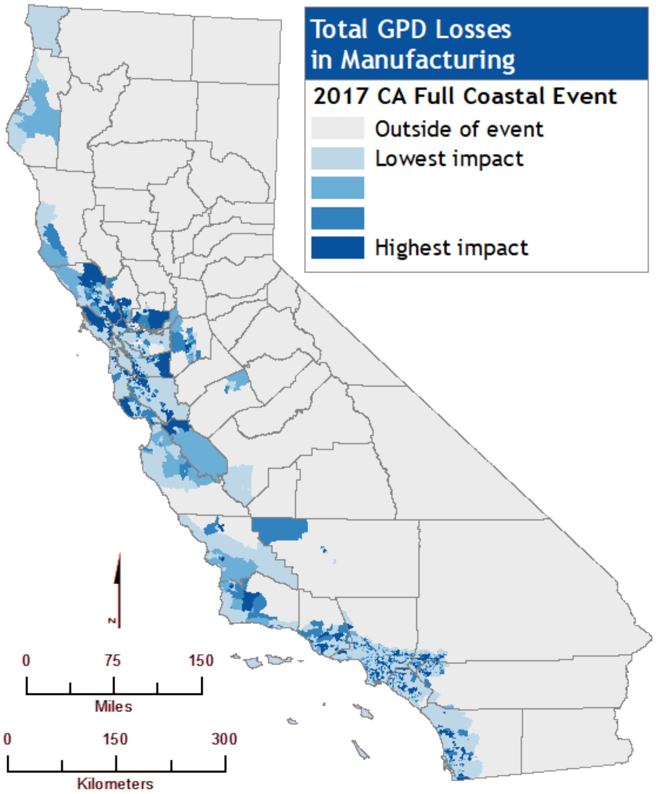
[‡] Call with Scott Barhorst of AON on October 31, 2023.

4.4.4 Manufacturing Productivity

Key Findings

- Manufacturing output decreases during extreme heat events given the lack of air conditioning in many facilities and the effects of high temperatures on human and physical capital.
- This study estimates reductions in manufacturing output ranging from $2.6 million to $310 million per heat event, with the highest losses experienced during the 2022 Coastal Inland event.
- Any insurance policies maintained by manufacturing entities are unlikely to cover heat as a peril.

Figure 14. Total Manufacturing GDP Losses: 2017 CA Full Coastal Event



Manufacturing is one of the non-agricultural industries known to suffer productivity losses from high heat conditions given that many of these indoor environments lack adequate air conditioning. Productivity suffers because workers experience cognitive deprivation, may need to take more breaks, or may not show up for work when conditions are unpleasant. Physical capital in these facilities can also be sensitive to the climatic environment, and some machines are more likely to malfunction during extreme heat events. Managers of these facilities may intentionally slow the pace of production to account for these multiple effects.

While there are many studies looking at the relationship between temperature and manufacturing output, only one – to our knowledge – uses data exclusively from manufacturing plants in the United States (including a data point for California) and is specific to extreme heat events (as opposed to warming in general). Cachon et al. (2012) isolates the effects of heat on the output of automobile manufacturing plants, which we extrapolate to all manufacturing types in California. To make our results specific to manufacturing facilities without air conditioning, we scale our estimated losses using available data on the portion of all manufacturing facilities without HVAC systems. The dearth of available data on facility-specific air conditioning investments and output levels limits the precision of our estimates, particularly given evidence demonstrating how the most productive manufacturing firms are most likely to adopt air conditioning given the known productivity losses associated with heat.

Table 11 summarizes the results of our analysis. Across heat events, we estimate output losses to the manufacturing sector lacking air conditioning on the order of $2.6 million to $310 million per event. The 2022 Coastal Inland event and 2017 CA Full Coastal event tally the largest losses, equivalent to approximately 2 to 3 percent of statewide manufacturing output. One reason that the coastal events have among the highest losses is that many of the largest manufacturers are located along the California coastline; for instance, San Diego is home to the largest number of manufacturing jobs in the state.

Table 11. Manufacturing Productivity Losses

*Total estimated reduction in manufacturing output (GDP) during heat events using evidence from Cachon et al. 2012 and HVAC availability in manufacturing facilities from the U.S. EIA (2022$). Percent decrease in statewide output is measured relative to typical output over the duration of the event (average statewide daily GDP from manufacturing * number of days in heat event). See Table B10 for a detailed description of methods and data sources.*

Heat Event	Total Manufacturing Output Losses	Percent Statewide Manufacturing Output
1. 2022 CA Coastal Inland	$310,000,000	2.84%
2. 2021 Desert Lands	$2,600,000	0.04%
3. 2019 NorCal Coastal	$74,000,000	1.34%
4. 2018 SoCal Coastal	$84,000,000	1.52%
5. 2017 CA Full Coastal	$230,000,000	2.27%
6. 2017 Central Valley	$35,000,000	0.40%
7. 2013 Eastern CA	$7,100,000	0.10%

Insurance policies maintained by manufacturing companies to protect against significant revenue losses are unlikely to include heat as a covered peril. Data is not available to document which portion of California-based manufacturing businesses have insurance coverage for extreme heat, although uptake and coverage are expected to be very limited.

4.4.5 Reduced Work Time in Weather-Exposed Industries

Key Findings

- Weather-exposed workers spend less time working on hot days, which has the potential to decrease take home pay and sector productivity.
- Across heat events, the total lost work time among these workers is valued between $7.7 million and $210 million per event. Workers in the construction and manufacturing sectors experience most losses given the concentration of these workers in heat-affected areas.
- Lost wages to workers and lost revenue to employers from heat are typically uninsured, although exceptions include construction delay insurance which often covers weather.

The manufacturing productivity estimates above demonstrate how specific sectors experience reduced output because of high heat, in part due to reductions in productivity and participation among workers exposed to unhealthy working conditions. Neidell et al. finds that workers across a broad set of outdoor and indoor industries with heat exposure reduce their time spent working on the hottest days, defined as days over 90°F.[33] The weather exposed works are concentrated in the agriculture, construction, and manufacturing industries – they include warehouse workers as well. Those estimates build on earlier work by Zivin and Neidell that additionally show that their results are insensitive to whether or not workers in the manufacturing sector are included, suggesting that indoor workers in facilities lacking air conditioning are likely to experience the same reduction in worktime as outdoor workers.[34,*] Reduced time spent working may occur because workers decide not to show up to work sites to avoid heat exposure or because employers cancel work activities on high heat days. Reduced labor participation is one avenue through which industries may see reduced output and workers

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[*] While Neidell et al. (2021) and Graff Zivin and Neidell (2014) include only manufacturing from the set of indoor industries with the potential for heat exposure, we extend the results to warehousing facilities as well given evidence on how vulnerable warehousing workers in California are to extreme heat conditions: https://warehouseworkers.org/wp-content/uploads/2014/06/Shattered_Dreams_and_Broken_Bodies718.pdf

may experience reductions in wages. For simplicity, we value lost work time using sector-specific wage rates, however lost work time may also affect employer revenue or sector productivity.[*]

Table 12 presents the results of applying findings from Neidell et al. to the heat events across several categories of outdoor and indoor weather-exposed workers.[†] As shown, the events with the most lost labor time include the 2022 CA Coastal Inland event ($210 million in lost wages) and 2017 CA Full Coastal event ($170 million) (lost wages per worker for this event also shown in **Figure 15**). Across the included sectors, construction and manufacturing typically have the highest estimated losses, indicating that these sectors have the most workers in the heat-affected areas.[‡] Importantly, the estimates presented here only include how workers reduce their worktime on hot days; workers are additionally harmed through increased prevalence of heat-related illness and workplace injuries (see the "Health and Safety" section).

Figure 15. Lost Wages per Worker: 2017 CA Full Coastal Event

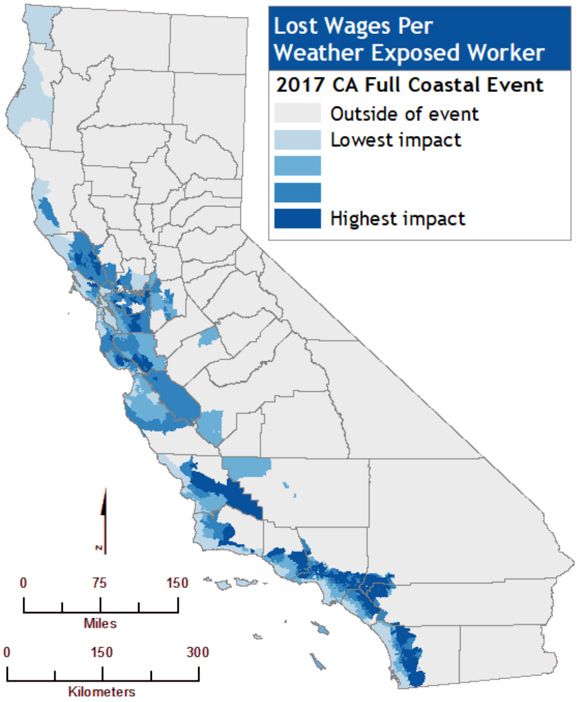

Table 12. Lost Wages in Weather-Exposed Industries

Total estimated reduction in wages to weather-exposed workers from reduced labor participation during high heat days using evidence from Neidell et al. 2021 (2022$). Lost work time is valued using sector-specific average wage hourly rates. See Table B11 for a detailed description of methods and data sources.

Heat Event	Agriculture, Forestry, Fishing and Hunting, Mining	Construction	Manufacturing*	Transportation and Warehousing, Utilities	Total
1. 2022 CA Coastal Inland	$8,800,000	$78,000,000	$77,000,000	$46,000,000	$210,000,000
2. 2021 Desert Lands	$1,400,000	$2,860,000	$1,960,000	$1,500,000	$7,700,000
3. 2019 NorCal Coastal	$810,000	$4,000,000	$5,300,000	$2,200,000	$12,000,000
4. 2018 SoCal Coastal	$1,500,000	$30,000,000	$31,000,000	$19,000,000	$81,000,000
5. 2017 CA Full Coastal	$4,700,000	$52,000,000	$55,000,000	$31,000,000	$140,000,000
6. 2017 Central Valley	$9,300,000	$24,000,000	$16,000,000	$13,000,000	$62,000,000
7. 2013 Eastern CA	$1,800,000	$8,000,000	$5,100,000	$3,700,000	$19,000,000

Notes: *The manufacturing wage losses in this table should not be combined with the manufacturing productivity losses presented in **Table 11** given the potential to double-count the same effect.

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[*] For manufacturing, this effect will be partially captured in the previous section.

[†] CalOSHA maintains standards for outdoor workers, which requires breaks on hot days (https://www.dir.ca.gov/title8/3395.html; indoor worker standards have not yet been adopted). In the data used to produce the estimates in Neidell et al., any breaks at work would not be counted as work time, therefore our estimate of reduced labor participation includes these mandated breaks. Because Neidell et al. is national in scope, any break time among California workers would be muted by the response in other states.

[‡] The American Community Survey data used to estimate the number of workers in each industry by location undercounts agricultural workers, including those in crop production specifically.

When lost work time results in lost take home pay to workers, losses in wages are unlikely to be compensated by insurance. Where reduced work time among workers translates to lost revenue among employers, most conventional insurance policies still do not cover heat. There may be exceptions, like construction delay insurance, which typically covers contractor delays for many reasons, including weather.[*,†]

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[*] Call with Yommy Chiu and Jackie Higgins of Swiss Re on October 16, 2023.

[†] Here is one example of a parametric insurance product for the construction industry insuring against weather related losses: https://www.zurichna.com/industries/construction/weather-parametric

4.5 Infrastructure Impacts

Extreme heat affects infrastructure primarily through physical deformation of components essential to the services infrastructure provides. Heat expands rails, for example, and they can deform; moderate heat can lead to speed restrictions and delays which increase with higher temperatures, and severe heat requires rail repair and in rare cases leads to derailments. Heat also softens road surfaces, causing ruts – these impacts begin to be seen when temperatures rise above those that at "typical" for each area of the state. For roads, the effect is mostly cumulative rather than acute, leading to a loss of lifespan of road surface and need for more frequent resurfacing. Extreme heat also reduces aircraft lift, which if severe leads to weight restrictions; delays; and/or flight cancellations.

Most of the losses associated with infrastructure exposed to extreme heat events are uninsured. Most rail costs are delays – the passenger delays are uninsured, and while freight costs might be insured, the heat peril is often excluded from business interruption policies. Road costs are mostly for physical repairs to the roads and the costs fall on government entities responsible for the impacted roads - virtually all are uninsured, but parametric policy coverages are beginning to be available that would provide some financial protection against infrastructure losses.

Infrastructure Key Findings

- Losses in the infrastructure sector are generally lower than for other sectors. The road sector impacts, however maybe locally important for municipal governments who may need to undertake more extensive maintenance as a result of heat damaging asphalt road surfaces.
- The by event magnitude of impacts is largely driven by the spatial extent of the event, similar to the relative magnitude per event seen in the Health and Safety sector.
- The impacts of heat on roads may fall disproportionately on low-income populations and those over 65, but other information on the incidence of these impacts is not available.
- Most of the losses associated with heat and infrastructure are uninsured, except for some instances of business interruption and government parametric policies, and travel insurance for passengers affected by flight cancellations.

Among air travelers, roughly 1/3 of passengers purchase travel insurance and the trend is for increased uptake. Airport operators and airlines can also purchase a newer "non-damage" type of business interruption insurance, but those are mostly geared toward storm events and may only apply in very limited conditions for extreme heat events.

The economic impacts estimated for rail and road categories are summarized below. Rail costs are higher for events where the event's spatial influence aligns with the state's rail inventory. The road impacts tend to align with both the spatial extent of the event, and the events with the highest absolute temperatures (such as the 2021 Desert Lands event) because humidity is not a factor in the road impact calculations.

Table 13. Summary of Economic Impacts (2022$)

Total losses across economic impact categories for seven extreme heat events. See Tables B12 and B13 for details on the methods and data used.

Heat Event	Rail Costs	Rail Miles Affected	Road Costs	Road Miles Affected
1. 2022 Coastal Inland	$21,000,000	3,700	$14,000,000	170,000
2. 2021 Desert Lands	$7,500,000	1,300	$3,800,000	56,000
3. 2019 NorCal Coastal	$2,000,000	600	$1,800,000	30,000
4. 2018 SoCal Coastal	$3,400,000	1,200	$3,800,000	64,000
5. 2017 CA Full Coastal	$12,000,000	2,600	$9,000,000	120,000
6. 2017 Central Valley	$14,000,000	2,500	$8,500,000	120,000
7. 2013 Eastern CA	$9,400,000	1,900	$7,300,000	110,000

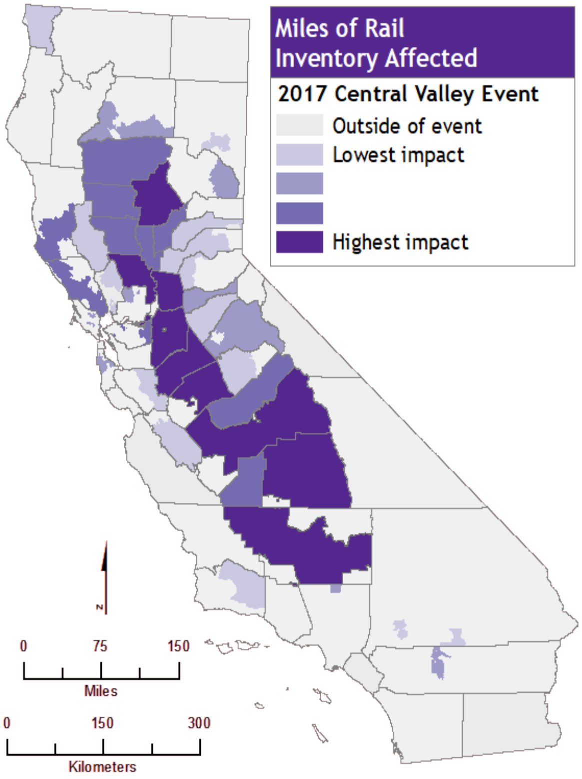
4.5.1 Rail

Key Findings

- Each of the seven events has a different spatial distribution – the 2018 SoCal Coastal, 2019 NorCal Coastal, and 2021 Desert Lands events are more concentrated in limited areas, while the other four events show rail impacts more evenly distributed across the state.
- In the 2021 Desert Lands event, where the extreme heat was most severe in the Southeastern desert areas and other parts of Southern California, the impacts in San Bernadino County account for over half of the total costs ($4.8 million of the $7.5 million in total costs), associated with impairment of the Inland Empire area freight rail and the western Los Angeles commuter/light rail systems.
- Data on insurance coverage are sparse. More than 95 percent of the estimated impact is associated with delays rather than repair costs, however, with an unknown distribution among passenger and freight categories. All passenger delays are uninsured, but freight delays may be partially insured, for downstream firms with a type of business interruption insurance that covers supply chain disruptions. Data on uptake for this type of insurance is not available.

Extreme temperature can lead to rail track deformities, as the metal in rails expands at higher temperatures, sometimes beyond the built-in tolerances that allow the rail to remain straight in its railbed. Derailments associated with these deformities often can be avoided by implementing speed restrictions, but these then lead to delays for users (service impairments). In extreme cases, a derailment can happen, which has been documented at least three times in recent years: for a Bay Area Rapid Transit (BART) train in July of 2022, when ambient temperatures in the low triple digits lead to a spike in track temperatures to 140°F, 35° above the track tolerance, leading to a three day closing of the line in one direction; for a 19-car cargo train in Tulare County in 2017; and to a cargo train near the California-Arizona border in 2020. More commonly, derailments are avoided as operators are able to slow trains to help limit rail temperature increases associated with the train itself moving over the rails, but these speed controls lead to service delays, and some repair of deformed rails is also required.

Figure 16. Miles of Rail Inventory Affected: 2017 Central Valley Event



Comprehensive data on the implementation of rail speed controls or of the need for deformed rail repairs is not available, so this report relies on results from a published study which estimated repair and delay impacts associated with the historical pattern of maximum daily temperatures.[35] This report estimates repair, equipment, and delay costs to rail infrastructure due to rail track buckling or the risk of buckling across the U.S. associated with elevated temperatures. Because speed controls are commonly implemented, we relied on a rail system operator response scenario most closely aligned with this current best practice among train operators. **Figure 16** shows an example of the extent of rail miles affected for the 2017 Central Valley event.

The importance of both systems to the Southern California economy could mean the overall economic impact could be underestimated, as secondary impacts felt through labor markets and delays in freight delivery might be more widespread than the estimated effects, which reflect a single national average direct and indirect cost of delay.

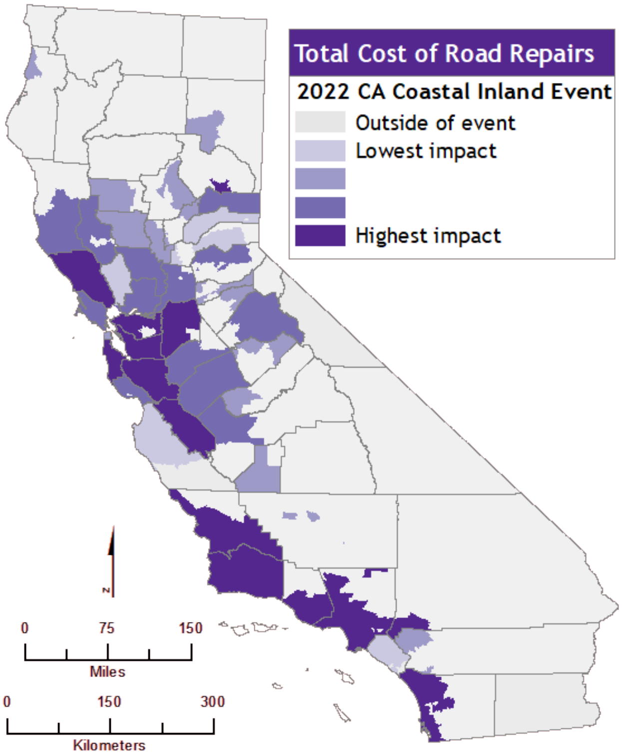
4.5.2 Roads

Key Findings

- Heat events have similar impacts on a cost per mile basis – meaning that variation in costs across events is largely dependent on the spatial extent of extreme heat during the event, and the number of total road miles affected by extreme heat.
- The impacts of heat on roads may fall disproportionately on low-income populations, and possibly other socially vulnerable populations, such as those over 65., Lower income individuals may also be disproportionately affected – they travel less than those with higher income both but spend proportionately more of their income on transportation.
- Data on insurance coverage are sparse. About 80 percent of the estimated impact is associated with repair rather than delay costs, and most repair costs fall on government entities, including state, county, and local governments (see Governance sector results for more detail). All of these costs remain uninsured for these government entities – but a market is emerging to offer insurance to governments for exceptional heat events – see Chapter 5 for more details.

Asphalt roads can be vulnerable to extreme heat, which causes the road surface to deteriorate, which leads to premature rutting of the surface. If left unrepaired, the rutting in turn can allow water to penetrate the road surface, prematurely limiting the useful life of the road, requiring more frequent repair and maintenance, and the possibility of an earlier than usual need for major resurfacing. Extreme heat damage to roads also affects the users of the roads - a rutted road can decrease vehicle speeds (relative to speeds in the preferred state of an intact, smooth road), lead to an increased need for vehicle repairs (e.g., from tire and suspension damage), and vehicles can be delayed by constructions crews undertaking repairs. Most of these costs, both to road maintenance entities and to users, are not tracked or directly associated with heat damage, but imply subtle increases in road repair and rehabilitation costs, or costs to vehicle users – but even a small increase in repair costs or time spent by each vehicle in delays add up over the full range of roads exposed to extreme heat and the large traffic volume these roads support across California.

Figure 17. Road Repair/Delay Costs by County: 2022 Coastal Inland Event



The impacts of heat on roads may fall disproportionately on low-income populations, and possibly other socially vulnerable populations, such as those over 65, as demonstrated in a recent USEPA report on climate change and social vulnerability. An individual's potential mobility—access to places and opportunities—are often limited by that individual's time and financial resources, which vary across the U.S. based on factors such as wealth, gender, religion, and age. As described in the USEPA report, lower income individuals travel less than those with higher income both in person-miles traveled and number of trips, but spend proportionately more of their income on transportation and may suffer larger income losses if delayed by traffic.

4.5.3 Aircraft

Key Findings

- ► Extreme heat reduces aircraft lift – if the heat is severe, the consequences include individual flight weight restrictions; delays; and/or cancellations.
- ► It is not possible to generate a comprehensive estimate of the impacts of heat for the seven events in this study. Assuming a "stylized" severe event were to affect Los Angeles International Airport (LAX), costs to airlines alone (not counting costs to passengers) could total lead to $3.1 million over five days. In this scenario, as much as 20 percent of flights could be weight restricted; 9 percent delayed; and 4 percent could be cancelled.
- ► Airlines might have business interruption insurance for these costs – but heat is not usually a covered peril. For impacts to passengers, roughly one-third purchase travel insurance and there is evidence that update is increasing in recent years.

Extreme heat reduces aircraft lift. If the heat event is severe, the result can be weight restrictions for planes that are still able to take off (that is, freight or passengers must be left behind); delays in flights associated with the time required for weight restriction compliance or simply to allow more time between flights to ensure safe operation; and in the most severe cases, flight cancellations. A key study of this effect is Coffel et al. (2017).[36] These authors note that the impact of rising temperatures on aircraft takeoff performance varies by aircraft (it is worse for larger planes), airport elevation (it is worse at higher elevations), and runway length (it is worse for shorter runways). Unfortunately, the literature and available data are not yet sufficiently robust to quantify the effect for our seven heat events.

On June 20th, 2017 in Phoenix, AZ a heat wave caused 122 flights to be weight restricted at PHX airport, 52 of which were delayed more than 15 minutes, and 25 flights were cancelled altogether.[*] Of the nearly 600 total flights to take off that day (Air Traffic Activity Data System), 20.3 percent were weight restricted and 8.7 percent experienced a delay more than 15 minutes, and 4 percent were cancelled.[†] Using these results, a five day heat wave at Los Angeles International Airport (LAX) similar to that at PHX in June 2017 could result in 350 flight delays at a cost of over $1.8 million; 160 flights could be cancelled for an additional nearly $790,000 lost; and an estimated 2,400 passengers could be removed on 810 flights with a weight restriction for an additional cost of $460,000. The total potential estimated cost is more than $3.1 million.[‡] Passenger losses are not estimated here but could also be substantial.

Travel insurance is available to passengers, and generally applies to cancellations and in some cases extended delays, but not all passengers purchase travel insurance. Limited survey evidence suggests about one third of domestic passengers and one quarter of international passengers purchase travel insurance, and these uptake rates have recently increased.[§] Insurance coverage also may be available to airlines within a broader definition of business interruption coverage, including non-damage coverage.[**] Generally these would appear to be

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[*] https://trace.tennessee.edu/cgi/viewcontent.cgi?article=1384&context=pursuit

[†] Average length of delay in 2023 is 53 minutes, and average cost of delay per minute is $101.18. A cancellation of a single plane results in $4,930 of losses. Airlines receive average revenue of $189 per passenger, so weight restrictions that require three passengers to deplane (corresponding to 0.5% of payload and fuel capacity, a typical weight restriction), imply that a weight restricted plane results in $567 in lost revenue.

[‡] This calculation requires some data from FAA, which indicates that from June 1st, 2022 to September 1st, 2022 there were 93 operating days and nearly 75,000 takeoffs at LAX, or an average of almost 4,000 takeoffs every 5 days. This estimate is only an approximation, meant to provide some context for potential impacts based on a broad range of assumptions grounded in literature.

[§] See https://www.usatoday.com/money/blueprint/travel-insurance/travel-problems-survey/

[**] See https://corporatesolutions.swissre.com/dam/jcr:af445de8-4e47-4414-97c4-21ccdb8f63cb/ndbi-airlines-airports.pdf

uncovered losses because extreme heat is not considered a covered peril by most business interruption insurance providers, based on currently known coverage types.

4.6 Energy Impacts

Energy Key Findings

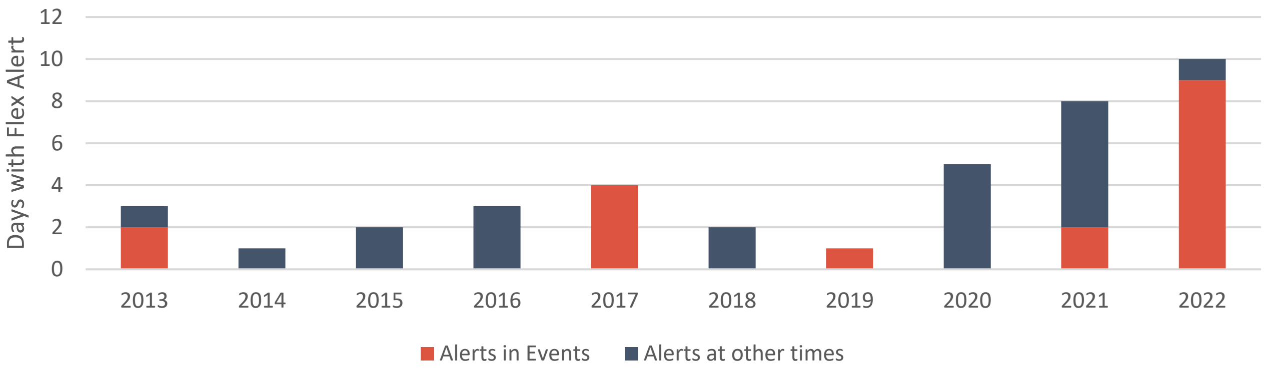
- The costs of power outages are the largest single impact of extreme heat quantified in this study.
- Insurance is likely only available for some of the commercial costs of outages as business interruption insurance for longer duration events and commercial property insurance if outages result in equipment damage.

Extreme heat interacts with the electricity system in a number of ways on both the supply reliability and demand side. Transmission and distribution lines experience reduced capacity under high temperatures while wooden poles, substations/large transformers and distribution transformers also experience a reduced lifespan as high temperature stress the infrastructure.[37] At the same time, demand for electricity peaks during high heat events and residents, businesses, and industry all use power for cooling. As air conditioning penetration increases in an effort to mitigate the health impacts described above, energy demand continues to increase.

In an effort to avoid forced outages when demand on the system exceeds supply, California ISO issues Flex Alerts to request voluntary conservation of energy during peak periods. These alerts ask electricity users to modify their non-critical energy usage in an effort to avoid forced widespread outages. As shown in **Figure 18** the number of days with Flex Alerts each year has increased over this study period. Flex Alerts were issued in all but one of the study events (2018 SoCal Coastal Event) and 46 percent of all Flex Alerts over this time period occurred during the six other events.

Figure 18. Days with Flex Alerts by Year

Flex Alerts are issued by California ISO when high demand is expected to exceed supply during high heat events. Orange bars represent days within the seven examined events, blue bars are days outside the seven events.



Source: California ISO

In this analysis we examine several electricity impacts of extreme heat including the costs of power outages to residents and businesses, costs of lost lifespan of large transformers, and increased costs to households for electricity during heat events.*

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* This section currently only includes the costs of power outages, which are expected to dominate total costs for this category. Lifespan lost to large transformers and increased costs to households will be added in future iterations of the analysis.

4.6.1 Power Outages

Key Findings

- Baseline costs of power outages in California are high, and extreme heat events further stress the grid, leading to more frequent and more severe outages and higher associated costs.
- Costs per event range from $230 million for the 2022 CA Coastal Inland event, to just under $10 million for the 2013 Eastern CA event. The differences by event are driven mainly by the length of the outage and the extent to which it affects areas with a higher density of manufacturing activity.
- There are more residential energy users than commercial and industrial energy users, but costs per unit of outage time are significantly higher for commercial and industrial users. This difference in damage rate produces much higher total costs for commercial and industrial users.
- These costs are unlikely to be covered by business interruption insurance where policies typically have strictly defined perils which exclude extreme heat, or which are triggered by physical damage rather than service outages. In cases where power outages lead to physical damage, such as to manufacturing equipment, property insurance coverage may apply.

Extreme heat impacts energy systems through effects on transmission and distribution infrastructure and electricity supply and demand. High ambient air temperatures decrease the carrying capacity of transmission and distribution lines and reduce the efficiency and capacity of some electricity generators, including thermal power plants and photovoltaics, potentially restricting energy supply.[38,39,40] Conversely, energy demand is often elevated during high heat events due to increased electricity usage for cooling. These effects are not independent and can have compounding impacts on grid reliability, increasing the frequency and severity of service interruptions and blackouts.

To estimate the costs of service interruptions during this set of heat events, we run a version of the Interruption Cost Estimate (ICE) model using county-level outage data.[*,†] This ICE model is parameterized using state- and county-specific customer numbers, usage statistics, and industry data. **Table 14** below, shows estimated costs above baseline. Note that comprehensive information on power outages is only available beginning in October 2018, therefore we are only able to fully document costs for four of the seven events – the most recent events – and estimates for other three are based on scaling of impacts from the four better documented events.

Note that this method may capture outages during the events that are not entirely heat-driven. For example, regular maintenance outages or Public Safety Power Shutoffs (PSPS), which are power shutoffs triggered by high wildfire risk conditions, could be captured in both event periods and baseline periods. The effects of these non-heat-driven outages on event costs should be minimal because baseline costs, which are subject to the same limitation, are subtracted out. PSPS outages, which are likely correlated with heat events, may be partially captured in the estimated heat event costs.

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[*] Documentation for this kind of interruption cost estimation using the ICE model is available here: https://eta-publications.lbl.gov/sites/default/files/interruption_cost_estimate_guidebook_final2_9july2018.pdf

[†] Outage data obtained from PowerOutage.us.

Table 14. Power Outage Costs by Events (Millions 2022$)

Total costs of power outages above baseline, split out by user type. Costs derived from county-level outage data and cost modeling using the ICE model. Results shown for the four heat events for which outage data were available. See Table B14 for details on the methods and data used.

Heat Event	Total Costs	Residential User Costs	Commercial and Industrial User Costs
1. 2022 CA Coastal Inland	$230	$2.2	$230
2. 2021 Desert Lands	$63	$0.84	$62
3. 2019 NorCal Coastal	$69	$0.81	$69
4. 2018 SoCal Coastal*	$83	$0.73	$82
5. 2017 CA Full Coastal*	$92	$0.93	$91
6. 2017 Central Valley*	$39	$0.40	$38
7. 2013 Eastern CA*	$9.6	$0.14	$9.5

Note: Totals may not sum due to rounding.

* County-level outage data not available for these events. Results are estimates based on person-days in the event and average costs from three events with outage data.

4.6.2 Residential Electricity Usage

Key Findings

- Households increase electricity consumption during heat events and therefore experience higher electricity costs due to these events.
- These increases vary based on air conditioning ownership rates, but could increase as more households adapt to warmer temperatures.
- The total costs per event are difficult to estimate, but in an illustrative example, Pasadena (one of zip codes most responsive to heat), experienced 111 days above 90 degrees in 2022, leading to residential households spending an average of $75 more in electricity expenditures than they would have if those days were instead 80 to 90 degrees.
- Low-income households are most impacted by the increases in expenditures, which are difficult to predict and budget for.

Household air conditioning reduces health risks during heat events and is a common adaptation to extreme heat. Running air conditioners comes at a cost to households in the form of higher electricity bills, while also further contributing to climate change through associated greenhouse gas emissions. A recent study of California households found residential electricity consumption increases during high-temperature days compared to a mild (65-degree) day, though there is variation in the response across households. The median household increased electricity consumption by 5.5 percent on days above 91 degrees and about 4 percent on days between 80 and 90 degrees compared to 65-degree days.[41] Increases in consumption vary significantly by zip code; households in warmer climate, and therefore more likely to have air conditioning in their homes, generally had a larger increase in consumption on warm days. Households in areas less accustomed to warm weather had small increases—following the logic that if households are not equipped with air conditioners, their consumption will only increase slightly.

Converting consumption changes to changes in expenditure is difficult due to the complexities in how electricity is priced in California. As an example calculated with simplifying assumptions, Pasadena (one of zip codes most responsive to heat), experienced 111 days above 90 degrees in 2022[*], residential households spent an average of

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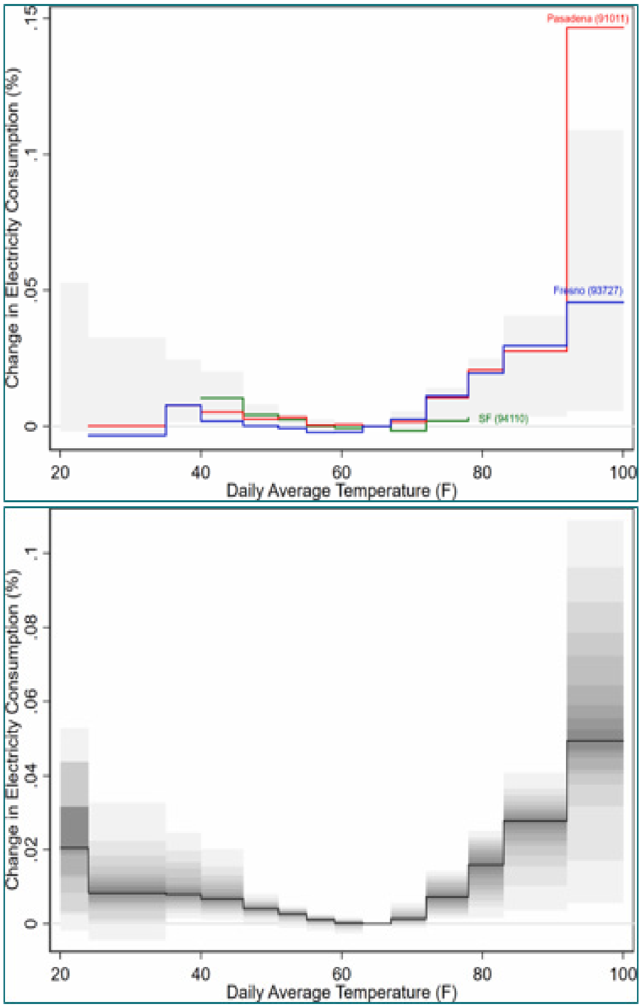
[*] See https://www.extremeweatherwatch.com/cities/pasadena/yearly-days-of-90-degrees.

$75 more in electricity expenditures than they would have i f those days were instead 80 to 90 degrees.* For low-income households, for whom an increase in electricity costs may represent a larger proportion of their monthly budget, the impacts of unexpected spending on electricity during heat events can cause wider ranging financial issues. In a recent study of 300,000 low-income households in California, Barecca et al. found a 1.2 percent increase in the risk of disconnection from electricity services following heat events for each day above 95 degrees.[42] These costs are not covered by existing insurance products.

Figure 19. Change in Electricity Consumption by Daily Average Temperature



Source: Auffhammer 2022.

4.6.3 Electric Transmission and Distribution Network Repairs

Key Findings

- Extreme heat reduces the capacity and lifespan of certain components of the electric distribution and transmission infrastructure. The two more important effects are the reduction of power carrying capacity of transmission lines, and a reduced useful life of transformers.
- A 1°C rise in ambient temperature over the 40-year lifespan of a transformer, for example, decreases the expected lifespan of the large and expensive substation transformers by about 10%, or a total of 4 years. Each heat wave therefore contributes to long-term premature aging of transformers.
- These risks do not appear to be addressed by existing insurance coverages. Department of Energy sponsored research concludes that utilities hold liability insurance for transformer assets, but do not insure the physical assets.

Extreme heat can directly affect the capacity and the lifespan of electric distribution and transmission infrastructure. One of the established connections between ambient air temperature and electric grid infrastructure damages is the reduced capacity and lifespan of large substation transformers and smaller but more numerous "pole-mounted" type distribution transformers.[43] The effects of heat on capacity are a contributing factor to the heat-induced power outages quantified in the previous section of this report. Effects of persistent heat on infrastructure lifespan, however, could add to the overall cost of extreme heat on the electricity supply system.

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[*] Calculated based on 1) average residential monthly bill in Pasadena of $175 in September (https://findenergy.com/providers/pasadena-water-and-power/), or $5.65 per day 2) 12 percent increase in expenditures between 80 to 90 and 90+ degree days for Pasadena households (see **Figure 19**). $5.65 x 12% = $0.68 x 111 days = $75

A national scale study of electric distribution and transmission infrastructure found that transformer failure due to heat waves is rare, but long-term warming and the long-term effect on operating temperatures reduces the expected life of both large and small power transformers. The result was that, on average, every 1°C rise in ambient temperature (over, for example, an annual period) decreases the expected lifespan of the large and expensive substation transformers by about 10%, or 4 years. Each heat wave therefore contributes to long-term premature aging of transformers. Results specific to California and the transformer category of assets examined in that study were not provided in the paper – but the national results suggest that by 2030, annual total costs of all aspects of climate change across multiple components of the distribution and transmission system might total $5 billion, of which the transformer component is about 40%, or $2 billion nationally. The study also provides evidence of adaptation potential for this effect. Advance planning by utilities to strategically build additional substation transformer capacity, reducing the load any single substation, can reduce impacts by a factor of 4 to 5 times by end century.

These risks do not appear to be addressed by existing insurance coverages. Department of Energy-sponsored research from the mid 2000's concludes that while utilities hold liability insurance which applies to their transformer assets, they do not insure the physical assets – this appears to be true today as well.[*] More recent Government Accountability Office research highlights voluntary cross-industry efforts to effectively pool risk of transformer failure through infrastructure sharing cooperatives, which apply directly to large power transformers and efforts to maintain some buffer capacity across the industry.[†] The same research also identifies recent supply chain difficulties and other transformer compatibility issues which complicate or increase the costs of such efforts (e.g., quotes for large transformer replacement increased from $24,000 in 2020 to a range of $81,000 to $109,000 in February 2023) – adding to the urgency of assessing the possible effects of extreme heat waves on premature infrastructure retirement or failure.

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[*] See, "Insurance and the Nation's Electrical Infrastructure: Mutual Understanding and Maturing Relationships," A Project of the Department of Energy with the Critical Infrastructure Protection Program of George Mason University School of Law, June 21, 2005. Available at: https://cip.gmu.edu/wp-content/uploads/2016/06/CIPHS_Insurance-and-the-Nations-Electrical-Infrastructure_White-Paper.pdf

[†] GAO, August 2023, "Electricity Grid: DOE Could Better Support Industry Efforts to Ensure Adequate Transformer Reserves." Available at https://www.gao.gov/assets/830/828093.pdf

4.7 Governance Impacts

The governance cost category is different from the others for several reasons. First, to our knowledge, there are no peer reviewed studies of the costs of extreme heat events to governments that provide impact functions similar to those used in other cost categories. An alternative approach would therefore be to build up total cost estimates from local and state spending data, however, available information on government spending on extreme heat is often annual, not event specific, and does not clearly differentiate between reactive event spending and proactive heat resiliency efforts.

Governance Key Findings

- The costs of power outages are the largest single impact of extreme heat quantified in this study.
- Insurance is likely only available for some of the commercial costs of outages as business interruption insurance for longer duration events and commercial property insurance if outages result in equipment damage.

Each of the three impact categories identified has additional unique considerations that make them difficult to include in this framework:

- **Response Costs**: Although these are real expenses to local and state governments, they are not necessarily a "damage" or negative outcome in the same way other cost estimates presented in this study are. For example, premature mortality and productivity loss are negative outcomes that would hope to be reduced due to adaptation and resiliency planning. The majority of government response costs could be considered adaptation and resiliency measures and therefore, we would not necessarily seek to reduce this type of spending in the future. For example, government spending on information campaigns and transportation or water distribution for vulnerable populations are forms of resiliency work that avoid negative health impacts. Climate adaptation is a continuous process that involves new and evolving types of costs to government planning, implementation, and services budgets.
- **Tax Revenues:** Because many of the economy impacts are measuring lost GDP, tax revenues are already included, and calculating these separately would duplicate losses. There are also many intricacies to the tax code that make precise estimation of tax revenues difficult. A detailed analysis of tax rates is beyond the scope of this current effort.
- **Increased Demand for Services:** Costs such as road repair costs or first responder costs are already captured in the infrastructure and health and safety categories, respectively. While in some cases we can pull out costs borne by governments from the total costs, these are not additional costs, rather a specific reporting.

For these reasons, we discuss governance impacts qualitatively, with quantitative estimates provided for context where available that are not included in sums of total cost per event.

Quantitative information on insurance coverage is also not available for governance costs, however we spoke to several insurance industry representatives with expertise in public sector coverage. Though an increasing number of parametric and index-based products are available for local governments to purchase against a number of hazards, including extreme heat, none of our contacts were aware of any government uptake of extreme heat products at this time. Instead, governments tend to self-insure by funding extreme heat-related costs with a budget funds set aside annually.

Though parametric options could be utilized in these cases, several potential difficulties were cited as impediments to largescale uptake. For example, extreme heat events are (increasingly) common. In order to create a program with affordable premiums, coverage would have to be limited to a scale of event that occurs relatively infrequently. In addition, similar to the challenges faced in this study, municipalities may not have good information on their annual expenditures related to extreme heat. Nevertheless, the insurance providers we spoke to expressed interest and optimism regarding expanded parametric insurance uptake by municipalities.

4.7.1 Response Costs

Key Findings

- ► Local and state governments provide a number of services in response to extreme heat events.
- ► Data on the costs of these expenditures are not well documented in publicly available sources.
- ► These costs are currently uninsured, though parametric or index insurance could be used for these types of costs.

As heat events occur, local and state governments deploy a number of resources to protect populations. The types and scale of government response efforts depend on a number of factors including available budget, specific vulnerabilities of the local population, and the amount of advanced notice officials have to respond to the event. Typical actions taken by local authorities include:

- Opening cooling centers and/or extending open hours for public buildings including pools and water parks.
- Providing transportation to vulnerable populations to cooling centers and other temperature-controlled buildings.
- Deploying stations the release "mist" in order to cool pedestrians in high traffic pedestrian areas.
- Distributing supplies such as water bottles and ice, particularly to populations experiencing homelessness.
- Public service alerts such as news alerts and social media posts warning people about heat and providing tips for identifying heat-related health issues.
- Volunteer/personnel hours to staff various initiatives including performing wellness checks on populations vulnerable to health effects of extreme heat.

Because of the different drivers of expenditures described above, it is difficult to estimate total costs across all jurisdictions for each event. This is compounded by the lack of reported expenditure data. The current survey efforts by CDI may provide information to better estimate these costs in the future. As described above, these costs are currently uninsured, however they could be covered under parametric insurance products available to public entities. Uninsured costs are typically funded by budget reserves which function as a form of self-insurance.

4.7.2 Tax Revenues

Key Findings

- ► Extreme heat disrupts a number of economic activities that make up local and state tax bases; therefore the indirect tax effect could be significant. Estimated state tax revenue losses range from $2 million (2013 Eastern CA Event) to $35 million (2022 CA Coastal Inland Event) excluding power outage-driven losses.
- ► There may be some offsetting revenue increases as people substitute activities during extreme heat (e.g., increased parking and entrance fee revenues at pools and beaches or increased sales tax from climate-controlled shopping).
- ► We do not include these lost revenues in total cost summaries because they are largely already captured in the economic loss calculations.
- ► These costs are currently uninsured, though they could be covered by a parametric product.

Extreme heat disrupts a number of economic activities that make up local and state tax bases. We evaluate the potential for lost tax revenues across several economic activities estimated under previous cost categories: crop and dairy productivity losses, manufacturing productivity losses, commercial and industrial power outage losses, and lost wages. Estimated state tax revenue losses range from $2 million (2013 Eastern CA Event) to $35 million (2022 CA Coastal Inland Event) excluding power outage-driven losses which add up to $84 million (2022 CA Coastal Inland Event). Manufacturing productivity and power outage commercial and industrial losses are the largest sources of lost revenues. As noted above, these estimates are illustrative of the potential magnitude of impact but do not reflect precise calculations because of a number of uncertainties.

4.7.3 Increased Demand for Services

Key Findings

- Extreme heat increases demand for government services that may not be perceived as extreme heat-driven costs. Not all costs for increased demand for services can be quantified, but the costs incurred by governments for road repairs that can be attributed to damage from high heat events were as large as $10 million per event for city and county governments, plus an additional $0.9 million for state highway repairs.
- These costs are already covered under other impacts in this analysis and therefore should not be summed with other impact costs. Reporting them separately provides information to government entities as to the “hidden costs” of extreme heat events.
- These costs are currently uninsured, though they could be covered by a parametric product.

As a result of extreme heat events, demand for typical government services such as infrastructure maintenance, emergency services, and public health services may increase. These costs may not be directly attributed to extreme heat events in local budgets in the same way more explicitly heat related costs such as cooling center operations might be, but they are nonetheless heat-driven expenditures.

Many of these costs are calculated under other categories in this analysis but here we pull out the costs to government entities for the purpose of communicating some of these “hidden costs”. We are able to identify costs to government entities for health care payments, road repairs, and rail repairs. Note that ambulances are mostly privately run in California therefore this type of emergency service is excluded.

Road costs in the infrastructure category include both repair costs (incurred by government) and delay costs (incurred by all road users). **Table 15** presents just repair costs, by maintenance jurisdiction, by applying a factor of 80 percent to total costs based on previous analyses of the breakdown between the two cost elements. Cities and counties bear the majority of the costs of road repair though the distribution between those entities varies by event (driven by the geography and road network of the affected area). To put these amounts in context, the U.S. Census Bureau estimates that California’s total annual highway expenditures in 2021, excluding capital expenditures, were about $13.4 billion, with about 42 percent spent by state government and 58 percent spent by local government.[44]

Table 15. Total Costs to Governments of Heat-induced Road Repair

Total costs ($2022) to governments of road repair for seven historical heat events, derived from analysis of a published study (Neumann et al. 2021). Total repair costs attributed to jurisdictions based on number of road miles maintained. Assumes 80 percent of total road cost are repair costs (the remaining 20 percent are delay costs) based on previous analyses of these data. See Table B15 for a detailed description of methods and data sources.

Heat Event	City Roads	County Roads	State Highway	Federal Agencies	Other State Agencies*
1. 2022 Coastal Inland	$6,320,000	$3,600,000	$880,000	$280,000	$56,000
2. 2021 Desert Lands	$1,280,000	$1,280,000	$288,000	$152,000	$28,800
3. 2019 NorCal Coastal	$696,000	$504,000	$136,000	$53,600	$21,600
4. 2018 SoCal Coastal	$2,240,000	$576,000	$184,000	$53,600	$13,600
5. 2017 CA Full Coastal	$4,480,000	$1,920,000	$544,000	$160,000	$55,200
6. 2017 Central Valley	$1,840,000	$4,000,000	$600,000	$304,000	$22,400
7. 2013 Eastern CA	$1,040,000	$3,520,000	$720,000	$584,000	$32,800

Note: Roughly 95% of the lane miles in the “Other State Agencies” category are attributed to roads maintained by state parks agencies.

5 | Insurance Coverage for Extreme Heat Events

A key objective of this study is to identify insurance coverages which could compensate for the cost impact of extreme heat, and clarify gaps in coverage, some of which may be addressed through better information or state policy initiatives. Chapter 4 above connects available information and data on insurance types, their applicability to extreme heat, and uptake rates for each of the impacts addressed in the scope of this study. Detailed information on uptake rates, connected to specific entities affected, is only available for the hospitalization, emergency department visit, outpatient, and birth outcome impacts, within the Health sector. Some data are also available for the crop productivity impacts. In other cases, only more general data on uptake rates and coverage amounts is available. This chapter provides an overview of types of insurance products known to be available for extreme heat impacts, as well as some barriers to extending uptake rates to more fully compensate for the large cost impacts of extreme heat identified in this study.

Note that one key source of information for this study was shared insights from insurance industry professionals with knowledge of coverages relevant to the extreme heat impacts explored in this report. Appendix C provides more detail on the insurance industry research conducted to support this study. The interviews were focused on refining a tabular summary of the categories of extreme heat impacts and a preliminary Project Team outline of possible insurance types relevant for that impact category. The discussions centered on answers to the following three questions:

1. What types of insurance products are available to cover the impacts of extreme heat?
2. What is the extent of coverage for the particular products related to extreme heat?
3. What data are available to quantify coverage and past claims?

Data on the extent of coverage was generally not publicly available, though the experts interviewed did in some cases share professional judgement on the breadth and nature of insurance covered entities for select categories of impacts. Most interviewees agreed that there are current coverage gaps for extreme heat related costs of the following impacts: Manufacturing Productivity, Lost Wages, and Lost Business Revenue from Closures; Rail and Roads in the Infrastructure sector; and Costs of Power Outages and other impacts in the Energy sector. Detailed results of the interviews are provided in **Table C-1** of Appendix C.

The remainder of this chapter reviews findings for four types of insurance that are relevant to extreme heat impacts: medical, life, crop, parametric (index) insurance (targeted on risks to government revenues and expenditures), and business interruption insurance.

5.1 Medical Insurance

Medical insurance addresses the non-fatal impacts in the Health and Safety sector. The most detailed information available on medical insurance coverage comes from two sources. The first is the California Department of Health Care Access and Information (HCAI) incidence data for relevant hospitalizations and emergency department visits was accessed for relevant diagnosis codes. The data is particularly helpful in determining the extent to which heat related incidence is associated with various health coverage status, including coverage through Medicare, Medi-Cal, Private Coverage, Uninsured (includes Self Pay), and other Public (Other Federal Program, Title V, Veterans Affairs Plan). The second is aggregated counts derived from Medicaid and Medicare administrative claims databases that are strictly and securely housed and managed at the Penn State University Centers for Medicare and Medicaid Services (CMS) Virtual Resource Data Center. The CMS data was used to characterize medical insurance coverage for outpatient insurance claims.

Overall, medical insurance covers nonfatal impacts of interest for this study, although a small percentage of those seeking care are uninsured. California law and the wide availability of publicly provided health insurances means that the insurance coverage gap for these outcomes remains small. The main gaps are associated with non-medical but associated consequences from these illnesses – such as lost income from employee or caregiver time spent away from work or from long-term complications of illnesses.

Separate from medical insurance but relevant to the nonfatal Health and Safety sector impacts is worker's compensation insurance. Because that impact is based on worker's compensation claims data and so is clearly connected to worker's compensation coverage, which is required for all employers on behalf of their employees under California Labor Code Section 3700, the coverage gap for this outcome is also considered to be small. Nonetheless there are exceptions, as worker's compensation insurance is not necessarily required for independent or contract workers and is not provided for informal workers.

5.2 Life Insurance

Life insurance coverage provides partial compensation for the premature mortality outcome in the Health and Safety sector. Multiple interviewees referenced a summary of the LIMRA 2023 Insurance Barometer Study which is cited and used in this report. Most data from that source are not publicly accessible, except to LIMRA members, but the publicly available report and survey summaries indicate that LIMRA estimates 52 percent of individuals have life insurance, from employer-sponsored, individual, and/or other policies. There is some evidence that uptake rates are higher among parents, and generally among middle-aged and older populations (older individuals are also more susceptible to death from extreme heat).

Other publicly available information indicates that the average payout for a life insurance policy when someone dies, among those covered, is $168,000.[*] This average payout is much smaller than $11.2 million value of statistical life we use to estimate total costs of premature mortality. The differences are attributable to factors mentioned in Chapter 4, such as life insurance applying to specifically identifiable lives, while the VSL represents a total willingness to pay to avoid mortality risk among a population exposed to a mortality risk from an external hazard (that is, other than routine "natural causes" of death). Other differences include that those who buy life insurance are typically considering such factors as affordability of the premium, specific uses they expect a payout to address (such as funeral expenses), and their other wealth and assets (self-insurance). Most or all of these factors tend to reduce the level of life insurance carried by individuals, but do not lessen the overall burden of unexpected loss of life to their heirs and society as a whole.

5.3 Crop Insurance

Crop and other agriculture sector insurance is widely available, but it not always specifically targeted at the agricultural sources of revenue in California, or extreme heat as a peril. For crops, Federally provided subsidized crop insurance, through the U.S. Department of Agriculture (USDA) is the primary source of insurance, and reflects multiple perils, including extreme heat, that could reduce productivity from "normal" conditions. Federal crop insurance mostly removes the need for private or secondary insurance, with an exception being organic/conservation practices farms which have lower uptake of USDA products owing to standardized crop-specific production history basis. Private insurance options such as weather index policies do exist and may be applicable to some specialty crops (e.g., grapes, strawberries, lettuce) which are important to California's economy but not typically covered under USDA policies – their uptake rate is unknown. Insurance experts shared that parametric coverage for extreme weather events is generally available but is more likely to be purchased to protect from frost events, rather than heat events.

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[*] https://www.aflac.com/resources/life-insurance/average-life-insurance-payout.aspx

In the dairy sector, there are options for insuring losses from reduced milk production and cow mortality. For dairy productivity, USDA's Dairy Revenue Protection program has been in effect since 2018, with subsidized premiums, and heat is a covered peril. There is also a private market – for example a private product by Scor is specifically focused on heat impacts, but uptake rates are unknown and experts suggest these products may currently have low overall uptake.

To address dairy cow mortality, there are products in the category of dairy farm insurance, but heat is not listed as a source of covered loss. Experts shared that there are two options which could apply for heat effects: 1) Actual mortality coverage (like life insurance for cows), where cows are part of "farm capital" coverage; 2). A preventative "health insurance" type option – used by some big dairy companies but overall there is limited uptake. Experts estimated that 75 percent of cows are insured by one of these two options.

5.4 Parametric (Index) Insurance

The general category of parametric or index insurance provides loss payouts in response to the exceedance of an agreed threshold of weather variables, for example, 98th percentile temperature exceedance for three or more days. While parametric insurance has long been available to cover crop losses in the agricultural sector, more recently, and of interest to this study, is the commercial availability of new parametric offerings to governments. Within the Governance sector, all categories of revenues and expenses addressed in the report, as well as others, can potentially be covered by parametric/index- based policies currently available in the market and could be based on temperature indices (such as X days above Y minimum temperature). One concern is that there can be potential for FEMA disaster payout duplication of benefits – existing policies include provisions on FEMA payout integration, and the lack of current disaster declarations for extreme heat events appear to minimize these concerns (but as noted in this report, extreme heat events can coincide with or exacerbate wildfire events, which are addressed in FEMA disaster declarations and could complicate integration). Existing policies in force focus on wildfire, earthquake, and flood perils for public entities – no U.S. based examples exist so far for heat peril,[*] but there are no barriers to firms offering a heat-based policy.

5.5 Business Interruption Insurance

Business interruption insurance could apply to multiple impacts in the Economy, Energy, and Infrastructure sectors, but most of the currently written business interruption insurance requires property damage (e.g. equipment made inoperable by a flood, wind, or lightning strike) to trigger coverage. That condition is not typically present for heat events, where the interruption is more commonly caused by a power outage or a direct impact on workers or customers, rather than direct damage to physical assets. There are some instances where standard business interruption policies apply – for example, if road or construction crews cannot work because of heat conditions, but are paid, these losses can be covered.

A newer type of non-damage business interruption insurance, however, could apply to some types of manufacturing productivity losses in the Economy sector. These newer policies are based on a weather index or a parametric hazard, which could include heat. For example, airport operations or carriers may be covered by certain extreme weather events (e.g., snowstorms that close an airport), using a parametric based non-damage business interruption policy for carriers. The existing offerings maybe more difficult to structure for heat

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[*] Recently a financial security mechanism that includes insurance as one component was implemented in India, see https://www.climateresilience.org/press-releases

events/impacts delays, however, which tend not to close an airport for a series of days, but rather affect takeoffs, delays, cancellations, and weight restrictions within the peak heat hours of a single day.[*]

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[*] Note that delays or cancellations of this type can be covered for airline passengers for at least some heat related occurrences if they purchase travel insurance.

6 | Benefits and Costs of Heat Risk Reduction Interventions

Individuals and decision makers can take steps that help people to adjust and respond to extreme heat by limiting exposure, increasing resilience, and reducing the severity of risk, measures typically referred to in the broader category of climate change adaptation. Chapter 4 of this report demonstrates that the societal costs associated with extreme heat events are multifaceted and can reach notable levels in magnitude. While insurance remains a mechanism for distributing the burden of those costs, and thereby minimizing the incidence of catastrophic damages, it is generally not a means for reducing the overall societal costs themselves of extreme heat events. Where coverage exists, encouraging the insured to invest in risk reduction in exchange for premium reductions is a standard incentive approach used in the industry.

Adaptation interventions aimed at extreme heat events can vary by the type of impact individuals seek to limit. For instance, interventions aimed at reducing effects to human health and safety may differ from those that seek to improve conditions associated with dairy cows or infrastructure. **Table 16** below provides a useful typology of collective adaptation interventions aimed at reducing human health consequences of extreme heat, drawn from information presented in Hess et al. (2023) and Abbinett et al. (2020).[45] As shown, different interventions can occur at different points in time relative to a heat event, including those before, early into, and during an event.

To quantify the costs and benefits of implementing heat risk reduction interventions, evidence on the effectiveness of the intervention at reducing the effects of heat is a key input. A review of existing literature and discussions with experts revealed that studies on the effectiveness of many interventions at reducing heat's impacts, especially those early into and during an event, are very limited. This is not to say there are no benefits associated with these interventions, but instead that it is challenging to quantitatively assess these interventions rigorously and/or there are few studies that have made these attempts.

Table 16. Adaptation Interventions Aimed at Reducing Health Consequences of Extreme Heat

Primary Prevention (pre-event)	Secondary Prevention (early event)	Tertiary Prevention (during event)
Climate sensitive infrastructure - Green and reflective surfaces - Urban greening	**Issue heat warning** - Use health and social care service network	**Efficient health surveillance, monitoring, and evaluation (SME) operations**
Heat action planning - Epidemiological research and surveillance - Develop early warning protocols and communication approach - Disaster response planning	**Ensure people have access to cooling and hydration** - Fans, misting - Cooling centers - Water bottles	**Rapid diagnosis and intervention of heat related illness**
	Ensure health system preparedness - Training on heat related illness - Staffing plans - Resources to treat hyperthermia	**Special attention to at-risk populations, including outreach** - Psychiatric - Unhoused - Elderly

Note: Categorization drawn from Hess et al. (2023) and Abbinett et al. (2020) focused on health risks

This analysis provides illustrative evidence from three pre-event interventions for which effectiveness evidence is readily available: Heat Action Plans, urban trees, and evaporative cooling for dairy. Given data limitations, the analyses rely on significant assumptions and, while informative, should not be used as a substitute for detailed cost-benefit analysis to inform specific investments.

6.1 Intervention #1: Heat Action Plans

As described in **Table 16**, planning for heat events before they occur is one way that municipalities can reduce the human health consequences of extreme heat. These plans outline strategies the state and local governments and other stakeholders can take to reduce fatalities and heat related illness as events unfold. The policy documents typically clarify roles, ensure systems are in place, and establish means of coordinating between stakeholder groups and the public. Not only do Heat Action Plans outline emergency planning, but they also provide a forum to discuss the feasibility of other pre-event interventions, including investments in climate sensitive infrastructure. In other words, Heat Action Plans are not a one-size-fits-all intervention and will take different forms in different communities.

Heat Action Plans

Intervention: Establish Heat Action Plans at the state and local levels

Annual cost: Unknown, but will vary significantly by jurisdiction

Annual benefit (quantified): 38 to 108 fewer deaths per year during heat events, valued at $420 million to $1.2 billion per year

Other potential benefits: Reduced non-fatal illness and injury

Evidence on the effectiveness of Heat Action Plans is limited in the United States, although several studies demonstrate benefits in Canada and across Europe. For instance, Benmarhnia et al. (2016) find a 5.7 percent reduction in fatalities in Montreal after the city established a Heat Action Plan.[46] In Spain, Martinez-Solanas and Basagana (2019) estimate a 16.4 percent reduction in mortality that they attribute to the country's HAP.[47] While situations in these places may differ significantly from California, these studies provide the best available information about how developing Heat Action Plans can reduce deaths during heat events. Applying these percent reductions to the fatalities associated with the heat waves identified in this study suggests that Heat Action Plans could have reduced the number of California fatalities by an average of 3.8 to 10.8 per event if Heat Action Plans were in place during those events. Assuming roughly 10 average heat events per year in California suggests that developing Heat Action Plans could save between 38 and 108 lives per year during heat events, valued at $420 million to $1.2 billion using the same premature mortality prevention valuation approach described in Chapter 4. Heat Action Plans may also reduce non-fatal health outcomes not quantified here.

The costs of developing and implementing Heat Action Plans are currently unknown, but will likely vary significantly by municipality.

6.2 Intervention #2: Trees in Los Angeles County

Trees reduce heat by providing shade and cooling through evaporation and transpiration. Trees can be especially important in urban areas that experience "heat island" effects, pockets of elevated temperatures due to the influence of infrastructure (e.g., buildings, roads, sidewalks) on trapping and exacerbating heat. Given their role in reducing temperatures, planting trees has the potential to curtail the effects of heat, especially those related to human health. This analysis investigates the avoided human mortality and illness benefits of trees through two scenarios which reflect the range in the published literature regarding the health effect prevention effectiveness of these measures.

Trees in Los Angeles County

Intervention: Plant trees on publicly owned parcels in LA County with less than 50 percent tree cover (estimated 7.9 million trees)

Annual cost: $351 million

Benefits (quantified): 0.5-13.9 avoided deaths, 1.5-42.9 avoided hospitalizations, and 33.9-941.6 avoided ED visits during the 2022 Coastal Inland Event ($6.8-$189 million)

Other potential benefits: Reduced energy needs, reduced atmospheric carbon, reduced stormwater, increase wildlife habitat, aesthetics ($520 million annually)

In the first scenario, evidence from Ziter et al. (2019) provides a basis to relate urban temperatures to effectiveness under and away from tree canopy.[48] We apply the "under tree" temperature reductions to observed temperatures during the 2022 Coastal Inland Event for publicly owned parcels in Los Angeles County with less than 50 percent tree cover. In other words, our modeled intervention scenario envisions an additional 7.9 million trees planted on publicly owned land where one or two mature trees could be accommodated, and we assume only the individuals residing in very close proximity to these parcels experience the associated temperature reductions. To estimate how mortality would have been reduced had these trees been planted during the 2022 CA Coastal Inland event, we apply a heat risk mortality function from Lay et al. (2021) under both the actual observed temperatures and the modeled "with tree" temperatures.[49] The difference between the two—0.5 deaths ($5.6 million), or 0.8 percent of the deaths in Los Angeles County during this event—represents the reduction in deaths attributable to tree planting.

To approximate the avoided non-fatal health consequences, we apply the 0.8 percent reduction to the number of hospitalizations and ED visits associated with the 2022 CA Coastal Inland event described in Chapter 2. In doing so, we estimate 1.5 avoided hospitalizations ($2,600) and 33.9 avoided ED visits ($1.2 million) attributable to our tree planting intervention in Los Angeles County during this single heat event.

To respond to concerns that the first scenario may undercount the health-related benefits of tree planting, we offer a second scenario that directly applies evidence from a detailed modeling exercise of tree planting and roof reflectivity in Los Angeles presented in Kalkstein et al. (2022).[50] For a 40 percent increase in tree cover and a more modest change in roof and pavement albedo, the authors simulated a 22 percent reduction in heat-related mortality during a September 2010 heat event. Based on the assumptions described in the paper, we believe the total increase in trees is roughly the same as scenario 1. Applying the 22 percent reduction to the 2022 Coastal Inland Event for all of Los Angeles County and the mortality estimates from Lay et al. suggests a potential reduction in 13.9 deaths ($155 million benefit for mortality prevention) during that event attributable to *both* the increase in tree canopy and surface albedo. Under the significant assumption that non-fatal health outcomes also reduce by 22 percent, we estimate 42.9 fewer hospitalizations ($73,000) and 941.6 fewer ED visits ($34 million) during the 2022 Coastal Inland Event.

Trees provide many other benefits beyond maintaining human health during heat events. For instance, trees: 1) reduce energy needs in nearby buildings by providing temperature-reducing shade; 2) sequester carbon, reducing the amount of atmospheric carbon dioxide; 3) intercept stormwater, reducing water treatment needs; 4) provide habitat for wildlife, and 5) offer aesthetic beauty, a sense of place, and well-being. To quantify these other benefits, we apply the $73 per tree per year co-benefits estimated by McPherson et al. (2011) for trees in Los Angeles to the 7.9 million trees associated with our first scenario, for a total of $520 million in annual benefits across these categories (2022 dollars).[51]

To estimate the cost of planting and maintaining 7.9 million trees in Los Angeles County, we rely on recent evidence showing the cost to be approximately $44 per tree per year over the first 40 years of the tree's life.[52] Therefore, across 7.9 million trees, we estimate a cost of $351 million per year, with higher expenses in the earlier years and lesser expenses in the later years. Relative to the avoided fatal and non-fatal health outcomes as well as the non-health co-benefits, planting trees at this scale would be net beneficial for Los Angeles County once trees reach maturity.

6.3 Intervention #3: Evaporative Cooling for Dairy in the Central Valley

The above two interventions target improving human health outcomes during extreme events. The analyses presented in Chapter 4 demonstrate the many other ways in which heat affects people, including through impacts on the economy. Here we explore how losses in the dairy sector could be reduced through investments in high pressure evaporative cooling on dairy farms, using the 2017 Central Valley Event as our case study. Evaporative cooling is a refrigerant-free option for reducing temperatures on dairy farms that uses less energy than typical air conditioning and less water than typical spray methods while still delivering heat-reduction benefits to cows. However, the systems appear to be quite different from the cooling strategies used in California currently and would represent a significant investment for many dairy operations.[*]

Evaporative Cooling in Dairy

Intervention: Widespread adoption of high-pressure evaporative cooling systems on dairy farms in Central Valley

Costs: $1 billion one-time cost, $615,000 variable cost during 2017 Central Valley Event

Benefits (quantified): 550 avoided cow deaths and 174 million kgs of milk gained relative to 2017 Central Valley Event ($71 million)

Other potential benefits: Reduced energy and water needs

To estimate the heat-reduction benefits of widespread adoption of evaporative cooling systems, we rely on a convenient functional relationship from St. Pierre et al. (2003) noting how the losses we estimate in Chapter 4 – both dairy productivity and dairy cow mortality – would decrease under these systems.[53] In doing so, we estimate a net reduction in 550 dairy cow deaths (8 percent) and an avoided 174 million kgs of milk lost (99 percent) during the 2017 Central Valley Event relative to losses incurred with only minimal cooling infrastructure, like natural ventilation and shade. Here, we focus on all losses associated with heat, not just those above typical baseline levels. Using the same valuation approach as Chapter 4, the benefits of investing in evaporative cooling would be approximately $71 million for a heat wave like the 2017 Central Valley Event that took a significant toll on the dairy industry.

The one-time evaporative cooling investment across Central Valley would cost approximately $1 billion to protect over 1.3 million cows. Operating the units during heat events would also result in variable costs. For the 11day 2017 Central Valley Event, the cost would have been approximately $615,000. Given the high fixed cost, it would take about 14 heat events like the 2017 Central Valley Event in order for the units to be net-beneficial when considering avoided dairy productivity and mortality losses. This calculation does not take into account the energy- and water-saving benefits associated with the systems relative to other cooling systems, like sprinklers and fans. Between 2013 and 2023, we identify 74 extreme heat event days that affected the Central Valley, or 7.4 days per year on average. Therefore, under this scenario, it would take approximately 21 years for these investments to be net beneficial to dairy farmers when considering extreme heat events specifically. This payback period estimate is very conservative however, because the benefits in the illustration above are only estimated for temperatures above the heat event threshold, and benefits will accrue to farmers and their herds even at much lower temperatures. For this reason, the payback period is likely to be much shorter than 21 years. In addition, with extreme temperature days increasing over time (for example, in the period 1981 to 2010 there were an average of 5.2 extreme event days in the Central Valley), if the future benefits considered future projections of high heat the payback would be even shorter.

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[*] See, for example, here: https://wcec.ucdavis.edu/improving-water-and-energy-efficiency-in-californias-dairy-industry/

7 | Areas for Further Research

This report provides a broad assessment of the costs of seven historical extreme heat events in California to the state's residents, businesses, and governments, in multiple sectors. The goal has been to make the assessment as comprehensive as possible, within existing data and methods limitations, as well as time and resource limitations established for this report. Nonetheless, because the study is focused on a select set of past events and because many impacts cannot be quantified or costs fully estimated, a full accounting of the annual historical costs and physical effect incidence is likely to be much higher than estimated here.

This section provides a short list of additional areas where further research could be beneficial in estimating a more complete accounting of the costs of extreme events in California; an improved assessment of the impacts on certain groups and the degree to which insurance coverages are available and/or prevalent as a means to distribute these risk; and in improving the breadth and depth of the analyses of the benefits and costs of adaptation actions geared toward reducing the impacts of extreme heat. In the end, the most important area for further research is identifying, assessing, and implementing actions to reduce these vulnerabilities. Insurance can certainly help – insured risks initiate a process of measuring the risk, quantifying the frequency and severity of the hazard that causes the risk, and then, when insureds are covered, providing a financial incentive for the insured and insurer to manage and mitigate that risk.

The key areas for further research developed by the authors of this report include the following:

- **Expand the Scope of Impacts Quantified**: This study provides cost estimates for a broad range of impacts of extreme heat, but there is evidence of other impacts of extreme heat which due to space and resource limitations were not included in the report. For example, a study by Park et al. (2020)[54] showed how extreme heat is associated with reductions in children's academic achievements, which can in turn affect the future income of graduating students – an analysis showing the effects could total billions of dollars in lost income across the U.S. is included in the U.S. EPA's *Climate Change and Children's Health and Well-Being in the United States* report, available here. These and other impacts not addressed in this report are evidence that further research could add to the understanding of a broader range of costs of extreme heat in California.

- **Consider Compound or Cascading Impacts**: Most of the work presented here focuses on the impacts of heat within specific sectors. The impacts of heat can span multiple sectors, however, or lead to a cascade of consequences which could be omitted when focusing on single-sector impacts. For example, recent research suggests that power outages have increased concern for health effects (see Casey et al. 2020[55]). While care is needed when considering compound or multi-sector impacts, to avoid double-counting of costs, greater focus on more complex linkages of the consequences of extreme heat across multi-sector pathways would likely result in still higher estimates of the cost of extreme heat than found in this study.

- **Refine and/or Provide More Detail Regarding Health and Cost Impacts for Differentially Sensitive or Vulnerable Populations**: Differentially high impacts of extreme heat on sensitive or vulnerable populations are identified in this report to the extent data and methods allow, but in many cases, there is some conceptual or empirical evidence of differential impacts that was not possible to incorporate in these estimates. In estimating the potential for disproportionate health incidence, for example, this study considers the spatial pattern of exposure to extreme heat, and differences in baseline health incidence that can reflect differences in population health status but does not consider differential sensitivity to extreme heat. Yet, as noted in the report elderly individuals tend to experience worse health outcomes from exposure to extreme heat than those of other age groups due to cardiac strain created by exposure to heat, and babies and young children sweat less than older people, limiting their body's ability to naturally cool.[56,57] Studies also examine the relationship between extreme temperature mortality and residence in an urban environment, poverty, identifying as a member of racial and ethnic groups including Black and African American and Hispanic and Latino individuals, suffering from social isolation, or working outdoors.[58,59,60,61,62] These differential sensitivities by age, race and ethnicity, and environment are apparent only in a small number of existing studies, most of which focus on localized events – for this reason they are less appropriate for the statewide analyses in this study, but they might be applied at a more localized level. In addition, a 2019 study by Son et al. found that out of 74 studies reviewed, half reported higher vulnerability of women to heat-related mortality compared to 12 that reported higher risks to men.[63] Future analyses of mortality impacts of extreme heat events could incorporate these findings and explore the impact across genders when reporting costs stratified by population subgroup.

- **Understand Government Expenditures on Extreme Heat Protection:** Currently most government spending on heat protection programs, either preventative or responsive to a particular event, is not tracked in a manner that allows those costs to be easily summed. A clearer understanding of annual expenditures, and trends over time, may help government entities, particularly local municipalities, to understand the costs of extreme heat and allow for informed decision-making regarding insurance choices.

- **Project the Impacts of Increasing Frequency and Severity of Impacts that Could Result from Climatic Change**: This study focuses on the impact of heat in historical events across California. Research on climate change, however, almost universally concludes that climate change will increase the frequency, severity, and spatial extent of extreme heat events in the future. As noted in this report, examination of the historical weather records shows that the number of extreme event days in California's Central Valley increased more than 40% in roughly one decade, from an average of 5.2 extreme event days in 1981 to 2010, to 7.4 days in 2013 to 2023. Continuation of these historical trends would show a pattern of steadily increasing costs of extreme heat impacts in the future.

- **Identify Key Metrics of Extreme Heat Impact and Vulnerability and Track Those Metrics Over Time.** Many of the impacts presented in this report are already tracked by state and local governments, public health departments, and utilities – for example hospital admissions associated with illness linked to extreme heat and power outages (and their causes, including extreme heat) are already tracked. Other impacts, though, are not currently tracked, such as increased expenditures on road and rail infrastructure, dairy cow mortality, and business and manufacturing interruptions. A process of developing a few key metrics of impact; mobilizing state, local, and private sector partners to collect data on these metrics over time; and using the results to measure trends and the results of investments to reduce these impacts could add substantially to public understanding of these effects and the efforts to mitigate risks.

- **Assess Insurance Coverages in Greater Depth**. This study provides an initial assessment of available insurance coverage for the impacts of extreme heat, but the result could be improved with a greater focus on survey research and broader canvassing of the insurance industry than was possible for this report.

- **Identify Additional Measures That Can Reduce Vulnerabilities to Extreme Heat, and Assess Their Efficacy, Benefits, and Costs.** This study examines three measures which could reduce extreme heat mortality (heat action plans; tree planting; and livestock cooling technologies), The breadth of the analysis is limited by lack of information on the efficacy of other measures that might be implemented, such as cool roofs and reflective road surfaces. As better information becomes available on the costs and efficacy of these measures in reducing impacts of extreme heat, analyses of risk mitigation actions should expand to include evaluation of these measures.

Appendix A | Extreme Heat Event Definition and Selection

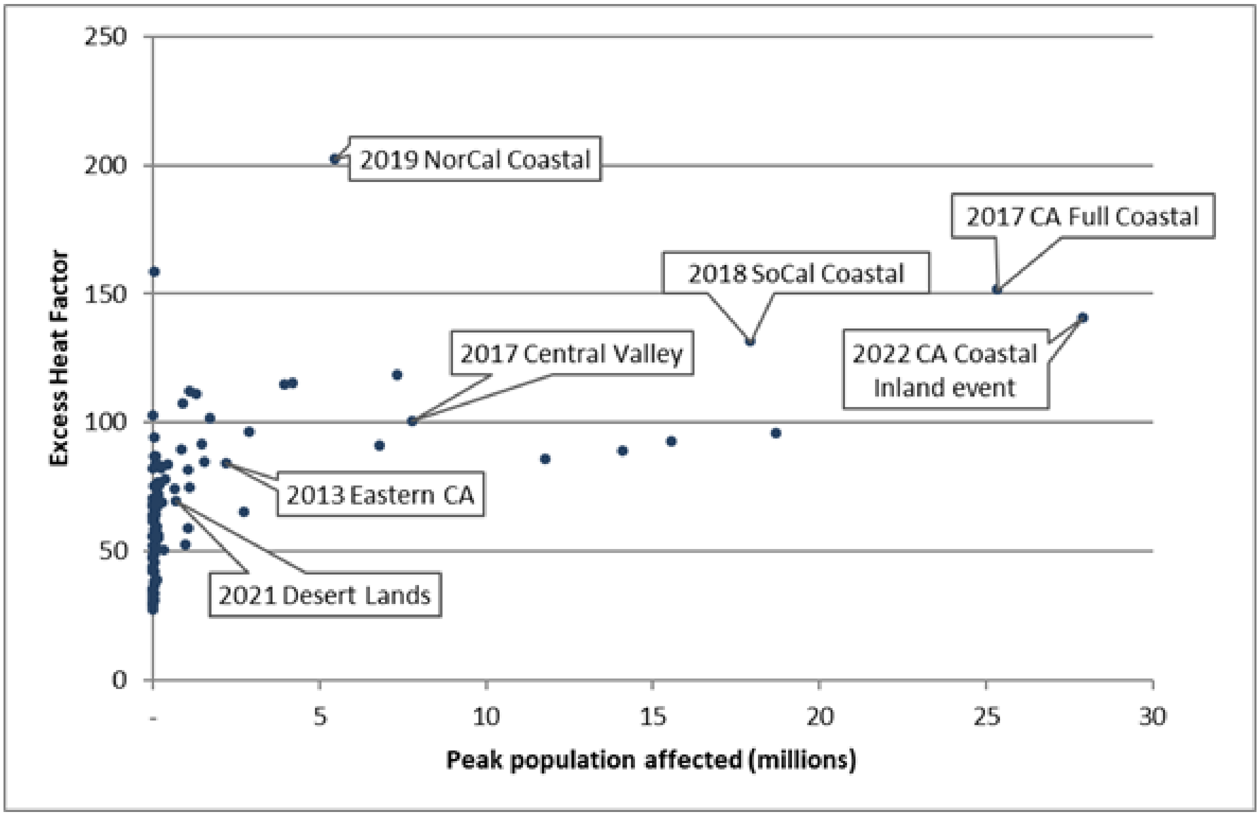
The table below summarizes the extreme heat event definitions considered as a basis for event selection in this study. These include options from California agencies, the National Weather Service, the Extreme Heat Resilience Alliance, and relevant academic literature. As described in Chapter 2 of the main text, the primary definition adopted for use in the study is the Excess Heat Factor method, which reflects heat relative to historic norms, humidity, and acclimatization considerations, and has been supported by the Extreme Heat Resilience Alliance. One event, the 2021 Desert Lands event, was selected using the Cal-Adapt 98th percentile temperature method, to ensure geographic coverage of arid areas in southeast California where the humidity is generally too low to trigger an exceedance of the Excess Heat Factor threshold.

Table A1. Extreme Heat Event Definitions Considered for this Study

Source	Adverse Heat Event Definition
Cal-Adapt and various California agencies	Four consecutive extreme heat days (i.e., when the daily maximum temperature exceeds the 98th historical percentile observed from 1961-1990) or warm nights (i.e., when the daily minimum temperature exceeds the 98th historical percentile observed from 1961-1990)
California Office of Environmental Health Hazard Assessment (CA OEHHA)	Five or more consecutive extreme heat days or nights make up a heat wave. On extreme heat days, temperatures are at or above the highest two percent of historical daily highs, while on extreme heat nights, they are at or above the highest two percent of historical daily lows.
National Weather Service (NWS) heat wave warning system, as documented in: Hulley et al.(2020).	NWS issues an excessive heat warning when the daytime heat index is expected to exceed 105°F and nighttime minimum temperatures are expected to stay 75°F for at least 48 hours. More recently, NWS has introduced an experimental HeatRisk forecast consisting of a daily value of expected heat risk for each 24-hr period on a 7-day forecast.
Watts and Kalkstein (2004).	Heat stress index (HSI) that incorporates apparent temperature and other derived meteorological variables (cloud cover, cooling degree-days, and consecutive days of extreme heat). The National Weather Service proposed an approach for standardizing the HSI and categorizing days as “extreme” and “severe.”
Excess Heat Factor method, as described in Nairn and Fawcett (2015).	Excess heat factor based on a three-day-averaged daily mean temperature; a calculation of apparent temperature that considers the impact of humidity; and a acclimatization factor, which considers differences between apparently temperature over the three days compared to the prior 30 days.
McElroy et al. (2020).	Considers and tests 18 definitions of heat waves using data from California and tests against hospitalization data.

The figure below provides additional context for the seven events chosen for this study. The graph shows all events (over 100 events in total) in the 2013 to 2022 period which met the heat, humidity, acclimatization, and event length definition of an Excess Heat Factor event, along with the maximum peak population affected for a single day during the event and the corresponding Excess Heat Factor value for that day. Data points for the seven events selected for study are annotated on the graph.

Figure A1. Peak Population Affected for All Events Exceeding the Excess Heat Factor Threshold for at Least Three Days, with Annotation of Seven Selected Events



Appendix B | Methods Details

Cost impacts presented in this report are derived from published literature and, with a few exceptions, publicly available data. Most of the details of the methods applied are omitted from the main document text for brevity. This appendix provides details for the following categories of impacts, organized by sector.

Table B1. Quantified Impacts of Extreme Heat

Category	Impact	Measure of Economic Cost to California used in this Study
Health and Safety	Mortality	Willingness-to-Pay to avoid fatal risks
	Hospitalizations and Emergency Department Visits	Cost of medical treatment and lost income
	Outpatient Visits	Cost of medical treatment
	Birth-related Outcomes	Lifetime cost of medical treatment
Economy	Dairy Productivity	Lost dairy farm revenue
	Dairy Cow Mortality	Replacement costs for herd
	Crop Agriculture Productivity	Lost crop revenue
	Manufacturing Productivity	Lost manufacturing GDP
	Reduced Work Time in Weather-Exposed Industries	Lost wages to workers
Infrastructure	Rail Costs	Repair and delay costs
	Road Costs	Repair and delay costs
Electricity	Costs of Power Outages	Customer interruption cost
Governance	Increased Demand for Government Services	Costs to local and state governments for road repairs during and after events

Note: Other impacts assessed qualitatively in the report are not described in this Appendix. Sources and methods used to characterize qualitatively assessed categories of impact are included in the main text and notes for those sections of the report. For those categories, data and methods do not support fully quantifying costs for California, or attributing costs to specific events.

Health and Safety Impacts

Table B2. Health: Premature Mortality Methods Summary

Step	Data and Notes
1a. Estimate Tmax days during extreme heat events	PRISM weather data, PRISM Climate Group, Oregon State University, https://prism.oregonstate.edu, Determine days on which daily maximum temperature exceeds 97th percentile threshold temperature by Census tract during extreme heat event. Excess mortality is estimated on these days, unless the day also meets the criteria for a Tmax day in the counterfactual scenario.
1b. Estimate Tmax days in counterfactual scenario	See above
2. Identify excess risk measure correlating extreme temperature and all-cause mortality	Excess risk measure from Rahman et al. (2022) Figure 3: Lag-0, above the 97th percentile, for extreme Tmax only days.
3. Estimate baseline incidence of mortality	Tract-level mortality incidence derived from USALEEP life tables (NHCS 2018), adjusted to year 2017. Sensitivity analysis conducted using county-level race- and ethnicity-stratified mortality incidence in BenMAP-CE, which is based on CDC WONDER data averaged over the years 2006 to 2017, as described in Appendix D of the BenMAP User Manual
4. Estimate population by Census tract	2010 Census total population by Census tract, stratified by age, race, ethnicity, and sex. Adjusted to year of extreme heat event using county-level growth weights from Woods and Poole (2015) built into BenMAP-CE.
5. Attribute premature mortality to extreme heat event by Census tract	Analysis conducted using BenMAP-CE. Estimate attributable premature mortality using health impact function based on excess risk from step #2, baseline incidence from step #3, and population from step #4 for each day above the threshold identified in step #1. Aggregate as needed to county and state totals. To generate race/ethnicity stratified standardized mortality rates for each event, re-run BenMAP using race/ethnicity specific incidence rates and stratify results by age (0-64, and 65 and older). Calculate crude rates by dividing attributable deaths for each race/ethnicity/age by the size of the affected population over the course of the extreme heat event. Age-standardize these race/ethnicity mortality rates by multiplying crude rates by the statewide proportion of Californians in each age group (below 65, 65 and above) according to the 2020 US Census. Sum the results to obtain a standardized rate for each race/ethnicity/event combination.
6. Estimate economic value of attributable premature deaths associated with extreme heat event	Multiply number of attributable premature deaths by estimate of VSL from Robinson and Hammitt (2015). Robinson and Hammitt estimate a VSL ranging from $4.2 million to $13.7 million with a midpoint of $9.0 million (2013 dollars). Adjusted to 2022 dollars, we employ a VSL of $11.2 Million.

Table B3. Health: Hospitalizations Methods Summary

Step	Data and Notes
1a. Estimate daily mean temperature during extreme heat events (**ARF**, **IS**, **MH**). Estimate Tmax days during extreme heat events (**R**).	PRISM weather data, PRISM Climate Group, Oregon State University, https://prism.oregonstate.edu, **ARF, IS, MH:** Estimate change in daily mean apparent temperature on extreme heat days relative to daily mean apparent temperature in counterfactual scenario. Exclude first day of heat wave per underlying study heat wave definition. **R:** Determine days on which daily maximum temperature exceeds 97.5th percentile threshold temperature by Census tract during extreme heat event.
1b. Estimate daily mean temperature (**ARF**, **IS**, **MH**) and Tmax days (**R**) in counterfactual scenario.	See above
2. Identify excess risk measure correlating extreme temperature and hospitalizations.	**ARF, IS, MH:** Relative Risks for Heat Wave from Sherbakov et al. (2018), single exposure model, Figure 2. **R:** Odds ratios from Schwarz et al. (2021), hw_975_1 model.
3. Estimate baseline incidence of hospitalizations	County-level incidence from California Department of Health Care Access and Information (HCAI). Stratified by race/ethnicity, insurance status (2013-2022).
4. Estimate population by Census tract	2010 Census total population by Census tract stratified by age, race, ethnicity, and sex. Adjusted to year of extreme heat event using county-level growth weights from Woods and Poole (2015) built into BenMAP-CE.
5. Attribute hospitalizations to extreme heat event by Census tract	Analysis conducted using BenMAP-CE. Estimate attributable hospitalizations using health impact function based on excess risk from step #2, baseline incidence from step #3, and population from step #4 for the given change in daily mean temperature (**ARF**, **IS**, **MH**) or for each day above the threshold identified in step #1 (**R**). Aggregate as needed to county and state totals.
6. Estimate economic value of attributable hospitalizations associated with extreme heat event	Multiply number of attributable ED visits by cost of illness unit value. Cost in 2022$ is estimated based on per visit charge data provided by (HCAI), adjusted using a statewide charge to cost ratio of 0.2327 for all CA hospitals and all health endpoints 2014-2021. Source: https://hcai.ca.gov/visualizations/hospital-financial-data-interactive-series-hospital-financials/ downloaded 02/13/24

Notes:

ARF = Acute Renal Failure; IS = Ischemic Stroke; MH = Mental Health; R = Respiratory

Table B4. Health: Emergency Department Visits Methods Summary

Step	Data and Notes
1a. Estimate daily max temperature during extreme heat events (**AC**). Estimate daily mean apparent temperature during extreme heat events (**MH**).	PRISM weather data, PRISM Climate Group, Oregon State University, https://prism.oregonstate.edu, **AC:** Estimate change in daily max temperature on extreme heat days relative to daily max temperature in counterfactual scenario. **MH:** Estimate change in daily mean apparent temperature on extreme heat days relative to daily mean apparent temperature in counterfactual scenario.
1b. Estimate daily max temperature (**AC**) and daily mean apparent temperature (**MH**) in counterfactual scenario.	See above
2. Identify excess risk measure correlating extreme temperature and ED visits	**AC:** Relative Risks for age 0-18 from Bernstein et al. (2022), Figure 3, all-cause mortality, overall RR. **MH:** Percent change in risk for ages 19-64 and 65+ from Basu et al. (2018), Figure 3, panel B.
3. Estimate baseline incidence of ED visits	County-level incidence from California Department of Health Care Access and Information (HCAI). Stratified by race/ethnicity, insurance status (2013-2022).
4. Estimate population by Census tract	2010 Census total population by Census tract stratified by age, race, ethnicity, and sex. Adjusted to year of extreme heat event using county-level growth weights from Woods and Poole (2015) built into BenMAP-CE.
5. Attribute ED visits to extreme heat event by Census tract	Analysis conducted using BenMAP-CE. Estimate attributable hospitalizations using health impact function based on excess risk from step #2, baseline incidence from step #3, and population from step #4 for the given change in daily max temperature (**AC**) or for the given change in daily mean apparent temperature identified in step #1 (**MH**). Aggregate as needed to county and state totals.
6. Estimate economic value of attributable ED visits associated with extreme heat event	Multiply number of attributable ED visits by cost of illness unit value. Cost in 2022$ is estimated based on per visit charge data provided by (HCAI), adjusted using a statewide charge to cost ratio of 0.2327 for all CA hospitals and all health endpoints 2014-2021. Source: https://hcai.ca.gov/visualizations/hospital-financial-data-interactive-series-hospital-financials/ downloaded 02/13/24

Notes:

AC = All Cause; MH = Mental Health

Table B5. Health: Outpatient Visits Methods Summary

Step		Data and Notes
1a.	Estimate daily max temperature during extreme heat events (**HROV**).	PRISM weather data, PRISM Climate Group, Oregon State University, https://prism.oregonstate.edu, **HROV:** Estimate change in daily max temperature on extreme heat days relative to daily max temperature in counterfactual scenario.
1b.	Estimate daily max temperature (**HROV**) in counterfactual scenario.	See above
2.	Identify excess risk measure correlating extreme temperature and outpatient visits	**HROV:** Percent change in risk from Vashishtha et al. (2018) study.
3.	Estimate baseline incidence of outpatient visits	County-level incidence for Medicare/Medicaid populations from the Centers for Medicare and Medicaid Services (CMS). Stratified by race/ethnicity (2013-2020).
4.	Estimate population by Census tract	2010 Census total population by Census tract stratified by age, race, ethnicity, and sex. Adjusted to year of extreme heat event using county-level growth weights from Woods and Poole (2015) built into BenMAP-CE.
5.	Attribute outpatient visits to extreme heat event by Census tract	Analysis conducted using BenMAP-CE. Estimate attributable outpatient visits using health impact function based on excess risk from step #2, baseline incidence from step #3, and population from step #4 for the given change in daily max temperature (**HROV**) identified in step #1. Aggregate as needed to county and state totals.
6.	Estimate economic value of attributable outpatient visits associated with extreme heat event	Using mean cost per visit provided from CMS.

Notes:
HROV = Heat-Related Outpatient Visits

Table B6. Health: Birth-Related Outcomes Methods Summary

Step	Data and Notes
1a. Estimate daily mean apparent temperature during extreme heat events (**LBW**, **SB**). Estimate Tmax days during extreme heat events (**PTB, GD**).	PRISM weather data, PRISM Climate Group, Oregon State University, https://prism.oregonstate.edu, **LBW, SB:** Estimate change in daily mean apparent temperature on extreme heat days relative to daily mean apparent temperature in counterfactual scenario. **PTB:** Determine days on which daily maximum temperature exceeds 98th percentile threshold temperature by Census tract during extreme heat event. **GD:** Determine days on which daily maximum temperature exceeds 97th percentile threshold temperature by Census tract during extreme heat event.
1b. Estimate daily mean apparent temperature (**LBW**, **SB**) and Tmax days (**PTB**, **GD**) in counterfactual scenario.	See above
2. Identify excess risk measure correlating extreme temperature and birth-related outcomes.	**LBW:** Percent change in risk from Basu et al. (2018) Table 3, Full gestation model. **PTB:** Hazard ratio from Ilango et al. (2020) Figure 2, HWD 12 (98th percentile, duration of 4 or more days). **GD:** Odds ratio from Teyton et al. (2023) Figure 1, 97th percentile, Tmax, gestational weeks 11-16. **SB:** Percent change in risk from Basu et al. (2016).
3. Estimate baseline incidence of birth-related outcomes.	**LBW, PTB:** County-level incidence from CDC WONDER Natality database (2013-2022). **GD:** County-level incidence from CDC WONDER Natality database (2016-2022). **SB:** County-level incidence from CDC WONDER Fetal Deaths database (2013-2021).
4. Estimate population by Census tract	2010 Census total population by Census tract for women aged 16-49, stratified by age, race, ethnicity, and sex. Adjusted to year of extreme heat event using county-level growth weights from Woods and Poole (2015) built into BenMAP-CE.
5. Attribute birth-related outcomes to extreme heat event by Census tract	Analysis conducted using BenMAP-CE. Estimate attributable birth outcomes using health impact function based on excess risk from step #2, baseline incidence from step #3, and population from step #4 for each day above the threshold identified in step #1 (**PTB**, **GD**) or for the given change in daily mean apparent temperature (**LBW**, **SB**) Aggregate as needed to county and state totals.
6. Estimate economic value of attributable birth-related outcomes associated with extreme heat event	Multiply number of attributable birth outcomes by cost of illness unit value. **LBW**: Value of $122,378 per birth <2,500 grams in 2022 dollars, adjusted from study's original dollar year of 2013 (Beam et al. 2020). **PTB**: Value of $79,298 per preterm birth in 2022 dollars, adjusted from study's original dollar year of 2013 (Beam et al. 2020). **GD**: Value of $6,496 per case of gestational diabetes, adjusted from study's original dollar year of 2017 (Dall et al. 2019) Note that stillbirths are not valued by this analysis due to lack of information in the literature.

Notes:

LBW = Low Birth Weight; PTB = Preterm birth; GD = Gestational Diabetes; SB = Stillbirth

Regarding the CDC Wonder natality data, from the Centers for Disease Control and Prevention, National Center for Health Statistics. National Vital Statistics System, Natality on CDC WONDER Online Database. Data are from the Natality Records 2007-2022, as compiled from data provided by the 57 vital statistics jurisdictions through the Vital Statistics Cooperative Program. Accessed at http://wonder.cdc.gov/natality-current.html on Oct 10, 2023 1:18:13 PM

Regarding the CDC Wonder fetal death data, Centers for Disease Control and Prevention, National Center for Health Statistics. National Vital Statistics System, Fetal Deaths on CDC WONDER Online Database. Data are from the Fetal Death Records 2005-2021, as compiled from data provided by the 57 vital statistics jurisdictions through the Vital Statistics Cooperative Program. Accessed at http://wonder.cdc.gov/fetal-deaths-current.html on Oct 16, 2023 11:57:52 AM

Economy Impacts

Table B7. Economy: Dairy Productivity

Step	Data and Notes
1a. Calculate the temperature-humidity index (THI) by day and Census tract during each extreme heat event	PRISM weather data, PRISM Climate Group, Oregon State University, https://prism.oregonstate.edu, THI formula comes from National Oceanic and Atmospheric Administration (1976), Livestock Hot Weather Stress. Operations Manual Letter C-31-76, Department of Commerce, NOAA, National Weather Service Central Region, Kansas City.
1b. Calculate the THI by day and Census tract during baseline (median temperature days)	See above
2. Calculate dairy productivity loss for 1a and 1b (kg/day/cow)	Loss formula from St-Pierre et al. (2003)
3. Estimate productivity losses per day per cow above baseline levels	LOSS(1a) – LOSS(1b)
4. Estimate the number of dairy cows by Census tract	Use GIS data on location of dairy farms to approximate the spatial distribution of dairy cows by Census tract Number of dairy cows per county (USDA 2022) Location of Dairy Farms (California Biomass Collective)
5. Calculate total dairy productivity losses (kg)	Results from 3 * Results from 4
6. Estimate total losses to producers ($)	Results from 5 * producer price of milk Price data for Northern CA (CDFA) and Southern CA (CDFA)

Table B8. Economy: Dairy Cow Mortality

Step	Data and Notes
1a. Calculate the temperature-humidity index (THI) by day and Census tract during each extreme heat event	See Step 1a for “Dairy productivity”
1b. Calculate the THI by day and Census tract during baseline (median temperature days)	See Step 1b for “Dairy productivity”
2. Approximate a total THI load for 1a and 1b	THI load formula from St-Pierre et al. (2003)
3. Calculate dairy cow mortality rate (monthly death rate?) for 1a and 1b	Mortality formula from St-Pierre et al. (2003)
4. Estimate mortality rate above baseline levels	PDeath(1a) – PDeath(1b)
5. Calculate total dairy cow mortality attributable to event	Results from 3 * Results from 4
6. Value lost dairy cows	St-Pierre et al. (2003) applies $1,800 per dairy cow (in 2003 dollars). Adjusted to 2023, the value is approximately $3,000 per dairy cow.

Table B9. Economy: Crop Agriculture Losses

Step	Data and Notes
1. Calculate county-month level total insurance claims caused by heat during months with chosen extreme heat events	Cause of Loss (USDA 2022) Select “heat”, “drought”, “failure of irrigation equipment”, “hot wind”, and “failure of irrigation supply”
2. Identify portion of cropland uninsured by county	Apply state-level California Crop Insurance Uptake (USDA 2022, USDA 2017, USDA 2013) to county-level distribution of acres by crop type (GIS.Data.CA 2019) to approximate a weighted-average area of insured and uninsured land
3. Impute total crop loss	Assuming uninsured crop land experiences losses at the same rate as insured crop land Total crop losses = Results from 1 / Results from 2

Table B10. Economy: Manufacturing Productivity Losses

Step	Data and Notes
1. Standardize heat events into “week equivalents” at the Census tract level	Paper below describes losses per week
2. Identify “baseline” weekly productivity across manufacturing in affected Census tracts	Use GIS data on location of manufacturing plants to approximate the spatial distribution of manufacturing GDP by Census tract County level manufacturing GDP: BEA (note: this data source uses the Sector 31-33 2012 NAICS code definition of manufacturing) GIS: Location of manufacturing plants: US Dept of Homeland Security
3. Estimate reduction in manufacturing productivity during heat event by Census tract	Based on findings from Cachon et al. (2012), assume 8 percent loss in productivity for one week during heat event Note: This paper is specifically about auto manufacturing, but we extrapolating to all manufacturing in California.
4. Account for HVAC in manufacturing facilities	In consult with the U.S. EIA, we approximate the number of manufacturing facilities in California with HVAC systems using data on the portion that installed or retrofitted HVAC systems in the latest MECS. The EIA reports 26.9 percent of manufacturing facilities did so in 2018 (2018 MECS from EIA Table 8.1). Thus, we assume 73.1 percent of manufacturing facilities do not have HVAC systems and multiply our results from Step 3 by 0.731 (1-0.269).

Table B11. Economy: Reduced Work Time in Weather-Exposed Workers

Step	Data and Notes
1a. Estimate number of degree days over 90F during heat event	PRISM weather data, PRISM Climate Group, Oregon State University, https://prism.oregonstate.edu,
1b. Estimate number of degree days above 90F in the baseline	See above
2. Calculate total degree days over baseline	Results from 1a – Results from 1b
3. Identify number of works in construction, transport/utilities, mining, ag/forestry/fishing/hunting, and manufacturing	American Community Survey (five-year average) Note: These are the sectors covered in Neidell et al. (2021)
4. Calculate total work time losses	Degree days over 90 (Results from 2) * number of workers (Results from 3) * 2.59 minutes lost (from Neidell et al. 2021)
5. Value lost work time using wages in affected industries	BLS State Occupational Employment and Wage Estimates (OEWS) for California Farming, Fishing, and Forestry Occupations: $17.65 / hr Construction and Extraction: $33.48 / hr Production: $23.40 / hr Transportation and Material Moving: $22.54 / hr

Infrastructure Impacts

Table B12. Infrastructure: Rail Methods Summary

Step	Data and Notes
1. Compile data on results of rail repair and delay costs from existing research/modeling	Baseline period (1986-2005) annual costs per census tract (Neumann et al. 2021). Focus on Reactive adaptation scenario results, which are costs associated with reactive actions to combat thermal rail buckling, namely speed decreases to reduce thermal load during high temperatures. Speed decreases lead to rail user delays. Results are from a simulation model, not actual incurred costs.
2. Compile Temperature Data for each year of 20-year baseline	PRISM weather data, PRISM Climate Group, Oregon State University, https://prism.oregonstate.edu/, Number of days over tract-level 90th percentile temperature, Number of days over the 95th percentile, Number of days over the 98th percentile.
3. Calculate baseline delay and repair cost per mile of rail track	Rail mileage from CA.gov Open Data Portal. Cost per census tract (from step 1) / miles of rail per census tract
4. Establish relationship between annual cost per mile of rail track and event days over 90th, 95th, and 98th percentile, using statistical techniques	Using regression estimation technique, relate tract-level annual cost to tract-level number of days year above 98th, 95th, and 90th percentiles. Analysis identified these three variables as providing the best fit temperature metrics for our estimation
5. Estimate per mile costs on rail infrastructure for the year of each heat event, both with and without the event, for each event	Use function: Regression intercept (1,485) + (YearlyDaysOver90th*71) + (YearlyDaysOver95th*95) + (YearlyDaysOver98th*1043)
6. Scale up using tract- level miles, and aggregate data to county level	Function returns marginal cost per mile, need to re-scale using miles per tract to estimate total costs. Aggregate over tracts

Table B13. Infrastructure: Road Methods Summary

Step	Data and Notes
1. Compile data on results of road repair and delay costs from existing research/modeling	Baseline period (1986-2005) annual costs per census tract (Neumann et al. 2021).
2. Compile Temperature Data for each year of 20-year baseline	PRISM weather data, PRISM Climate Group, Oregon State University, https://prism.oregonstate.edu,
3. Calculate baseline delay and repair cost per mile of road	Road mileage from Neumann et al. study. Cost per census tract (from step 1) / miles of road per census tract
4. Establish relationship between annual cost per mile of road and event days over 90th, 95th, and 98th percentile, using statistical techniques	Using regression estimation technique, relate tract-level annual cost to tract-level number of days year above certain thresholds. Results show threshold of 90th percentile events is meaningful, above that threshold is not meaningful.
5. Estimate per mile costs on road infrastructure for the year of each heat event, both with and without the event, for each event	Use function: Use function: Regression intercept (-17.67) + (YearlyDaysOver90th*14.89)
6. Scale up using tract- level miles, and aggregate data to county level	Function returns marginal cost per mile, need to re-scale using miles per tract to estimate total costs. Small number of tracts with negative values (only possible with less than two 90th percentile days during period) reset to zero. Aggregate over tracts

Electricity Impacts

Table B14. Electricity: Costs of Power Outages

Step	Data and Notes
1a. Process outage data to heat event-level for four events with available data (2018 SoCal Coastal, 2019 NorCal Coastal, 2021 Desert Lands, and 2022 CA Coastal Inland).	Combine outages in the same county during the event period into single outage event for each heat event. County-level daily outage data obtained from PowerOutage.us.
1b. Estimate outages by type of energy user.	Using ICE's residential, small commercial and industrial, and medium and large commercial and industrial customer count data at the state level, distribute customers to counties based on each county's proportion of state residential and non-residential usage, calculated from CEC data.
2. Calculate outage statistics.	Calculate System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI) from processed outage data. SAIDI = Customer Hours Out/Customers Tracked SAIFI = 1
3. Calculate the baseline costs of outages for each heat event.	Baseline costs of outages are calculated using the ICE cost model for each of the event periods as the average cost across the same date range in all non-event years in the study period (2018-2022).
4. Calculate the costs of outages during the identified heat events.	Costs of outages during heat events are calculated using duration and frequency statistics calculated in step 2 and the ICE outage cost model.
5. Estimate outage costs above baseline during heat events.	Cost(4) - Cost(3)
6. For three events without available data (2013 Eastern CA, 2017 Central Valley, and 2017 CA Full Coastal), estimate outage costs using observed data from other events.	Calculate average per-customer, per-event-day outage cost for the events with available data. Using tract-level customer (calculated as in Step 1b) and event day data, calculate outage costs.

Notes:

In distributing customers at the state level to counties and tracts, we assume linear relationships between number of users and total usage for both residential and non-residential user and usage data. Non-heat-driven outages may be captured in both event and baseline costs, so net costs should be minimally affected by unrelated outages. In Step 6, the 2019 NorCal Coastal event is excluded from the average cost calculation because its per-customer, per-event-day outage costs were significantly higher than the other three events with available data.

Governance Impacts

Table B15. Governance: Road Repair Costs by Jurisdiction

Step	Data and Notes
1. Identify the number of miles of road maintenance jurisdiction by county.	Source: CalTrans. 2023. California Public Road Data 2021: Statistical information Derived from the Highway Performance Monitoring System. April 2023 (link)
2. Adjust total road costs from the infrastructure category to reflect just repair costs.	Road costs include repair cost (paid by government entities) and delay costs (borne by all road users). Previous studies conducted on data from the same underlying study (Neumann et al. 2021) found that about 80 percent of total costs were related to repair. We use this estimate to approximate this breakdown in California.
3. Attribute county-level repair costs to jurisdictions in each county based on the county-level proportion of miles maintained.	Summarize by event.

Appendix C | Insurance Product Availability Research

One key source of information for this study was shared insights from insurance industry professionals with knowledge of coverages relevant to the extreme heat impacts explored in this report. This appendix summarizes the result of this insurance industry research.

Interview Approach

Representatives of the Department of Insurance and Industrial Economics arranged interviews with the following insurance industry contacts – the Project Team wishes to thank all interviewees for offering their time and sharing their expertise, their insights have improved this report, but the Project Team is solely responsible for any remaining errors or omissions in this report:

1. **Swiss Re:** Yommy Chiu and Jackie Higgins, on October 16, 2023 – this interview was broad in scope, reviewing all possible types of coverage that might address the extreme heat peril.
2. **AON:** Katie Sabo and Cole Mayer on October 17, 2023 – this interview was wide-ranging but also had a particular spotlight on relevant coverages for municipal government entities.
3. **AON:** Scott Barhorst on October 31, 2023 – this follow-up interview with AON was particularly focused on agricultural sector coverages and data sources.
4. **Insurance Information Institute (III):** Janet Ruiz on November 14, 2023 – this interview as focused on information sources, reports, and other data availability on relevant coverages, particularly data and information relevant to III's mission.

The interviews were focused on refining a tabular summary of the categories of extreme hat impacts and a draft presentation of possible insurance types relevant for that impact category. The discussions centered on answers to the following three questions:

1. What types of insurance products are available to cover the impacts of extreme heat?
2. What is the extent of coverage for the particular products related to extreme heat?
3. What data are available to quantify coverage and past claims?

Data on the extent of coverage was generally not publicly available, though the experts interviewed did in some cases share professional judgement on the breadth and nature of insurance covered entities for select categories of impacts.

Summary of Results

Results of the interviews are provided in Table C1 below. The table includes 19 of the 20 metrics in the scope of this report – discussion of insurance coverage was omitted for the Workplace Injuries impact category because characterization of that impact is directly based on worker's compensation insurance claims data. The second column of the table provides a summary of the project team's initial research on possible coverages, and the last column provides a summary of the interviewee's collective responses.

Table C1. Summary of Research on Insurance Coverage for Extreme Heat Impacts

	Categories of Extreme Heat Costs Explored in the Report	Project Team Assessment of Potential of Insurance Coverages for Impacted California Entities	Summary of Insurance Industry Interviewee's Responses
HUMAN HEALTH			
1	Human mortality	Medical insurance, life insurance	Interviewees were not directly or indirectly engaged in provision of medical or disability insurance coverage, although they generally confirmed these coverages were applicable to the extreme heat peril. For life insurance coverage, multiple interviewees referenced to a summary of the LIMRA 2023 Insurance Barometer Study which is cited and used in this report.
2	Hospitalizations & ED visits	Medical insurance, short-term disability coverage	
3	Outpatient visits	Medical insurance	
4	Prenatal outcomes	Medical insurance, short-term disability coverage	
AGRICULTURE			
5	Dairy productivity	Business interruption, dairy farm insurance	USDA's Dairy Revenue Protection program has been in effect since 2018, with subsidized premiums, also applies to heat. There is also a private product by Scor specifically focused on heat impacts, but which may currently have low overall uptake.
6	Dairy cow mortality	Project Team found some dairy farm insurance, but heat is not listed as a source of cover loss.	Theare are two options which could apply for heat effects: 1. Actual mortality coverage (like life insurance), or where cows part of "farm capital" coverage – estimated that 75 percent of cows are insured by one of these options; 2. Preventative "health insurance" type option – used by some big dairy companies but overall there is limited uptake.
7	Crop agriculture productivity	Federal crop insurance is primary. Private insurance options such as weather index policies (uptake unknown)	Federal crop insurance mostly removes the need for private or secondary insurance, with an exception being organic/conservation practices farms which have lower uptake of USDA products owing to standardized crop-specific production history basis. Parametric coverage is an option, but more likely for frost than heat events.
ECONOMY			
8	Manufacturing productivity	Business interruption (standard based on damage, and also newer non-damage-based business interruption based on index or parametric hazard)	Most coverages do not apply to heat peril. There are some instances where policies apply – for example if road or construction crews cannot work but are paid, these losses can be covered.
9	Lost wages to weather-exposed workers	Workers' compensation or short-term disability?	While there are some coverages that apply for employers of weather-exposed workers (see above), wage recovery for employees might only apply if there is a heat-related injury or illness incurred while working.
10	Lost business revenue from closures or shifting consumer demand	Business interruption insurance, perhaps under limited conditions of typical riders.	Most business interruption insurance requires property damage to trigger coverage – a condition not typically present for heat events.
INFRASTRUCTURE			
11	Rail repair and delay costs	General business or business interruption insurance (particularly for freight users, perhaps for carriers also?)	Interviewees generally agreed these are coverage gaps for public and private entities.
12	Road repair and delay costs	General business or business interruption insurance?	

Categories of Extreme Heat Costs Explored in the Report		Project Team Assessment of Potential of Insurance Coverages for Impacted California Entities	Summary of Insurance Industry Interviewee's Responses
13	Airport delays	Travel insurance for consumer delays, business interruption or parametrics for carriers	Passengers are covered for at least some delays if they purchase travel insurance. Airport operations may be covered by certain extreme weather events (e.g., snowstorms that close airport) but more difficult to structure a policy for heat events/impacts.
14	Costs of power outages	Business interruption for commercial, homeowners/rental/property insurance if it leads to property damage (also health insurance may apply)	No specific coverages were mentioned in interviews; this report therefore references available information from DOE and GAO research, which acknowledges low or no insurance coverage for distribution and transmission infrastructure.
15	Costs of residential energy for consumers	Believed to be uninsured as of December 2023	
16	Electricity distribution and transmission infrastructure repairs	General business or business interruption insurance for utility providers.	
GOVERNANCE			
17	Local government heat event response costs (e.g., cooling centers)	Unknown	All of these categories, as well as others, can potentially be covered by parametric/index- based policies currently available in the market and could be based on temperature indices (such as X days above Y minimum temperature). There is some potential for FEMA duplication of benefits – existing policies include provisions on FEMA payout integration. Existing policies in force focus on wildfire, earthquake, and flood perils for public entities – no examples so far for heat peril, but there are no obstacles to a heat-based policy.
18	Lost tax revenue	Believed to be uninsured as of December 2023	
19	Increased demand for government services	Believed to be uninsured as of December 2023	

Note: The interviews did not discuss the Workplace Injuries impact category, because that impact is based on worker's compensation claims data and so is clearly connected to worker's compensation coverage (required for all employers on behalf of their employees under California Labor Code Section 3700, but not necessarily for independent or contract workers).

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