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INSURING *Extreme Heat* RISKS

Scoping the potential for insurance innovation to support heat mitigation and response

DECEMBER 2020
Policy Report

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FOREWORD

California Insurance Commissioner Ricardo Lara

Extreme heat is one of the most urgent public health and economic issues of our time, and a risk that has never been fully recognized by policymakers. *Insuring Extreme Heat Risks* will further action at the state and local level to better prepare for and mitigate this climate risk that millions of residents are already facing.

I commissioned this visionary report because of the immediate impacts from extreme heat that already are rippling through communities, especially our most vulnerable communities. California's recent catastrophic wildfires are the most obvious example, with hotter, drier summers stressing our forests and contributing to explosive fires. As I pursue insurance solutions to increasing climate risk, extreme heat must be part of the agenda. The magnitude and duration of extreme heat events are climate risks for jurisdictions throughout the world, and the California Department of Insurance is leading the way through research collaborations such as this one and national and international partnerships.

As we look at the impact of extreme heat waves in 2020, we can project a future where families and seniors living without air conditioning, with medications and food that need to be kept cool, face serious health consequences. In California's sun-baked fields and sweltering warehouses, heat waves punish agricultural workers and packers and the businesses that drive our economy. More extreme heat events will continue to strain local governments' response, including the deployment of cooling centers, as well as our public health and emergency response safety nets.

This is our window for action to prevent the most dire scenarios.

Scientists now know more about the significant health impacts of high temperature, their duration, and the lack of recovery time if temperatures do not drop in the evenings. We have an urgent need for policymakers to work on ways to mitigate the compounding impacts of heat events, and innovative insurance solutions have the potential to strengthen local planning and response. Businesses have an important role to play through market-based mechanisms such as insurance that can guard against crop damages and community health impacts.

As we have with so many other climate challenges, from reducing super pollutants, increasing clean air vehicles, and mitigating wildfires, California has an opportunity to be creative and proactive in confronting the challenge of extreme heat.

I welcome *Insuring Extreme Heat Risks* and look forward to working with its authors as we create innovative solutions that protect California's residents.

Ricardo Lara
CALIFORNIA INSURANCE COMMISSIONER

DECEMBER 2020 | POLICY REPORT

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ABOUT THE CENTER FOR LAW, ENERGY & THE ENVIRONMENT

The Center for Law, Energy & the Environment (CLEE) channels the expertise and creativity of the Berkeley Law community into pragmatic policy solutions to environmental and energy challenges. CLEE works with government, business and the nonprofit sector to help solve urgent problems requiring innovative, often interdisciplinary approaches. Drawing on the combined expertise of faculty, staff and students across University of California, Berkeley, CLEE strives to translate empirical findings into smart public policy solutions to better environmental and energy governance systems.

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CONTENTS

EXECUTIVE SUMMARY

As the physical risks of climate change unfold and intensify, extreme heat events—which already exact a significant toll on human health in the United States and across the world—will become more frequent and severe. These impacts will hit hardest in cities due to the urban heat island effect (in which urban areas experience increased and sustained heat exposure due to their highly built environments), in lower-income and disadvantaged communities where resilient infrastructure is most limited, and for vulnerable populations including seniors and the unhoused. An increasingly robust body of science is identifying the benefits of measures to address extreme heat (including built infrastructure, natural resources, and social responses) and a growing number of governments are developing comprehensive heat resilience plans. But they often lack institutional and financial capacity to implement these responses, requiring additional policy and market support.

This report assesses the potential for risk transfer mechanisms, including insurance-based or other financial instruments, to address the local government, public health system, community, and other costs of climate change-related extreme heat while promoting risk-mitigating investments. Key findings include:

- Extreme heat is responsible for thousands of deaths and hospitalizations throughout the United States every year, and extreme heat days are expected to increase exponentially throughout California in the coming decades. Extreme heat also reduces labor productivity, threatens infrastructure and supply chains, hurts educational attainment, and impairs outdoor industries from agriculture to construction to tourism.
- A group of infrastructure investments—including tree canopy, cool and green roofs, and cool surfaces—can significantly reduce ambient temperatures, while immediate response efforts, from public cooling centers to mass communication efforts, are generally effective in protecting vulnerable populations. Researchers are increasingly able to measure the temperature, public health, and economic benefits of these interventions.
- Local governments are crafting comprehensive heat mitigation and response plans combining five types of resilience infrastructure: natural, built, social, communications, and planning. These plans will rely on significant coordination across government and private capacities, as well as new funding streams.
- Insurers and financiers have developed innovative mechanisms to address climate risks and adaptation, including parametric insurance and catastrophe and resilience bonds. These instruments hold significant potential for extreme heat risk transfer, but a number of questions—including the need for more complete data demonstrating the costs of extreme heat and value of resilience investments, and the lack of a clear insurance 'customer' for extreme heat—remain open.
- A model for risk transfer to support and incentivize comprehensive extreme heat mitigation and response could include the following elements:
    - Development of a comprehensive local extreme heat plan including appropriate components across natural, built, social, communications, and planning infrastructure.
    - Analysis of financial implications of heat plan implementation including the cost of mitigation investments and responses; anticipated temperature reductions; expected health impact of social and communications investments; and estimated savings generated by these measures.
    - Certification of the heat plan through a model "performance contract" that identifies necessary plan components and monitors achievement of key milestones and adherence to recurring plan elements.
    - Establishment of a local heat vulnerability index including multiple trigger points at different daytime and overnight temperatures and time periods in multi-day extreme heat event.

- Creation of an insurance policy with payouts linked to heat triggers, vulnerability indicators, and appropriate responses from the heat plan, to provide financial support where and when it is most needed.
- Provision of premium discounts or other subsidies for investment in and maintenance of long-term heat mitigation infrastructure.

The report concludes that there is substantial overlap between the risk transfer mechanisms that insurers and governments have developed to address climate-related risks and the particular threat posed by (and tools to address) extreme heat. However, a number of outstanding needs must be addressed in order to develop a risk transfer model that properly aligns the relevant incentives. Section I provides an overview of extreme heat event impacts and analysis, the investments that can be made to mitigate them, and the public benefits of those investments. Section II reviews a range of leading local and regional heat mitigation plans and initiatives. Section III briefly identifies legal considerations for extreme heat preparation, response, and risk transfer in California. Section IV identifies existing insurance and risk transfer innovations that may be applied to climate change-related risks and natural infrastructure-based mitigation. Section V identifies the key determinants of feasibility for a potential extreme heat risk transfer and mitigation framework and outlines complementary mechanisms that could form such a framework; Section VI proposes potential models for this framework; and Section VII offers a set of policy, research, and collaborative next steps for local governments, insurance, and public health leaders.

There is substantial overlap between the risk transfer mechanisms that insurers and governments have developed to address climate-related risks and the particular threat posed by extreme heat. However, a number of outstanding needs must be addressed in order to develop a risk transfer model that properly aligns the relevant incentives.

INTRODUCTION

Among the many risks posed by climate change, extreme heat has perhaps the greatest potential to threaten life and health on a regular basis. The insurance and financial sectors are developing innovative approaches to address climate-related risk, but extreme heat presents a particularly complex challenge.

CLIMATE CHANGE AND EXTREME HEAT

Climate change will amplify (and is already accelerating) a range of physical risks to life, health, and property throughout the world, including more frequent and intense wildfires; sea level rise and coastal flooding; extreme storm events and inland flooding; increased drought; and extreme heat.[1] Each of these risks will exact a significant toll worldwide, and in particular in California due to the state's diverse climate and topography, development patterns, and populations. Insurers, the providers of risk-transfer instruments that allow individuals, businesses, and governments to manage the financial risks associated with these threats, will face industry-wide stress as climate change stretches their risk assessment and management capabilities. Yet they will also have new opportunities to engage in proactive risk mitigation efforts that help reduce exposure to climate-related threats.[2]

Extreme heat, including city-scale impacts amplified by the urban heat island effect, is a leading climate risk and weather-related cause of death in the U.S. While the federal Centers for Disease Control and Prevention (CDC) estimate over 600 deaths per year nationwide due to extreme heat, recent analyses incorporating the full range of excess deaths attributable to heat place that number as high as 5,000 to 12,000 per year, with thousands more deaths per year expected by midcentury.[3] Extreme heat can also cause stress to the built and physical environments, such as infrastructure and disruption costs to electrical utilities, transportation, and construction and other outdoor labor businesses. Under high-emission scenarios, total US population heat exposure to local extreme heat may increase by nearly 30 times by 2100.[4]

These impacts are of particular concern in California, with tens of millions of residents in Southern California and the Central Valley exposed to regular high heat risks that will increase due to climate change. According to the California Department of Health and California Environmental Protection Agency (CalEPA), by the end of the century at least 10 of California's major cities could experience 75 or more extreme heat days (defined as exceeding the 98th percentile of historical baseline temperatures) per year, including more than 100 days in each of Los Angeles, San Diego, San Jose, and San Francisco.[5] The late summer 2020 heat wave, which set record high temperatures (and fueled record-setting wildfires) throughout the state, offers a preview of the conditions the state is likely to face.[6]

Extreme heat events cause human health risks like heat stroke and heat exhaustion, exacerbate underlying morbidity and mortality, and trigger associated response costs borne by local governments, public health systems, and communities.[7] These impacts are felt most acutely in low-income and minority communities, which are disproportionately likely to suffer extreme heat without access to the health, infrastructure, and social systems best suited to address it.[8] And in many cases, this disproportionate exposure to the threat of extreme heat is the result of decades of planning and housing policy decisions that consistently left communities of color with fewer trees and green spaces that offer cooling benefits, and in closer proximity to highways and other infrastructure that raise temperatures.[9]

Extreme heat events cause human health risks like heat stroke and heat exhaustion, exacerbate underlying morbidity and mortality, and trigger associated response costs borne by local governments, public health systems, and communities. These impacts are felt most acutely in low-income and minority communities.

As these risks accelerate, governments will face new challenges and opportunities in implementing both immediate public health responses and long-term investments to mitigate the harmful effects of climate-driven extreme heat.[10] Advanced efforts combining satellite data, remote sensing, and volunteer tracking have the potential to enhance detailed, community-scale understanding of extreme heat patterns and inform locally appropriate responses.[11] Some jurisdictions have begun to prepare innovative heat action plans that can leverage such data, from robust heat elements contained in comprehensive climate resilience plans to stand-alone plans dealing with urban tree canopy. But the funding streams and planning capacities needed to execute these plans are largely not yet coordinated, and in many cases they exceed current capacities. And the response to the COVID-19 pandemic—including shelter-in-place measures, social distancing requirements, and business closures—will have significant implications for community vulnerability to extreme heat and the ability of local governments to effectively implement response actions.

In 2018, then-California State Senator (and current Insurance Commissioner) Ricardo Lara sponsored Senate Bill 30 (Chapter 614, Statutes of 2018) to form a working group focused on identifying "risk transfer market mechanisms that promote investment in natural infrastructure to reduce the risks of climate change related to catastrophic events."[12] The law was intended to facilitate development of financial and insurance mechanisms that create incentives for risk-reducing and mitigating investments; cover public safety, property and infrastructure, and public utilities; can apply at community scale or greater; and can be profitable. In 2019, Commissioner Lara convened the Department of Insurance's Climate Insurance Working Group, which seeks to identify and propose insurance-based solutions to climate risks, including extreme heat.[13]

And in August 2020, Commissioner Lara joined the Extreme Heat Resilience Alliance, a multi-sector coalition formed to craft innovative heat risk solutions, including extreme heat risk transfer products and insurance-based mechanisms.[14]

INSURANCE, INCENTIVES, AND CLIMATE CHANGE RESILIENCE

Insurance and other risk-transfer instruments exist primarily to shift risk of financial loss from a party unable to bear a major loss (but able to pay regular premiums) to an entity with the ability to pool risk and withstand potential loss.[15] Essential criteria for this risk-transfer to function include:

- Risks are random, rather than certain, to allow for compensation at full cost;
- Risks are sufficiently well understood to allow for modeling and pricing;
- Risks can be pooled across multiple insured parties to ensure diversity; and
- Insured parties are not disincentivized to invest in risk mitigation.[16]

Climate-driven disasters are rapidly evolving and accelerating risks that could defy these criteria, given their relative lack of historical precedent, their interrelated nature, and their potentially all-encompassing regional impacts. Experts have characterized natural systems and infrastructure as having "insurance value" due to their capacity to support resilience, but identifying clear monetary values—particularly for the urban context—to inform policy and investment decision-making remains a challenge.[17] While there is great need for insurance to address the protection gap between the massive climate risks facing society and level of coverage for those risks, adequately linking insurance and climate resilience may require a number of innovations across insurance, risk-assessment, and policymaking capacities.[18]

Identifying an appropriate insurance 'customer' with responsibility to address heat risks and an incentive to purchase insurance to support that response presents a particular challenge. The diffuse nature of most climate risks has been a barrier to effective climate policy-making for decades, and the distribution of extreme heat impacts—across individuals, public health systems, employers, and some infrastructure—may inhibit effectively coordinated public response in general and insurance-based approaches in particular. Where climate risks are amenable to insurance-based solutions, private property owners' financial incentives to protect against catastrophic damage may play an essential role.[19] Thus, for example, insurers and governments have begun to develop innovative financial risk-transfer models to help protect coastal communities from climate-driven storm surge events, integrating the shared public and private interest in health, infrastructure, and economic continuity.[20] In 2018, the Mexican state of Quintana Roo, The Nature Conservancy, and Swiss Re pioneered a form of parametric insurance in connection with a coral reef that protects local coastline and resort properties: the local government and resorts jointly fund a trust dedicated to protecting coastal resources; the trust purchases a parametric insurance policy, with payouts triggered by predetermined hurricane wind levels; and payouts are returned to the trust for reef recovery activities.[21] This novel framework uses the shared public and private interest in a natural resource to support disaster recovery and risk mitigation investment.

However, the nature and structure of extreme heat risks pose a particular challenge to insurability principles. Extreme heat impacts primarily threaten the health and productivity of vulnerable populations, rather than discrete and identifiable physical assets; can transpire over many days in escalating fashion; are supported by a relatively limited set of historical analyses; and are mitigated through an especially broad set of immediate and long-term responses.

A growing body of science is developing to assess and model the nature of extreme heat events, their public health impacts, and the ability of investments in urban vegetation and cool surfaces to mitigate them. These analyses and data support heat mitigation plan implementation, helping governments to craft locally appropriate comprehensive plans and target investments efficiently. Innovative risk transfer instruments could in turn deploy this science to support investment in heat mitigation and response, potentially building on developments such as the parametric model for climate risks, use of advanced geospatial data to offer granular premium discounts, and adapting land-use and planning policies to reduce risk exposure.[22] The remainder of this report discusses these innovations in extreme heat science, mitigation and response investments, and risk transfer, and offers a potential framework to better align them.

I.

EXTREME HEAT EVENT IMPACTS AND MITIGATION INVESTMENTS

Extreme heat causes thousands of excess deaths and hospitalizations per year, limits economic productivity, inhibits education attainment, and threatens infrastructure. Natural and built modifications to the urban environment—including tree canopy and vegetation, green and cool roofs, and cool surfaces—can reduce temperatures by multiple degrees, significantly reducing the incidence of these harmful impacts. And researchers are increasingly able to document the health and economic benefits of these interventions.

EXTREME HEAT EVENTS AND IMPACTS

A robust and growing body of research describes the known and anticipated threats posed by extreme heat risk, including threats to public health, economic productivity, and infrastructure. The National Weather Service issues excessive heat warnings when the heat index (a combined measure of temperature and humidity) is expected to exceed 105 degrees Fahrenheit for two days or more. Other measures of extreme heat are region-specific and account for local baseline temperatures in order to take preparedness and response capacity into account. One common definition employed by the California Energy Commission and other state regulators is a day that reaches the 98th percentile of regional temperatures for the warmest six months of the year. (In San Francisco, for example, where temperatures are mild and few residents have air conditioning, an extreme heat day is one that surpasses 85 degrees Fahrenheit.[23]) The California Environmental Protection Agency and California Department of Public Health estimate that extreme heat events will increase from a historical average of four per year per population center to between 40 and 53 per year by 2050 and up to 99 per year by 2099. Los Angeles, San Diego, Sacramento, and San Francisco are all expected to have over 100 extreme heat days by 2099.[24]

These events pose severe threats to public health.[25] Heat waves have been responsible for hundreds of thousands of known deaths in recent decades, including 650 in the July 2006 California heat wave.[26] By some estimates, the Los Angeles and San Francisco metropolitan areas experience between 100 and 350 deaths combined per year due to excess summer heat.[27] Extreme heat can cause exhaustion, seizures, and renal and cardiac irregularities; people with chronic cardiovascular, cardiac, and diabetic conditions, outdoor workers, pregnant women, and elderly and disabled populations are especially vulnerable.[28] High heat in California has been associated with increased emergency room visits for renal failure, stroke, and other conditions;[29] increased emergency room visits for mental health;[30] increased frequency of preterm birth and low birth weights;[31] and increased infant mortality.[32] Researchers have even linked high heat to decreased academic performance, with high classroom temperatures shown to cause statistically significant reductions in educational attainment and reinforce long-term achievement gaps.[33] These impacts are known to vary widely within cities based on local weather variability, socioeconomic conditions, and access to air conditioning.[34] Lower-income, older, and other vulnerable populations are disproportionately affected (and may benefit most from mitigation measures).[35]

Between 1999 and 2009, extreme heat was responsible for 11,000 excess hospitalizations in California, with the most severe impacts felt in the North Coast and Central Valley (which experienced a 10.5 and 8.1 percent increase in hospitalizations)—but the majority of the extreme heat events did not trigger a National Weather Service heat advisory or warning.[36] A review of the 2006 California heat wave identified 16,000 excess emergency room visits and 1,100 excess hospitalizations statewide. These impacts were most significant among young children and the elderly and along the Central Coast. Emergency room visits showed significant increases for acute renal failure, cardiovascular diseases, diabetes, electrolyte imbalance, and nephritis.[37] By some estimates, the statewide healthcare costs of this event range from approximately $120 million to $175 million and lost productivity costs neared $10 million, while the societal cost of over 650 premature deaths exceeded $5 billion.[38] Analyses of heat-related morbidity and mortality are complicated by the fact that few hospital systems comprehensively track heat-related illness and death as such (e.g., by failing to record all cases where respiratory or cardiac illness is triggered or exacerbated by extreme heat exposure), leaving the total number and type of heat-related hospitalizations and deaths unclear. Furthermore, under the United States' hybrid, multi-payer health care system, these costs are first borne by a mix of entities—public hospital systems, private hospital systems, and individuals—and then reimbursed, often not fully, by a mix of private and public insurance providers, leaving the financial impact of these events widely dispersed.

DEFINING AND DECLARING EXTREME HEAT EVENTS

Effectively responding to extreme heat events, and structuring risk transfer mechanisms to support mitigation and response, relies on the ability to track and declare extreme heat events. The National Weather Service typically issues an Excessive Heat Warning when the Heat Index (combining temperature and humidity) is expected to reach 105 degrees for two or more days and night temperatures will not drop below 75 degrees.[39] A Heat Advisory is issued when the Heat Index is expected to reach 100 degrees for two or more days. In both cases, the Weather Service issues the warning up to 12 hours prior to the onset of the event. Excessive Heat Watches and Excessive Heat Outlooks are issued in the days leading up to an expected extreme heat event. (These thresholds include some variability to reflect local conditions and preparedness.) The California Office of Environmental Health Hazard Assessment (along with other state entities) defines an "extreme heat event" as a day between April and October during which the temperature exceeds the 98th percentile of historical daily maximum temperatures between 1961 and 1990 (and a heat wave as five or more such days), but does not separately declare heat events or issue warnings.[40] Advanced measures of heat impacts track heat "stress" by incorporating additional factors like cloud cover, wind speeds, and consecutive heat days to better assess local sensitivity to a heat event.[41] Extreme heat event definitions that are widely accepted, locally specific (factoring for regional climate and community characteristics), and include multiple thresholds will be necessary to craft comprehensive extreme heat responses, as well as to develop robust risk transfer mechanisms.[42] The National Integrated Heat Health Information System, a federal multi-agency working group, has the potential to build a national information network on extreme heat and vulnerabilities, which could be used to track and predict heat events with greater precision and granularity.[43] The Office of Environmental Health Assessment, with its statewide leadership position and its existing extreme heat metrics, has similar potential at the California level.

Extreme heat increases due to climate change could cause up to 16,000 heat-related deaths per year nationwide by the end of the century.[44] By one estimate, meeting the widely shared climate change target of limiting global temperature increases to 1.5 degrees Celsius could result in thousands of avoided deaths in major U.S. cities over a 30-year period, including over 1,000 in Los Angeles alone.[45]

Extreme heat also has serious implications for labor and economic productivity. Outdoor work is directly impacted by heat-related illness; one study of Los Angeles County found that communities with more construction and agricultural workers also experience more heat-related emergency room visits, with each percentage increase in residents performing outdoor work correlated with an up to 10.9 percent increase in total heat-related emergency room visits.[46] Researchers have found that heat and economic productivity are negatively correlated: every increase of 1.8 degrees Fahrenheit above 59 degrees can reduce productivity by 1.7 percent, with each weekday above 86 degrees Fahrenheit costing an average county approximately $20 per resident in lost productivity.[47] In a year with annual temperatures 2 degrees Celsius warmer than average, heat-exposed industries could experience a 4.5 percent reduction in per capita payroll across the US.[48] This effect may have a sustained impact on economic growth and will likely accelerate due to climate change.[49] These industries may include agriculture, construction and contracting, public works, landscaping, and outdoor recreation and entertainment. (Crop insurance, including policies issued by the US Department of Agriculture's Federal Crop Insurance Corporation, has long been deployed by the agricultural sector to manage productivity risks—including risks such as drought, extreme weather, and other climate-related risks—but it is typically focused on crop yields and revenue, and is not specifically targeted at extreme heat events.[50])

Extreme heat also threatens utility infrastructure. Extreme heat can reduce the generation capacity of fossil fuel and renewable energy sources, reduce transmission system efficiency, and increase overall energy demand.[51] Climate change-related temperature increases could increase peak demand by as much as 18 percent, requiring hundreds of billions of dollars in new capacity installations and straining the electrical grid.[52] While electricity generation and distribution systems are designed to handle the peak demand and stress placed on them during sustained high heat periods, heat waves and extreme heat events can affect the efficiency and stability of these systems and create a heightened risk of system failures and outages. A statewide extreme heat wave in August 2020 threatened the California grid's ability to generate sufficient power to meet high demand, leading to rolling blackouts in many parts of the state.[53] Increased extreme heat events, including those associated with urban heat island effect, will affect energy demand and pricing, grid strain, and potentially energy availability.[54] Electric utilities and distribution systems will need to invest heavily in resilient grid infrastructure and grid management technologies to ensure the flow of energy during increasingly frequent and severe heat-related events, particularly as access to air conditioning becomes an even more pressing equity issue.

In addition, extreme heat poses a severe operational threat to transportation systems.[55] Extreme heat directly stresses road and rail infrastructure through thermal expansion and buckling effects; places strain on electrical infrastructure necessary for public transit and all forms of travel; and can reduce passenger willingness to use transit, threatening agency budgets.[56] At the same time, increasing transportation access is a key tool for limiting impacts of extreme heat in low-income and disadvantaged communities, where residents are most likely to travel by foot or bicycle and experience higher exposure to heat events.[57] Heat presents a particular threat to the aviation sector, with the potential to damage runways and ground flights (including 50 on one 2017 extreme heat day in Phoenix); while measures to accommodate higher temperatures, including lengthening runways and limiting plane weight, could prove highly costly.[58] These impacts are likely to impose high costs on public and private transportation systems, including increased road and rail maintenance costs, airport delay and cancellation costs, and public transit revenue gaps. (These public health, productivity, and infrastructure impacts are compounded by a host of other extreme heat impacts—from heightened wildfire risk to increased ozone pollution and associated air quality reduction—that are not discussed in this report, but only add to the total human and financial cost of extreme heat events.)

Comprehensive approaches to cool surfaces and green infrastructure could generate hundreds of millions of dollars in local benefits over the multi-decade lifetime of the investments for cities with a range of urban and climatic features

EXTREME HEAT MITIGATION INVESTMENTS

A synergistic relationship exists among surface cover (i.e., area occupied by built or paved surfaces), the urban heat island effect, and discrete heat wave events, suggesting that the urban heat island effect will increase even faster than average global temperatures due to climate change. A number of strategies are available to mitigate this effect, including natural infrastructure (such as green roofs and increased tree cover) and built infrastructure (such as cool roofs and pavement).[59] Comprehensive approaches to cool surfaces and green infrastructure could generate hundreds of millions of dollars in local benefits over the multi-decade lifetime of the investments for cities with a range of urban and climatic features.[60] Built shade structures and building design features and location choices can also provide significant cooling benefits to built environments (as, of course, does air conditioning for interior environments). Investment in these strategies forms a core element of comprehensive approaches to extreme heat, and recent analyses demonstrate increasing certainty around the benefits of these interventions.

Urban Vegetation

Researchers have also broadly established the ability of urban tree canopy and vegetation to reduce urban heat island effects and extreme heat, with multiple degrees of cooling potentially available from tree canopy coverage greater than 40 percent in areas with high impervious surface cover.[61] In the Washington D.C. area, for example, 50 percent tree cover (with decreases in road width to accommodate new tree planters) could have a nearly 10-degree impact on surface temperatures in urban street canyons due to shading and evaporation.[62] A global study of existing tree canopy in 245 cities found that tree planting is one of the most cost-effective heat mitigation investments, with a median cost of $468 to cool an area of 100 square meters by approximately 1.8 degrees Fahrenheit.[63] While increasing tree canopy is universally understood to have beneficial cooling impacts, they can vary significantly depending on local context. In Dallas, where a comprehensive cool infrastructure program could reduce summer high temperatures by as much as 15 degrees Fahrenheit and reduce heat-related mortality by up to 20 percent, newly added tree canopy could have cooling benefits three to seven times greater than those of cool surfaces.[64] By contrast, in Louisville, Kentucky, cool surface treatments may yield the greatest temperature-reducing benefits since a greater total amount of land is available for this type of conversion.[65] These findings suggest that comprehensive infrastructure approaches, incorporating built and natural cooling strategies, will be necessary to support optimal temperature-reduction efforts in most jurisdictions.

Cool Roofs

Cool roofs (i.e., roofs that are coated in high-albedo white or reflective materials to decrease their absorption of solar radiation) are a particularly promising investment for urban heat mitigation. Sophisticated modeling is beginning to quantify the potential benefits of these investments, though expected outcomes vary in the absence of existing neighborhood- or city-scale applications. By one estimate, while climate change and population growth patterns may increase statewide public exposure to extreme heat days and heat waves by over 200 percent by 2050, cool roofs could reduce the additional exposure by 50 to 100 percent—with the potential to almost entirely counteract the effects of climate change on extreme heat events in urban areas.[66] At a more granular level, city-wide introduction of cool roofs in Los Angeles and San Diego could reduce daytime temperatures by up to 1.5 degrees Fahrenheit, significantly offsetting anticipated climate change impacts on urban temperatures.[67] Others have found that introduction of cool roofs at a global scale could cause a statistically significant (though somewhat smaller) reduction in urban heat islands.[68] In addition to these cooling benefits (and associated energy use savings potentially in the tens of millions of dollars[69]), cool roofs can also significantly reduce water demand for outdoor irrigation by decreasing surface evapotranspiration, potentially saving tens of millions of gallons per day in large, hot jurisdictions like Los Angeles County.[70] (In 2015, Los Angeles mandated cool roof installation for new residential construction.[71])

Green Roofs

Green roofs (i.e., roofs planted with vegetation to decrease solar absorption and increase water retention) also have the potential to significantly reduce urban temperatures. Modeling of highly dense Chicago has found that 100 percent green roof coverage could reduce peak summer daytime surface temperatures by up to 5 degrees Fahrenheit and near-surface (ambient) temperatures by over 1 degree Fahrenheit.[72] Benefits of green roofs and cool roofs can vary, with the former more effective in cool climates and the latter more effective in warm and sunny climates. Cool roofs may have higher overall temperature-reducing potential when installed aggressively and maintained well, though benefits of either intervention are limited when installed in high-rise buildings.[73] In general, a high level of implementation (up to 90 percent coverage for green roofs and 95 percent coverage for cool roofs) is needed to achieve these potentially significant temperature reductions.[74]

Cool Surfaces

Cool pavements and surfaces, which incorporate high albedo and permeable elements have also been demonstrated to reduce ambient temperatures, in some cases by double digits.[75] However, some research indicates that the greenhouse gas emissions associated with producing some current cool pavement materials could outweigh the emission reduction effect of the energy savings they produce, a finding that, while relevant for long-term climate policy, does not diminish cooling benefits and could have limited implications for the viability of risk transfer (and may be mitigated by development of new surfacing materials).[76] Widespread adoption of exterior cool wall surface coatings and materials can also have a notable downward impact on urban air temperatures.[77]

MITIGATION INVESTMENTS AND PUBLIC HEALTH IMPACTS

Comprehensive approaches to cool surfaces and green infrastructure could generate hundreds of millions of dollars in local benefits over the multi-decade lifetime of the investments for cities with a range of urban and climatic features

Researchers are using synoptic climate analysis, which assesses the temperature, humidity, and other specific traits of location-specific air masses during multi-day heat events, to model the public health benefits of extreme heat mitigation investments like cool roofs and urban vegetation. In one such analysis based on four historical Los Angeles heat waves, researchers found that aggressive, comprehensive implementation of cool roof (up to 75 percent reflectivity), cool pavement (up to 35 percent reflectivity) and tree canopy (up to 40 percent coverage) could have cooling benefits sufficient to reduce heat-related mortality by up to 80 percent in vulnerable districts.[78] This implementation could yield temperature reductions equivalent to decades of delay of anticipated climate change-induced warming.[79] Synoptic analyses of heat events in Boston and Chicago have estimated that increasing roof surface reflectivity an additional 25 percent could lower air mass temperatures enough to reduce heat-related mortality by 10 and 13 percent respectively, potentially saving hundreds of lives per decade.[80] A similar study of Washington, D.C. heat events found that increasing both urban surface reflectivity and vegetative cover by 10 percent could reduce the number of deaths during heat events by an average of 7 percent.[81] In some U.S. cities, comprehensive cooling strategies could potentially reduce heat mortality by 40 percent or more.[82]

The public health benefits of more immediate extreme heat response measures are also well established, though modeling and data are more limited. Researchers have found that increased ownership of air conditioning (across all California climate zones) is associated with a statistically significant reduction in general heat-related respiratory and cardiovascular disease.[83] This finding is particularly relevant for coastal and northern parts of the state that have generally low air conditioning ownership rates but will experience increasing numbers of extreme heat days in coming decades, and for low-income communities with low air conditioning penetration that are most vulnerable to extreme heat events.[84] Visiting any air-conditioned space, private or public, during a heat event can reduce heat-related mortality risk, potentially by more than half.[85] Where residents do not have (or cannot afford) air conditioning at home, public cooling centers are generally recognized as an effective strategy to prevent heat-related mortality and morbidity, but operational limitations and lack of public outreach can limit total public benefits.[86] Since the same cooling center visitors who lack access to air conditioning home may also lack access to private vehicles, transportation and other access assistance programs are highly valuable.[87]

The growing body of knowledge on the heat-reducing and public health benefits of urban cooling investments suggests a robust future for local governments seeking to understand the value of these investments. Taken together with estimates of the costs of extreme heat events—which can exceed the tens and potentially hundreds of millions of dollars, and will only increase in coming decades—these analyses have the potential to support both the risk modeling and the cost-benefit assessment that would be necessary to inform the design of risk transfer mechanisms. But additional research and data collection are necessary to support a complete understanding of the relative public health, and financial, benefits and costs of various interventions. The environmental and climatic complexity of heat effects, the need to address indoor temperatures that have the most direct impact on residents' health, and the regionalized impacts of extreme heat events all call for policy responses that are comprehensive, locally tailored, and supported by appropriate financial mechanisms and incentives.[88]

VALUING NATURAL INFRASTRUCTURE INVESTMENTS

Developing risk transfer mechanisms to support extreme heat mitigation investments will require robust financial valuation of those investments. Local governments' ability to conduct this valuation is bolstered by the synoptic methods just described, and by the development of new tools that facilitate comprehensive assessment of the economic and public health benefits of different investments. For example, the C40 Cities Heat Resilient Cities tool uses data on the known temperature reduction benefits of various natural and built infrastructure interventions (such as urban vegetation and cool roofs), interactions between heat and health impacts (such as cardiovascular and respiratory disease), and city-specific temperature and demographic profiles to project the temperature, public health, and economic benefits of a particular intervention in a particular city.[89] This tool can inform local decision-making by quantifying benefits of a specific project (for example, a project to increase tree canopy or cool roof coverage by a known percentage), and could in turn facilitate the use of financial risk transfer instruments to support these investments.

In addition, policy tools such as payments for urban ecosystem services (PUES, described later in this report) are increasingly being used to assess the public value of urban cooling infrastructure through methodologies including avoided costs, consumer willingness to pay, and replacement costs of engineered alternatives.[90] In this context, valuation of tree canopy may be considered in terms of the avoided cost of additional air conditioning and cooling services that would be necessary in the absence of the green infrastructure. For example, analysis of the temperature-reduction value of tree canopy using these methods found that street and park trees in Modesto, California saved approximately $870,000 per year in avoided cooling costs, or about $10 per tree; and tree canopy in Sacramento, California saved nearly 10 megawatts of energy use for cooling per year, or about $1,700 per hectare.[91]

II.

HEAT MITIGATION AND ADAPTATION PLANNING AT THE LOCAL LEVEL

Leading jurisdictions are developing innovative heat mitigation and adaptation plans that incorporate natural and built infrastructure, social and communications responses, and long-term planning approaches to reduce heat and heat impacts. These plans are ambitious and in many cases comprehensive, but most lack coordinating functions and dedicated funding streams. Increasing outreach to and involvement of public and private stakeholders will be vital to bring them to implementation.

A number of jurisdictions have begun to develop extreme heat mitigation and response strategies, typically as components of broader climate action plans or adaptation strategies. These strategies can rely on input or participation from a range of local departments such as mayor's offices, public health departments, public works departments, transportation departments, offices of emergency management, law enforcement agencies, and more, as well as private and nonprofit partners. The embedded and distributed nature of these approaches suggests that greater coordination will be required for cohesive implementation, a role that risk-transfer mechanisms could potentially play or support. This fragmentation also poses a challenge to implementing a risk-transfer mechanism, as no single government body bears all the costs of an extreme heat event or controls all the responses. In addition, while local governments are taking the lead in planning and coordinating extreme heat response, in most cases they are not directly responsible for the impacts of extreme heat, which tend to fall on individuals, employers, and health systems, with private or state insurers often providing reimbursement. As a result, there may be no natural 'customer' for risk transfer, despite the increasingly robust plans to combat extreme heat. This section offers an overview of leading extreme heat-related resilience plans at the local level.

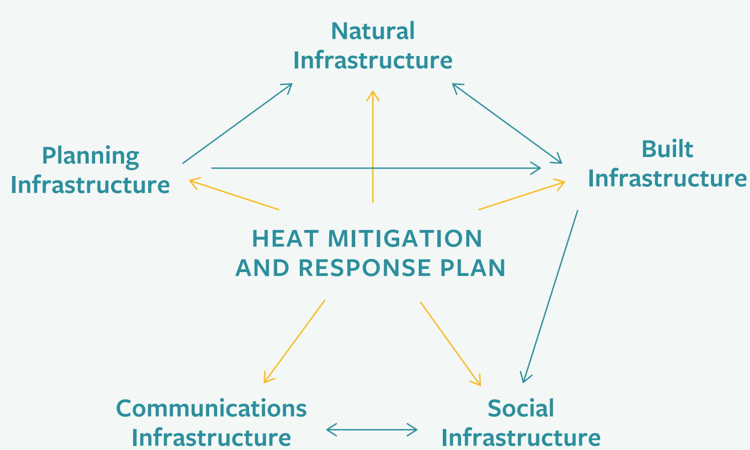
The constituent elements of extreme heat strategies can be broken into five categories of response infrastructure:

- *Natural infrastructure*, such as tree canopy, green roofs, other urban greening;
- *Built infrastructure*, such as cool roofs, cool pavements, shade structures, and building design improvements;

- *Social infrastructure*, such as cooling centers, cooling equipment, and subsidized transportation;
- *Communication infrastructure*, such as early warning systems and public information campaigns; and
- *Planning infrastructure*, such as zoning policies and urban design programs.

Leading jurisdictions' efforts typically include or plan for neighborhood-level urban heat vulnerability assessments; cover a suite of measures across multiple response infrastructure categories; and prioritize solutions for highest-risk communities. The most robust approaches include multiple natural infrastructure solutions (from increasing tree canopy to expanding parks and green roofs), multiple cool surface solutions (from cool pavement and cool roofs to permeable pavement and cool transit corridors), and multiple social solutions (from cooling centers to hydration stations). These comprehensive plans, combining immediate response and long-term measures to combat heat impacts, may be most effective at addressing extreme heat risk.

FIGURE 1: Extreme heat mitigation and response infrastructure types



Many of these approaches are aspirational, with long-term targets not supported by current funding streams. Governments may struggle to finance some or all of the urban heat measures they seek to implement them alongside other resiliency elements in their comprehensive sustainability plans, particularly if wildfire, electricity reliability, or disaster concerns arise more prominently. This suggests that additional financing or incentives would be highly valuable to drive extreme heat mitigation efforts. A review of these plans offers a picture of their constituent elements and how they can be combined, which will inform the structure and scope of potential risk-transfer mechanisms related to urban heat impacts.

EXTREME HEAT AND COVID-19

The social distancing and shelter-in-place guidelines of the COVID-19 pandemic raise questions about the viability of cooling centers and shaded outdoor spaces as an extreme heat response, since they rely on congregating individuals outside the home with limited ability to maintain physical distance.[92] (The pandemic response and associated economic downturn also raise questions about the financial assets available to address extreme heat and other climate-related crises.) The combination of social distancing and extreme heat could prove especially deadly in low-income communities where access to air conditioning is limited, particularly for those living in older housing and mobile homes.[93] In response, some jurisdictions are modifying cooling center operations to accommodate social distancing needs (potentially reducing capacity) or providing air conditioning units or utility bill assistance to residents in need, in accordance with CDC recommendations.[94] Comprehensive, coordinated heat plans that include outreach to vulnerable populations and investment in long-term cooling infrastructure (particularly cool roofs and walls that can directly reduce indoor temperatures)—and, potentially, risk transfer solutions to support them—will become increasingly important as extreme heat and pandemic response unfold together.

The plans and academic literature reviewed indicate that primary extreme heat mitigation and response obligations (and costs) are shared among a wide range of public actors, including but not limited to:

- Health departments;
- Hospitals;
- Emergency service and response departments;
- Health insurers, including Medicare and Medicaid;
- Transit agencies and systems (including airports);
- Housing agencies;
- School systems and libraries;
- Public works departments;
- Building departments;
- Planning and zoning departments;
- Parks departments;
- Utilities;
- Police and fire departments;
- Homeless services agencies; and
- Mayor's offices.

Entities with public health responsibilities—including hospitals, health departments, emergency service departments, and public health insurers—bear the greatest responsibility for managing immediate heat response and planning, as well as the greatest financial stake in effective management. Others, such as public works and parks departments responsible for urban infrastructure, play important but less focal roles.

In addition to these public entities, many heat response plans rely on participation from nonprofit, academic, philanthropic, and private partners, in some cases to provide key funding for pilot projects or full implementation. Private employers, infrastructure service providers, and transportation companies may also face heat-related costs and play key roles in response. This diversity of responsibilities demonstrates the potential for collaborative, dynamic responses but also highlights the 'customer' problem that may face extreme heat risk transfer. With no single public or private actor operationally responsible for a majority of the response or financially responsible for a majority of the risk—and with comprehensive extreme heat response still an emerging practice—identifying an entity or combination of entities whose financial interests are aligned with risk transfer investment could prove challenging.

Los Angeles City:
comprehensive response at the city level

Resilient Los Angeles, issued in 2018 by Mayor Eric Garcetti, is a city-wide plan for resilience and adaptation to a range of shocks and stresses, including but not limited to climate-related risks and extreme urban heat.[95] Four of the plan's 15 core goals relate to extreme heat resilience concerns, including one goal specifically focused on protecting vulnerable populations from extreme heat impacts.[96] Heat-related plan actions include:

- Developing an urban heat vulnerability index and mitigation plan.[97]
- Developing a neighborhood retrofit pilot program to test natural and built infrastructure cooling strategies.[98]
- Planting trees in communities with fewer trees to grow a more equitable tree canopy by 2028.[99]
- Expanding the city's neighborhood cooling center program.[100]
- Funding incentives for residential building cooling and energy efficiency measures.[101]
- Using transfer of development rights and Enhanced Infrastructure Financing Districts to invest in housing and green infrastructure along the LA River.[102]
- Integrating a climate resilience and sustainability framework into city capital planning.[103]
- Developing recommendations for sustainable building construction including energy efficiency and heat resilience.[104]
- Connecting homeless residents near the LA River with housing and services to address risks including heat exposure.[105]
- Identifying priority areas for investments in green infrastructure to fight climate impacts including heat islands.[106]
- Prioritizing electrical grid upgrades and infrastructure investments to mitigate risks including major heat waves.[107]

PRIVATE STAKEHOLDERS IN EXTREME HEAT RESPONSE

In addition to the many public entities that have some role in extreme heat response, extreme heat events affect a number of private entities that stand to benefit from effective responses and may be willing to participate in or contribute to comprehensive heat planning and to risk transfer. Examples of these private entities may include:

- Hospital systems that experience increased patient visits due to extreme heat;
- Outdoor employers, such as the construction and agricultural sectors, that need to provide extra breaks during extreme heat;
- Utilities, which can experience system stress due to increased demand and infrastructure damage from heat;
- Airlines, which can experience systemic delays during extreme heat; and
- Landlords, which can save building energy costs and improve tenant quality of experience through community-level heat mitigation.

- Developing distributed energy generation solutions that can serve emergency needs during crises including cooling and medical infrastructure during heat waves.[108]
- Coordinating city leadership with hospitals and health organizations to prepare critical health infrastructure for disasters.[109]

These actions cover a full range of types and timelines, including urban greening, community assistance and coordination, major capital investments, and long-term planning. They also involve a panoply of actors, including city infrastructure, public health and safety, planning, transportation, law enforcement, and other departments, the mayor's office, state and county counterparts, nonprofit entities, research institutions, and unidentified private partners. The plan does not identify funding streams for these interventions.

In 2019, the mayor issued LA's Green New Deal, another comprehensive plan for city sustainability, climate mitigation, and resilience goals.[110] Its focus extends beyond resilience into emission reduction and green jobs targets, but extreme heat-related actions figure prominently in the elements focused on urban ecosystems and resilience. Key heat-related targets and actions include:

- Increasing tree canopy in areas of greatest need 50 percent by 2028, including a citywide tree inventory and urban forestry management plan.[111]
- Reducing urban/rural temperature differentials by 3 degrees Fahrenheit by 2035, including an all-cool-roof mandate for new construction in 2020; 10 cool neighborhoods pilots combining cool roofs, cool surfaces, and urban greening, plus increased air temperature monitoring and communications, by 2025; 250 lane-miles of cool pavements installed by 2028; and a requirement that 50 percent of all non-roof surfaces meet cool criteria by 2028.[112]
- Establishing 30 new parks by 2025.[113]

As with the Resilient Los Angeles plan, the plan includes a wide range of diverse partners, including non-profit and private parties outside city government, and does not explicitly identify funding streams.

Los Angeles County:
comprehensive response at the county level

In 2019, Los Angeles County (which governs areas in the county outside of incorporated cities) issued the OurCounty Los Angeles Countywide Sustainability Plan, a comprehensive sustainability plan ranging from emission reduction and transportation policy to food systems, water supplies, and economic prosperity, including resilience goals that feature urban heat concepts.[114] Extreme heat-related action items include:

- Converting 30 percent of heat-trapping surfaces to cool or green surfaces and reducing heat-stress emergency room visits by 75 percent by 2045, by:
    - Conducting a countywide climate vulnerability assessment that addresses social and physical infrastructure vulnerability including urban heat;

    - Developing a comprehensive heat island mitigation strategy and implementation plan that addresses cool pavements and roofs, pavement reduction, and urban greening; and
    - Building shade structures at major transit stops, prioritizing communities with high heat vulnerability.[115]

- Ensuring a climate-appropriate, healthy, and equitably distributed urban tree canopy with 20 percent more tree cover by 2045, by:

    - Creating an urban forest management plan;
    - Implementing locally appropriate vegetation projects; and
    - Strengthening protection of native species.[116]

- Adopting a "living streets" approach to transportation health and safety that includes cool surfaces and green infrastructure.[117]

Much like the Los Angeles City plans, these actions will rely on a full range of county-level departments, nonprofits, research entities, and private parties.

San Francisco: *comprehensive response and an urban greening focus*

San Francisco's 2019 Hazards and Climate Resilience Plan profiles the city's urban heat exposure and risk, including a neighborhood-scale overview of extreme heat vulnerability, predicting extreme heat days (measured at 85 degrees Fahrenheit or greater in San Francisco) will increase 15 times by 2100.[118] The neighborhood-level vulnerability assessment could serve as a valuable basis for development of granular risk-transfer mechanisms. The plan includes extreme heat-related action items including:

- Urban greening through expansion of existing tree planting initiatives, consideration of tree canopy and shade cover in capital parks projects, and selection of heat-resistant tree types for planting.[119]
- Adding respite and cooling centers in existing recreation centers and at new public and private locations.[120]
- Studying air cooling capacity at existing community facilities such as schools and clinics, increasing weatherization of existing private structures, and increasing building electrification.[121]
- Transit system repairs and investments to address physical infrastructure stresses of extreme heat.[122]
- Community-based response and preparedness actions such as creating a homeless disaster response plan, building volunteer and in-home service capacity, and developing a centralized extreme heat preparedness plan.[123]

Like the Los Angeles City and County plans, it relies on actions across city government including public health, transportation, planning, emergency response, and law enforcement, as well as private and non-profit partners.

The city's 2017 Climate and Health Adaptation Framework is a public health department approach to climate risk management which identifies extreme heat as one of eight key climate health risks and proposes a range of responses.[124] These responses include

investigating opportunities to develop urban green space and tree canopy; preparing continuity plans for extreme heat events; establishing memoranda of understanding between the department of public health and other city agencies on making cooling centers available; developing cool pavement and cool roof pilots; and developing thermal comfort recommendations for facilities serving vulnerable populations.[125] As the framework is prepared from the public health department perspective, it does not include significant detail on government-wide investment or response strategies, though the scope of its recommendations indicates the breadth of the department's approach to heat impacts on health.

In addition to these comprehensive plans, San Francisco is also home to an Urban Forestry Council, an advisory body constituted under the San Francisco Environment Code that issues annual reports tracking city tree planting, removal, maintenance, and funding.[126] In 2014, the San Francisco Planning Department issued an Urban Forest Plan that cataloged the city's tree canopy and set out a policy plan to comprehensively manage the urban forest, including increasing street trees 50% by 2034 with partners including the departments of public works, the parks department, and the forestry council.[127] (Neither the forestry council's plans nor the urban forest plan places specific emphasis on extreme heat mitigation.)

Oakland:
equity focus

Oakland's Equitable Climate Action Plan is an example of an equity-focused climate mitigation and adaptation plan, with a requirement that strategies are "structured to maximize benefits and minimize burdens on frontline communities," "prevent displacement," and "address[] disparities in resource allocation and local vulnerability."[128] The plan includes urban forestry and tree canopy measures, based on development of an urban forest master plan, to address urban heat island effects and to sequester carbon, but does not extend to cool surfaces or other cool infrastructure measures. Similar equity focuses may be particularly valuable for heat-specific planning given the connection between socioeconomic, health, and extreme heat vulnerabilities.

Inglewood & Lennox and Canoga Park, California:
community-level urban greening approach

The Inglewood and Lennox Greening Plan is an example of a community-scale, urban greening-specific plan, with targets of increasing urban canopy cover from 18 percent to 25 percent by planting 2,500 new trees over five years; prioritizing greening of transit areas; and incentivizing green retrofits of private properties.[129] The plan encourages the use of native and locally appropriate plant species and includes maintenance protocols for urban green installations, which are essential to long-term sustainability.

The Canoga Park Urban Cooling Plan, led by Los Angeles-based nonprofit Climate Resolve, is another community-scale plan noteworthy for its selection of three transportation corridors for extreme heat-specific interventions.[130] The plan targeted transportation corridors to marry the benefits of urban cooling and active transportation, with the end goal of reducing heat-related barriers to accessing low-emitting public transit options. The interventions include addition of shade trees, a planted meridian, and cool-paved bike paths along a major arterial; converting a neighborhood street to pedestrian-only use with shade trees and built shade sail structures; and installation of shade sails and hydration stations along an existing bike path.[131]

Maricopa County, Arizona:
community-based approach

Maricopa County's multi-stakeholder 2019 Heat Action Planning Guide is a leading example of a community-led approach, based on collaboration between The Nature Conservancy, the Maricopa County Dept. of Public Health, Arizona State University, and others including extensive participation of community residents.[132] The guide is particularly noteworthy for its focus on three individual Phoenix-area communities with heightened but distinct extreme heat risks, and its reliance on community residents to prioritize locally appropriate responses.[133] It identifies a complete range of natural infrastructure, built infrastructure, and behavioral measures to address extreme heat, including three neighborhood-specific analyses of surface temperature and vegetation, heat-related illness and utility complaint profiles, and resident-sourced preferred heat solutions focusing on shade structures and shade trees. Action plans were tailored to individual neighborhoods through an engagement process that included design workshops, demonstration projects, and engagement with existing community organizations, a methodology that may support greater overall public awareness of heat-related issues and solutions.[134] (Maricopa County's Climate and Health Strategic Plan for 2016-2021 also addresses extreme heat concerns, though strategies are more limited.[135])

New York City:
heat-specific planning

The 2015 Cool Neighborhoods NYC plan is an example of a mitigation and adaptation strategy focused exclusively on extreme heat risks. The plan includes tree planting, prioritizing the most heat-vulnerable neighborhoods; evaluation of cool pavement benefits and feasibility; and training, messaging, community outreach, and cooling center efforts.[136] The plan also calls for increased investment in NYC CoolRoofs, a city program that provides no-cost and subsidized cool roof coatings and has coated millions of square feet of rooftop space to date.[137]

The Cool Neighborhoods plan is part of the broader OneNYC plan, a comprehensive city development, equity, sustainability, and resilience plan. The resilience aspect of the plan includes an explicit focus on mitigating extreme heat risks with emphasis on citywide temperature monitoring, tree canopy mapping, and increasing access to air conditioning and cooling centers, but little detail and no discussion of planned infrastructure interventions.[138]

Portland, Oregon:
zoning-based approach

Portland's Better Housing by Design is a stand-out example of a codified zoning-based approach to climate resilience. The program consists of a residential zoning code update that includes elements specifically targeted toward reducing urban heat island effects, including limitations on large paved areas and impervious surfaces, limiting parking requirements, and increasing flexibility in meeting green landscaping requirements.[139]

Boston:
incorporation of insurance considerations

Climate Ready Boston is a city-wide adaptation plan that focuses on flood and sea level rise risks, but also documents extreme heat event risks to human health and to infrastructure (such as rail and road swelling/stress in 90+ degree heat).[140] The plan includes responses such as updating the city heat emergency plan, developing green infrastructure plans and incentives to address urban heat among other risks, and developing an urban tree canopy plan, and basic references to cool roofs.[141] Importantly, the plan includes an entire strategy based on promoting needed flood insurance to address sea level rise, a risk transfer focus not seen in many other resilience plans.[142]

Leading jurisdictions' efforts typically include or plan for neighborhood-level urban heat vulnerability assessments; cover a suite of measures across multiple response infrastructure categories; and prioritize solutions for highest-risk communities. The most robust approaches include multiple natural infrastructure solutions, multiple cool surface solutions, and multiple social solutions.

Chicago:
comprehensive urban greening

Following a 1995 heat wave that killed hundreds of residents, Chicago instituted a range of urban heat reduction measures, including a plan for 6,000 rooftop gardens and 1 million new trees by 2020, and a building energy code that requires high-reflectivity roofs.[143] The city also developed a stand-alone urban greening plan that included plans for sustainable landscaping standards, green roof expansion, improved maintenance and soil standards, expanding the urban forest, implementing reflective and permeable paving, and other measures.[144]

France:
heat planning and communications

France's National Heatwave Plan is an example of a large-scale heat wave mitigation strategy that employs community outreach, meteorological data, and government action at the national and local levels in order to anticipate heat waves and minimize loss of life.[145] Originally implemented in 2004 following a historically extreme heat event in the summer of 2003 that resulted in more than 15,000 deaths across the country,[146] the plan focuses on weather prediction and communications strategies and is generally recognized as a leading example of heat response planning.

The plan's prevention system primarily identifies at-risk populations, such as those experiencing homelessness, children, the elderly, and those with certain high-risk jobs, and provides these groups services and accommodations to minimize adverse health impacts.[147] The plan's protection system uses a data-based "Heatwave Warning System" to forecast heat wave severity and a four-color code (green, yellow, orange, red) to categorize the heat wave risk local populations will experience in the next 24 hours, with specific actions outlined for various government agencies at each color level.[148]

The plan's communication system uses a two-prong approach of preventative and emergency communication.[149] Preventative communication involves national outreach (including press releases, radio broadcasts, newsletters, leaflets, and posters) and local outreach (including "heat wave communication kits" made available to regional health agency workers responsible for raising community awareness).[150] Emergency communication is implemented based on the severity color code at both the national and local level and includes a 24-hour emergency hotline and in-person outreach.[151] Following each heat wave episode, the government collects data at the local level and tabulates it at the national level in order to assess the plan's effectiveness, and an official government committee evaluates the plan semi-annually.[152]

The French government has updated and revised the plan annually since its inception, and its effectiveness has been readily apparent in terms of declining mortality: Following implementation, a milder 2006 heat wave claimed 2,065 lives (approximately 4,400 fewer than predicted by modeling),[153] a historically severe heat wave in 2015 claimed 3,300 lives,[154] five heat waves in 2016 claimed a total of 700 lives,[155] and another historically severe heat wave in 2019 claimed 1,462 lives.[156] The latter figure marks a 90 percent reduction in fatalities since the 2003 episode.[157] The effectiveness of these strategies in reducing heat-related deaths points to the importance of preparedness, planning, and communications in effective heat response.

Paris:
comprehensive heat response at the city level

In 2018, the city of Paris published a comprehensive Resilience Strategy (in partnership with the 100 Resilient Cities program) to tackle a wide range of challenges the city is facing or will face in the future, including climate change and air pollution.[158] Goals within Paris' three pillar action plan related or applicable to tackling extreme heat include:

- Transforming schoolyards into cooling island "oases";[159]
- Transforming public spaces to increase social wellbeing and inclusion through integrated planning, innovation, and a better incorporation of nature;[160]
- Adapting public facilities to address priority challenges and ensure that they are flexible, modular and capable of accommodating multiple uses;[161]
- Developing integrated green spaces to respond to climate and social challenges;[162]
- Exploring the city from its roots to its canopy and assess the potential for rooftop and basement development;[163]
- Establishing an observatory to understand how different risks impact public health and study socio- environmental vulnerabilities;[164] and
- Developing new finance mechanisms for resilience solutions in Paris, including sustainability bonds to resilience bonds.[165]

State of California:
planning tools for local action

While extreme heat investment and response are primarily local responsibilities, California operates a number of state-level programs that support and inform these local capacities. The California Department of Public Health Climate Change and Health Equity Program (CCHEP) is designed to embed health and equity in state climate change planning and climate and equity in health planning. The program works with local governments on a range of climate and public health planning and investment strategies including green infrastructure, building efficiency and cooling, and land use planning, each of which has deep connections to extreme heat impacts.[166] A key element of CCHEP is California Building Resistance Against Climate Effects (CalBRACE), a public health planning program funded by the CDC that includes extreme heat components.

The CalBRACE program's Climate Change and Health Vulnerability Indicators (CCHVIz) tool helps county and local governments to assess public health vulnerabilities due to climate change. The tool depicts heat-related vulnerability indicators—such as percentage of senior residents, percentage without tree cover, percentage of impervious surfaces, percentage of outdoor workers, and projected number of extreme heat days—at the census tract level, allowing local governments to assess vulnerabilities in a targeted manner.[167] The state has also prepared county climate change and health profile reports, which provide county-specific information on extreme heat thresholds, populations without air conditioning, outdoor workers, and more, along with recommended resilience actions.[168] CalBRACE also includes an adaptation toolkit that presents these and other resources for use by local governments in a planning process-friendly format.[169]

Much of this recent work builds on the 2013 Preparing California for Extreme Heat report, which outlines key measures including shading, cool roofs, urban greening and more, and catalogs health risks and vulnerable populations. It recommends a set of steps including cool building standards, cool land-use strategies, studies of urban heat impacts and cool surfaces, urban greening, and preparedness/response improvement, many of which are reflected in the CalBRACE program guidance.[170] The report also includes sector-specific action plans for local governments to use as a template for developing locally appropriate action plans, with a public health plan that incorporates a full range of recommended infrastructure investments and response measures.[171] Building on the CalBRACE program, Contra Costa County prepared a climate change vulnerability assessment with a focus on extreme heat risk across population-level age, socioeconomic status, medical health, and living condition indicators, which can be used to inform mitigation and resilience planning.[172]

While a number of local governments have begun to undertake planning along these lines, it is unclear whether many have been able to commit funding to investments in heat mitigation and response. The state's Transformative Climate Communities Program, which makes grants (funded by revenues from the state's greenhouse gas cap-and-trade program) for projects that provide greenhouse gas emission reduction and local economic, environmental, and health benefits in disadvantaged communities, has funded some projects that include urban greening and cool roof elements, and may fund more projects to combat urban heat island effects in the future.[173]

Finally, the California Energy Commission's California Heat Assessment Tool (CHAT) maps projected heat health events (based on anticipated temperature and humidity levels), public health and socioeconomic indicators of heat vulnerability (such as asthma rates), and environmental indicators (such as tree canopy) to demonstrate heat vulnerability at the local level.[174] The California Environmental Protection Agency also offers urban heat island interactive maps that show heat island effects statewide.[175] These tools allow policymakers to visualize heat vulnerability at a granular level, adding to the robust set of resources that the state offers to assist local planning for extreme heat.

The breadth of these heat response and mitigation plans, and the range of public capacities they draw on, demonstrate both the level of local innovation taking place and the coordination challenge that extreme heat presents. At present, it appears that no single government body is responsible for extreme heat response at the state or local level, which calls upon dozens of government efforts and which necessarily involves both long-term investment and immediate action. While the comprehensive approaches that Los Angeles City, Los Angeles County, and others are beginning to develop are an encouraging step in combating extreme heat impacts, they demonstrate the complexity and likely cost of meeting the challenge, and the extent to which these cities' current piecemeal approaches to resilience may need to be rethought. These in turn highlight the difficulty of crafting risk transfer mechanisms that draw on aligned incentives, funding streams, and action plans, address both near-term response and long-term infrastructure investments, and are financially viable for a single 'customer.' At the same time, the development of innovative, comprehensive extreme heat plans—as well as many informative plan components and focuses, from zoning to equity—is evidence of growing opportunity for risk transfer mechanisms to support those plans or their constituent elements.

At present, it appears that no single government body is responsible for extreme heat response at the state or local level, which calls upon dozens of government efforts and which necessarily involves both long-term investment and immediate action.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III.
LEGAL CONSIDERATIONS

The current legal landscape at the California and federal levels offers few requirements or guidelines for managing extreme heat. However, some legal requirements for local government planning processes may shape extreme heat responses. The current legal landscape at the California and federal levels offers few requirements or guidelines for managing extreme heat across the climate adaptation, public health, and insurance contexts. However, some legal requirements for local government planning processes may shape extreme heat responses.

State law governing city and county planning processes does not currently require any heat-specific actions, but recent updates are relevant to heat mitigation and response. California Senate Bill 379 (Jackson, Chapter 608, Statutes of 2015) required all cities and counties to add to their general plans a safety element that includes climate adaptation and resilience strategies. This element must include a vulnerability assessment, adaptation and resilience goals, and an implementation strategy, including natural infrastructure measures like urban forestation to mitigate high heat. Senate Bill 1000 (Leyva, Chapter 587, Statutes of 2016) required local governments to add an environmental justice element to their general plans, focusing on health risks in disadvantaged communities, which in many parts of the state are especially vulnerable to extreme heat risks. And Senate Bill 1035 (Jackson, Chapter 733, Statutes of 2018) required local governments to update these safety elements at least every eight years to reflect newly available climate adaptation strategies.[176] These local plans may overlap with local hazard mitigation plans adopted pursuant to the federal Stafford Act, which conditions federal disaster relief funds on preparation of these plans.[177] The California Adaptation Planning Guide provides state-level guidance for local governments integrating climate adaptation into their general plans.[178] In addition, the Adaptation Clearinghouse managed by the Governor's Office of Planning and Research includes case studies on local climate resilience actions and plans, including for extreme heat.[179]

At the level of state action, Assembly Bill 296 (Skinner, Chapter 667, Statutes of 2012) is one of the few laws directly targeted at extreme heat issues. It made a statement of legislative intent to direct CalEPA to develop a standard definition of the urban heat island effect; CalEPA and the state Climate Action Team to develop heat reduction strategies including cool surfaces and urban forestry; and Caltrans to develop cool pavement specifications and the state Building Standards Commission to consider adopting them under the Title 24 building energy efficiency standards.[180] Following the legislation, CalEPA commissioned the first study creating a California-specific urban heat island index, which identified heat island effects ranging from 0.5-1.0 degrees Celsius in smaller urban areas to 5 degrees Celsius or more in the largest urban areas.[181] The Title 24 building energy efficiency standards include minimum solar reflectance requirements for new and renovated roofs.[182]

California was also the first state to enact a heat illness prevention standard, which is administered by the California Occupational Safety and Health Administration. Employers in the agriculture, construction, landscaping, and oil and gas sectors are legally required to maintain ventilated shade structures for employees whenever temperatures exceed 80 degrees, to provide ten minutes' cooling break for every two hours of work when temperatures exceed 95 degrees, and to prepare extreme heat preparedness plans.[183] As extreme heat days increase throughout the state in coming decades, employers and employees will likely face increasingly frequent work interruptions to protect employee health and safety.

California was the first state to enact a heat illness prevention standard. As extreme heat days increase throughout the state in coming decades, employers and employees will likely face increasingly frequent work interruptions to protect employee health and safety.

In addition, two bills were introduced in the 2020 session of the California legislature that, for the first time, would explicitly focus on extreme heat. Assembly Bill 2441 (Rivas) would establish an Extreme Heat and Community Resilience Program at the Governor's Office of Planning and Research to coordinate state activities on extreme heat and distribute grants to local governments to reduce risk from exposure to extreme heat. And a climate resilience-related bond act, Assembly Bill 3256 (E. Garcia), would provide hundreds of millions of dollars to fund projects to reduce climate impacts to disadvantaged communities, including funds allocated specifically to a grant program to reduce urban heat island effects. The legislature failed to act on either bill before the end of its 2020 session.

State insurance law does not deal directly with extreme heat risk or related insurance coverage (although the Insurance Commissioner's regulatory authority extends to heat-related issues, such as licensing and regulation of workers' compensation insurers). The California Insurance Code does generally define what constitutes an insurable interest beyond existing interests in life and property, stating that a "mere contingent or expectant interest in anything, not founded on an actual right to the thing, nor upon any valid contract for it, is not insurable."[184] However, given the interests of local governments in the health and welfare of their residents, their responsibility for some portion of response costs, and their role in funding or facilitating long-term investments in cooling infrastructure, this requirement should pose no barrier to the creation of an extreme heat-related insurance mechanism that is not directly linked to real or personal property.

IV.
EXISTING RISK TRANSFER MECHANISMS TO ADDRESS CLIMATE-RELATED RISKS

Governments are increasingly turning to risk transfer instruments to manage the financial impacts of climate risk. Tools like parametric insurance, which provides reliable payouts based on weather-based trigger events, and bond financing, which can support catastrophe recovery and proactive mitigation, offer potential models for extreme heat risk transfer, including index-based triggers, integration of and premium discounts for mitigation strategies, public-private partnerships, and multi-jurisdiction risk pooling. But barriers remain to craft a feasible structure.

Insurers, financial institutions, and governments have pioneered a range of innovative mechanisms to address catastrophic and climate-related risks that are relevant to understanding the feasibility of risk transfer to address extreme heat.[185] These mechanisms deploy insurers' and other financial actors' expertise in risk assessment, modeling, and pricing to address a range of varying factors including hazard type, exposed assets, governance structure, and market conditions.[186] Mechanisms described in this section include:

- Parametric insurance, which international governments have used to address a range of climate- and weather-related risks;
- Captive insurance, which facilitates self-insurance for particularly challenging risks;
- Bond financing, which is increasingly being applied to catastrophe risks and resilience needs; and
- Payment for urban ecosystem services, which could be particularly useful for valuing extreme heat mitigation efforts.

While the existing solutions described in this section may not be wholly appropriate to address extreme heat risks, one or more structural components may be useful in crafting an extreme heat risk transfer instrument.

PARAMETRIC INSURANCE

Parametric (or index-based) insurance involves the standard premium and payout structure of traditional insurance, but bases payouts on the occurrence of pre-determined "trigger" events rather than the incurrence of a loss and submission of a claim (as is the case for traditional indemnity- or loss-based policies).[187] The trigger is typically determined based on an agreed index of weather or natural phenomena, allowing the policyholder (often a government) to protect against the anticipated financial loss of a catastrophic natural event without having to assess and claim actual damage. Rather than damage incurred, claimants are compensated based on the value of the index, which serves as a proxy for damage.[188] These products are sometimes referred to as "disaster liquidity" products as they can provide immediate funds for under-resourced governments responsible for natural disaster response.[189]

Parametric insurance policies offer several key differences from loss-based insurance that make them potentially valuable for insuring climate-related and other catastrophic risks, including extreme heat events.

Parametric insurance policies offer several key differences from loss-based insurance that make them potentially valuable for insuring climate-related and other catastrophic risks. Parametric insurance payouts are disbursed more rapidly, because the payout is determined by the trigger event and a preset formula in the policy, avoiding the often time- and labor-intensive claims adjustment process. Since parametric policies rely on publicly available risk information (such as weather indices), they can reduce information asymmetry between the policyholder and the insurer, although insurers' pricing and product structuring will ultimately derive from proprietary models and actuarial calculations. Parametric policies can also have lower transaction costs, since confirming the pre-determined trigger event and calculating the payout involves less administrative effort by both parties. Conversely, parametric insurance also raises the potential, known as basis risk, that a policyholder may incur losses without the trigger event occurring, limiting the value of the policy (and, similarly, that an insurer will pay out where there is no loss).[190]

Parametric insurance can eliminate disincentives to invest in risk mitigation, because payouts are decoupled from actual losses (which would be limited by successful mitigation), which may be particularly valuable in the context of extreme heat where current investment in mitigation remains rare. Conversely, parametric policies could also provide little incentive to proactively reduce risk of loss (since payouts are tied solely to the occurrence of the trigger event), suggesting a need to incorporate payout or premium structures that are specifically tied to risk mitigation investments—and underscoring the uncertainty about how policies will play out in operation.[191]

Parametric insurance policies are commonly used to manage financial risk in business operations, including for crop and livestock insurance in connection with precipitation conditions and for manufacturers facing temporary depletion of essential raw materials.[192] Increasingly, governments have turned to parametric policies to manage catastrophic, national-scale risks from hurricanes and similar phenomena at a national scale (and in some cases at a regional scale, expanding and diversifying the risk pool).[193] These policies are typically used to finance immediate response actions, rather than long-term investments, though the insured's use of funds is typically not restricted.[194] The following examples provide an overview of how governments and private actors are using parametric insurance to address climate risks.

- The ***Caribbean Catastrophe Risk Insurance Facility (CCRIF)*** provides parametric coverage for hurricanes, excess rainfall, and earthquakes to 19 Caribbean and Central American governments. Payouts are based on triggers for wind speed and storm surge, rainfall, and earthquakes, and between 2007 and 2016, the facility paid out $130 million in total, in each case in under two weeks. CCRIF was the first risk transfer pool to cover sovereign risk; crucially, participating states' premium payments are based on their individual amount of risk transferred, allowing the facility to pool diverse risk with proportionate premium burdens.[195] Payouts are directed to participants' treasuries to cover short-term budget shortfalls in post-catastrophe periods.[196] Since its creation, CCRIF introduced additional mechanisms to provide payouts for events that cause damage but do not trigger the index, thus protecting against basis risk (known as Aggregate Deductible Cover), and to expand access to coverage when policyholders exceed their coverage limits (known as Reinstatement of Sum Insured Cover). In June 2019, all of its members renewed their coverage with nine states increasing their level of coverage, demonstrating the facility's success.[197]
- ***African Risk Capacity (ARC)*** was organized by the African Union in 2012 as a sovereign risk pool to cover losses associated with food production risk in 33 African countries. The policies are indexed to rainfall (future plans will cover flood and other conditions) and pay out two to four weeks after a harvest. The model requires member countries to submit peer-reviewed contingency plans in order to participate, allowing the parametric insurance policy to also serve a useful capacity-building function for policyholders.[198]
- The ***Pacific Catastrophe Risk Assessment and Financing Initiative (PCRAFI)*** is a sovereign catastrophic risk pool, similar to the CCRIF, offering parametric policies covering cyclones, earthquakes, and tsunamis. PCRAFI includes a technical assistance element that helps member countries implement comprehensive disaster risk finance and insurance and natural disaster management strategies.[199] The program was created via a seed grant from the governments of Germany, Japan, the United Kingdom, and the United States, but it targets long-term financial self-sustainability and independence.[200]
- The ***Uruguay HydroEnergy Insurance Program*** was designed to manage risk to Uruguay's hydroelectric power generation capacity during drought. The country relies on hydropower for 80 percent of its electricity, so when water levels drop, the Uruguayan state-owned power company has to buy fossil fuels to meet energy demand. After an extreme water supply shortage in 2012 created an energy gap over $1 billion, the World Bank facilitated a parametric policy based on a rainfall index that is re-established every few months, including partners from the insurance, reinsurance, and hedge fund sectors.[201] The payout is based on both the severity of drought and cost of oil prices, thus insulating the government from multiple disaster-related risk variables.
- The ***Coastal Zone Management Trust***, established by the Mexican state of Quintana Roo in 2018, is a leading example of parametric insurance used to support natural infrastructure-based resilience.

The coast off the state of Quintana Roo is home to coral reefs that serve both as tourist attractions and natural storm surge and flooding barriers. Research has found that a healthy coral reef can reduce wave energy by up to 97 percent, an effect that played out when the reef-protected town of Puerto Morales suffered minimal damage in an otherwise major 2015 hurricane.[202] To protect the reefs along the coast, the state government, local hotel owners, and the Nature Conservancy organized the trust, which is funded through regular tourism tax payments by beachfront property owners, to serve two purposes: ongoing repair and maintenance of the reef and beaches and purchasing a parametric insurance policy, which pays out funds for reef restoration activities when winds exceed a trigger speeds in predetermined areas. The project thus offers multiple public and private benefits: the local government has immediate access to recovery funds and ensures that those funds are spent on natural infrastructure recovery; the local resort owners reduce their risk of beach erosion and lost income; and the insurer cultivates an innovative new market at a measurable risk level.[203]

- ***HazeShield*** is an insurance solution created by Swiss Re for businesses in Singapore that face financial losses due to the severe haze events that periodically strike the city-state. Severe haze results from a combination of peat forest burning in neighboring Indonesia and seasonal dry, high-wind conditions; a range of businesses can suffer losses from reduced tourism and travel, reduced productivity or suspended operations in outdoor labor, and event cancelation. Swiss Re developed a haze pollutant index based on proprietary and government data, accounting for fire activity, weather patterns, and other factors, and a parametric policy with incremental payouts based on both the cumulative number of unhealthy haze days and the single worst day recorded over predefined thresholds.[204] This standalone business interruption instrument could serve as a valuable precedent for addressing the impacts of extreme heat to outdoor and travel-based industries.

These programs demonstrate how parametric policies can be used to address climate-related risks, including key risk-pooling, capacity-building, and public-private elements. New parametric insurance products are emerging for risks such as pandemics, including an innovative pandemic policy uses a trigger based on a combined index incorporating travel, spending, and other pandemic impacts rather than just the infection rate.[205] Parametric policies can also provide financial support for risks of very different natures, such as the risk that a hurricane may pose to a school district's physical assets and federal funding streams.[206] As these products evolve, they may increasingly encompass broader sets of climate risks, and will likely take on more regional risk-pooling approaches, potentially evolving into more comprehensive "climate risk insurance."[207] (They could also raise legal questions around the nature of the insurance contract, given the non-traditional nature of the "insurable interest" in the context of a climate-related trigger, rather than damage or loss to specified property).[208]


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Discussions with interviewees in the insurance sector indicated that parametric insurance mechanisms can be and have been developed for extreme heat risks facing particular sectors. These include, for example, electric utilities seeking protection against the financial risk of purchasing additional high-cost generating capacity to meet heightened demand during heat events; agricultural operations facing loss of particular high-value crops that can be destroyed in extreme heat; and construction firms whose operations may be closed due to heat-related regulatory requirements in some jurisdictions. In each context, the clear link between extreme heat and financial risk in an economic sector supports the introduction of insurance cover; as discussed throughout this report, the primarily public health-related impacts of extreme urban heat may not offer such a clear link. Yet the existence of these policies indicates the willingness of properly incented actors to engage in risk transfer for extreme heat, the ability to craft viable parameters and indices, and the potential to expand the model for a local government 'customer.'

CAPTIVE INSURANCE

Captive insurance companies are wholly owned by their insureds, providing a form of insurance (through a licensed insurer) exclusively for the risks of the owner. Captives can insure risks that are otherwise impossible or costly to insure in the market, potentially including climate risks. Their non-market posture allows them to insure risks that might not prove profitable, and may expose them to less stringent regulation than traditional third-party insurers. Captives are typically set up by large multinational companies that seek to self-insure through a formal risk transfer structure and have extensive risk management programs to limit exposure relative to the market, but they may be feasible options for groups of smaller companies or potentially governments seeking to cover challenging climate risks.[209] In this context, a captive could serve essentially to build up internal reserves and risk management capacity over time, share risk among a pooled group of captive owners, and establish a formalized approach to self-insurance, while avoiding high premiums. For local governments seeking to address a systemic climate risk like extreme heat, the captive model could provide valuable insurance elements in a financially feasible structure.

BOND FINANCING INSTRUMENTS

Governments and financial institutions are also partnering to implement bond financing tools targeted at climate risk transfer and disaster resilience, including catastrophe bonds, resilience bonds, and environmental impact bonds. In California, recent resilience-related bond measures have included traditional structures like 2018's Proposition A in San Francisco, which authorized $425 million in bonds to pay for sea wall repairs along the city's Embarcadero, and multi-benefit natural infrastructure measures like 2004's Proposition O in Los Angeles, which is designed to fund projects that serve water supply, flood management, habitat restoration, and other goals.[210] While some of these instruments are well established, their application to specific climate risk and resilience contexts offer some innovative elements that could inform extreme heat solutions.

Catastrophe Bonds

A catastrophe (or CAT) bond has a structure similar to that of parametric insurance, in which funds are paid to the bond issuer when a predetermined index is triggered, creating a relationship between issuer and investors (which surrender their principal upon the trigger event) similar to that between parametric insured and insurer. Proceeds from the CAT bond issuance are not delivered directly to the issuer, but instead are placed in a collateral account and released only upon occurrence of the trigger event. Governments (to finance recovery) and insurers (to transfer part of the risk they hold under parametric insurance policies, performing the same function as reinsurance) use CAT bonds to provide long-term financial protection against climate-related risk, which typical one-year insurance contracts do not.[211] CAT bonds typically cancel or defer the issuer's principal repayment obligation if the payout parameter is triggered, and pay high interest rates to investors as a result. They can also incorporate interest/repayment rate discounts for governments that make approved investments in risk-mitigating infrastructure.

Examples of climate risk-related CAT bonds include the World Bank's 2019 issuance of a $150 million CAT bond to help the government of the Philippines protect against financial losses due to tropical cyclones, and a 2020 $425 million hurricane and earthquake risk-related bond on behalf of the government of Mexico, with proceeds from the bond sale tied to sustainable development projects.[212] This type of hybrid CAT/sustainable development bond, in addition to the longer duration of CAT bonds, could potentially be of value for extreme heat applications.

African Risk Capacity is also in the process of developing the Extreme Climate Facility, a funding mechanism designed to issue CAT bonds to support member nations' climate catastrophe response efforts through a multi-hazard index focused on climatic changes in temperature and precipitation. The multi-year facility would trigger graduated payments in regional clusters based on changes in the frequency of extreme climate events, potentially serving as a model of risk transfer for more dispersed climate risks like extreme heat.[213]

Environmental Impact Bonds

Environmental impact bonds are bonds whose proceeds are specifically linked to funding green infrastructure projects, similar to traditional green bonds, but with additional requirements that the projects adhere to predetermined scientific guidelines and are regularly monitored to track the achievement of expected benefits. Baltimore, Maryland and Hampton, Virginia have pioneered this kind of bond for green infrastructure projects to reduce flooding risk from sea level rise, including watershed restoration, green space, and water storage systems.[214] The benefit-monitoring model could potentially be applied to address a wide range of environmental hazards, including extreme heat.

The Washington, D.C. Water and Sewer Authority has pioneered an environmental impact bond "pay for success" model based on a consent decree with the US EPA that requires the authority to manage stormwater runoff from rainfall events. The authority issued a $25 million, 30-year tax-exempt municipal bond to finance green infrastructure. The bond includes a mandatory tender after five years that requires the authority to make a one-time $3 million "outcome payment" to the investors if the project reduces runoff by more than 41 percent of baseline, and allows the authority to withhold from the investors an equivalent "risk share payment" if it reduces runoff by less than 18 percent of baseline.[215] If the project reduces runoff by an amount between these two values (as is anticipated), no additional payment is owed and the investors recoup the principal and interest without adjustment. This structure provides the authority with the upfront funding to invest in green infrastructure and a hedge against under-performance of the infrastructure (and potential violation of the consent decree), while appealing to investors with the possibility of over-performance payment. A similar structure could prove valuable to finance heat mitigation investments that are not currently factored into local government budgets. Insurers interested in supporting innovative risk transfer could invest in the bonds, as could philanthropies engaging in program-related investment.

Forest Resilience Bonds

Forest resilience bonds also facilitate targeted investment in green infrastructure, using private capital to pay the upfront costs of forest restoration activities and engaging a group of stakeholders that benefit from the project to repay its cost plus a modest return. The bonds can be used by rural communities that are particularly reliant on healthy forests as sources of timber and other income, and can also benefit from the local employment generated by forest restoration projects like controlled burns and thinning. A 2018 pilot bond in California's North Yuba River Watershed raised $4 million for a 15,000-acre forest restoration project, to be repaid by the state and a local water utility based on the anticipated ecosystem and water quality benefits.[216] While this model is directly linked to the financial value of forest resources, it offers a useful example of private capital leveraged for public benefit through ecosystem service values.

Resilience Bonds

Resilience bonds are a form of CAT bond that link catastrophe insurance with resilient infrastructure by estimating avoided losses into a "resilience rebate" (based on modeling comparing catastrophe event impacts with and without the infrastructure) that can be used to fund investments in risk mitigation.[217] By allowing future insurance savings to be used on the front end as a new source of capital to fund climate adaptation and hazard mitigation projects, resilience bonds link the insurance aspects of CAT bonds and the resilience investment of impact bonds. This model may be most effective when there is a large risk, existing insurance coverage, and an established risk-mitigating investment.[218]

PAYMENTS FOR URBAN ECOSYSTEM SERVICES

Payments for urban ecosystem services (PUES) is another mechanism for developing financial incentives for the provision of natural infrastructure that could leverage this type of data. PUES programs operate through payment by the beneficiary of a public good (i.e., a local government that benefits from enhanced air quality) to a landowner in exchange for continued or increased maintenance of that infrastructure, which traditionally has only had non-market value. The urban ecosystem services provided by tree cover, vegetation, and other green infrastructure could potentially support monetary investment through PUES.[219] PUES can include payment for maintenance or improvement/expansion of green infrastructure in exchange for public benefits; installation of green infrastructure to offset negative externalities from other activities (such as construction); and philanthropic provision for public benefit or to generate goodwill.[220] This model could be useful for valuing and investing in urban vegetation, which confers public temperature-reducing benefits when spread widely throughout the urban environment and may require installation on private as well as public property.[221] (The diffuse provision and benefits of these ecosystem services partly explains why pricing schemes are not well developed, even though the benefits to humans are well known.[222])

A robust PUES program might rely on coordinating action across stakeholders including commercial landowners, residential landowners, and public landowners, each with different capacities and incentives, through a common cost-benefit estimation tool such as that created by C40 Cities. Local governments may be able to serve as a PUES "buyer" across all these entities, leveraging commercial owners' financial capacity, residential owners' interest in aesthetic and health benefits, and public ownership of rights-of-way and park spaces.[223] If these investments are shown to reduce temperatures and are priced via the PUES scheme, they could potentially feature in a parametric or other risk-transfer mechanism.

COMPLEMENTARY POLICY ELEMENTS

These novel insurance programs and financing schemes offer a number of mechanisms that could be incorporated as part of extreme heat risk transfer framework. Elements that could support a structure and incentives to finance heat risk reduction and cover heat-related losses include:

Parametric trigger

The parametric or trigger-based model affords both the insurer and the insured an increased level of certainty regarding potential payouts and speeds the delivery of funds post-disaster event, supporting immediate response efforts and lowering costs of modeling and administration. The existence of established indices, such as the National Weather Service's Heat Index and CalEPA's Urban Heat Island Index, supports the potential feasibility of parametric instruments for heat. Multiple, escalating triggers with increasing payouts can fit the escalating, multi-day nature of extreme heat events.[224] The success of models like the Caribbean Catastrophe Risk Insurance Facility and innovative applications like the Coastal Zone Management Trust suggest an increasingly robust marketplace.

Public-private partnership

Linking government and private actors through their shared interests in addressing climate risks supports more comprehensive, nuanced risk management and response. In addition, it can be essential where no individual actor's interest is sufficiently large to justify purchasing a policy, or where multiple interests are inextricably bound together—as in the case of both the tourist industry and the local government with respect to the Mesoamerican Reef's protection of Quintana Roo. Similar benefits could flow in the context of extreme heat, which triggers a wide range of public health, infrastructure, and business impacts.

Multi-jurisdiction risk pooling

Facilities that include multiple jurisdictions can lower participation costs by pooling a more diverse set of risks, while ensuring participants pay at their financial capacity by adjusting premiums according to total risk transferred. They can also, as in the case of African Risk Capacity, facilitate sharing of crisis management plans among similarly situated actors. These pools can implement community risk rating, like the National Flood Insurance Program's community rating system which offers reduced premiums across participant communities that invest in community-wide flood mitigation measures.[225]

Incorporation of crisis management plans

Risk transfer mechanisms that require and review crisis management plans (such as African Risk Capacity), or provide technical assistance to support their preparation (such as the Pacific Catastrophe Risk Assessment and Financing Initiative), help build participating governments' risk management capacity. In addition, by directly tying risk transfer payouts to proactive planning, they can increase the likelihood that funds are directed to the most effective mitigation and response measures.

Discount for risk mitigation investments

Frameworks that offer premium discounts or rebates for participants that make investments in qualifying risk mitigation measures create new incentives to invest in beneficial infrastructure and programs. Under the parametric model, these investments do not diminish the likelihood of payout.

Repayment moratorium/cancelation

Cancelation of bond principal repayment obligations at the occurrence of a trigger event ensures that a local government just hit by a natural catastrophe does not suffer escalating financial exposure (although it also requires higher interest payments as compensation). A repayment moratorium, rather than full cancelation, allows governments time to recover financially without diminishing investors' long-term interests.[226]

Ongoing monitoring

Frameworks that include monitoring of crisis management and infrastructure investments, like environmental impact bonds, help ensure that local governments make the most effective use of funds and engage up-to-date science.

Direct links to natural infrastructure

Risk transfer mechanisms that directly link funding to specified elements of natural infrastructure offer a compellingly holistic form of resilience. The Coastal Zone Management Trust and the North Yuba River forest resilience bond, for example, use natural resilience investment to tie together government interest in healthy ecosystems and populations with local business interests in sustainable revenue. Together with investments in crisis response and built infrastructure, these investments have the potential to drive complete resilience portfolios at the local level. Where investments in urban forests and other green infrastructure mitigate extreme heat, there is clear potential for overlap.

Application to business interruption

Industries that face business interruption due to extreme heat may be the most easily identifiable 'customer' for an extreme heat risk transfer product. Business interruption could potentially serve as a component of a broader heat risk transfer framework, or as a standalone product (similar to the Singapore HazeShield instrument) to prove the viability of a parametric heat index.

V.

A CONCEPTUAL FRAMEWORK FOR EXTREME HEAT RISK TRANSFER

Comprehensive extreme heat mitigation and response may align with an index-based risk transfer model. But the mismatch between existing risk transfer frameworks and the risks presented by extreme heat highlights a group of top-priority needs: more robust data on the costs of extreme heat and the benefits of mitigation and response; new mechanisms for coordination within and among jurisdictions; and clearer links between the incentives of private and public entities.

While each of the frameworks and constituent elements discussed in the prior section offers compelling and potentially beneficial elements for the design of an extreme heat risk transfer mechanism, fitting them together in an actuarially sustainable instrument poses a complex challenge. But policymakers have a clear need for comprehensive extreme heat solutions and interest in developing innovative financial structures to pay for them.[227] And given the potential to craft a heat-related risk transfer framework based on elements of existing instruments—such as parametric insurance and environmental impact bonds—analysis of applicable risk transfer models is informative. In particular, scholars have analyzed three characteristics of a potential extreme heat framework that may be instructive: insuring climate-related risks, which is relevant due to the evolving nature of climate-related heat risk and the lack of historical precedent; insuring natural infrastructure, which is relevant due to the centrality of urban greening to comprehensive heat response plans; and insuring to support proactive risk mitigation, which is relevant due to the need for long-term mitigation measures to figure in heat solutions.

INSURING CLIMATE RISKS

Extreme heat differs from other climate risks like wildfires and flood events in that it typically does not cause immediate destruction of physical infrastructure and it typically transpires in an incremental fashion. But heat also shares a number of characteristics with these other risks that render them informative: they are all increasingly severe, increasingly complex and inter-related, experienced across wide swaths of the public and multiple geographies, and without consistent historical precedent. As a result, the barriers to insurability of climate risk and resilience in general may render some key insights for extreme heat. These include:

- The diversity of actions and investments that must be undertaken to reduce risk and improve resilience and the lack of clear, long-term data on their effectiveness;
- The widely distributed public and private beneficiaries of resilience investments, and the lack of mechanisms to coordinate their actions and align their incentives;
- The mismatch between long-term resilience investments and short-term insurance policy periods;
- Barriers to entry such as insurance market regulation and lack of intellectual property protection; and
- Lack of incentive for insurers to reduce premiums.[228]

The mismatch between standard insurance contract periods (typically one year and in some cases up to three years) and the time necessary to implement robust resilience and adaptation measures (potentially ten years) presents a particular barrier. Long-term insurance contracts could strain insurer solvency through the risk of multiple consecutive losses, requiring insurers to substantially increase their capital reserves and in turn raise premium costs, potentially to prohibitive levels.[229] This limitation suggests that risk transfer for extreme heat may require support from non-insurance instruments (such as catastrophe or impact bonds), or might need to focus narrowly on resilience measures that do not rely on multi-year implementation windows. In addition, the increasingly regular nature of extreme heat events—which will render them financially unappealing to private insurers reliant on actuarially sound premiums and random risks—and the dispersed nature of the costs may point toward the potential for bond mechanisms that rely on public financing.

Extreme heat differs from other climate risks like wildfires and flood events in that it typically does not cause immediate destruction of physical infrastructure and it typically transpires in an incremental fashion. But barriers to insurability of climate risk and resilience in general render some key insights for extreme heat.

INSURING NATURAL INFRASTRUCTURE

As discussed earlier in this report, effective heat mitigation measures will include (but likely will not be limited to) ecosystem-based measures such as urban tree canopy and green roofs. The centrality of urban greening to comprehensive extreme heat mitigation planning indicates that supporting natural infrastructure solutions could be a core element of a potential risk transfer mechanism. While insurance innovations such as the Quintana Roo parametric reef insurance model demonstrate that natural infrastructure can be insured, the key criteria supporting this model may prove difficult to replicate. Analysis of the insurability of natural infrastructure has yielded a core set of those criteria:

- A party or group of parties (private, government, or some combination) must be interested in transferring a portion of risk by purchasing insurance;
- Those parties must be able to pay the premium associated with an insurance policy;
- The natural infrastructure in question must be threatened by a random peril;

- The ecosystem must be capable of rehabilitation through actions funded by an immediate infusion of post-disaster money; and
- Insurance must be cost-effective relative to other instruments.[230]

As a result, few scenarios may exist in which it is both cost-effective to pay insurance premiums in exchange for potential payouts, and the ecosystem in question is amenable to rapid recovery funded by those payouts. This dynamic may be particularly true of extreme heat events, which may be mitigated by natural infrastructure like tree canopy and green roofs, but which only damage that infrastructure through repeat exposure (with immediate impacts instead focused on public health). And where natural infrastructure can only be restored by natural processes, or where specific components of that infrastructure are not directly damaged or destroyed by an extreme event, direct insurance of that infrastructure may not be feasible. Moreover, the feasibility of crafting insurance protection for natural infrastructure will depend upon the ability to quantify the risk-reduction benefit of that infrastructure. Scientists are performing this quantification with increasing precision for coastal risks, but it is a complex task in the context of extreme heat risks to public health, economic systems and productivity, and infrastructure that researchers are only beginning to comprehensively assess.[231] This challenge does not mean, however, that natural infrastructure investments cannot feature in a comprehensive heat mitigation plan that integrates risk transfer mechanisms—rather, that more precise data, and new risk transfer innovations, may be needed.

In addition, risk transfer in the natural disaster context raises questions around risk pooling. Risk pooling is necessary to ensure that an insurer covers a group of risks that are sufficiently independent, with only a small portion likely to materialize in a given year. (Risks covered by health and automobile insurers, for example, are independent—one insured's risk is generally not related to another's.) Climate disasters, however, have the potential to pose a group of risks that are highly correlated—and a climate disaster event will likely affect a large group of people and institutions, potentially through multiple hazards.[232] This "spiky" loss profile limits insurers' ability to reliably cover loss payments with annual premiums, and in turn necessitates the purchase of reinsurance or investment in catastrophe bonds. These products allow insurers to smooth out their own risk profiles and cover year-to-year loss payments, but they also significantly increase the cost of insurance premiums, rendering them unaffordable in some cases. As a result, many effective disaster risk transfer programs are based on public-private partnerships involving governments and insurers, in addition to philanthropic support or low-risk loans (and many of those, such as CCRIF, are multi-jurisdictional to ensure maximum risk pooling). Pooling risk by crafting a heat risk transfer product for multiple, geographically and climatically diverse jurisdictions could help mitigate this issue.[233] And the involvement of government actors may not present a significant barrier for extreme heat risk transfer, which likely would rely on government participation in any case.

INSURING TO PROMOTE PROACTIVE RISK MITIGATION

Finally, the importance of using risk transfer to support not only immediate heat crisis response but also long-term mitigation investments highlights an area in which the insurance sector has a much longer track record. Insurers structure risk transfer mechanisms to incentivize risk-reduction, such as by reducing automobile insurance premiums for safe drivers or home insurance premiums for fire-hardened structure. The ability of insurance to proactively drive risk-reducing investments (like building and maintaining the urban cooling infrastructure that could drive sustainable, long-term heat reduction) has historically been greatest in contexts where insurers could push for safety-related legal or regulatory requirements to address their own financial risks, such as the institution of seatbelt laws and building fire codes. These contexts met a few basic criteria:

- Clear and effective measures were available to reduce risk (and rising insurance industry losses were occurring);
- The measures were affordable for consumers; and
- Advancing these measures aligned well with the established business models and financial interests of insurance industry firms.[234]

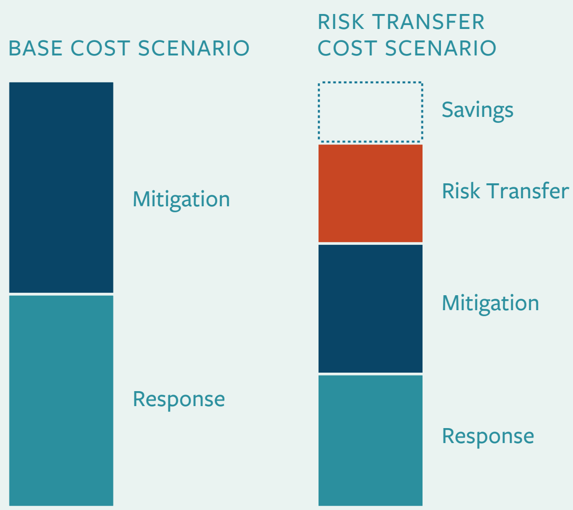
While more data are needed to fully understand the cost and benefits of long-term extreme heat mitigation investments, it is increasingly clear that such investments will become key urban planning instruments and should be able to satisfy these criteria.

Each of these criteria presents a potential barrier for the extreme heat context: While the public and decision-makers increasingly understand the importance of heat mitigation and response measures, they have limited experience with real-world implementation of comprehensive solutions; they lack sufficient data on cost and cost-effectiveness; and face still-nascent consumer (or government) and insurance industry interest in addressing heat. Established business models may not squarely meet the challenge.

These analyses, along with expert interviews, yield a number of key insights for extreme heat risk transfer. In order for public and private actors to be interested in purchasing insurance, they will require extensive data demonstrating the costs of extreme heat risks and the value of resilience investments to address them. To align risk-reduction incentives and drive coordinated response and investment across public and private entities, multi-stakeholder coalitions will likely be necessary. In addition, decision-makers and insurers may need the involvement of multiple jurisdictions—for example, a group of cities within a single climatic zone in Southern California, such as the South Coast Air Basin—to smooth risk over time and geography. Insurance may be best able to address extreme heat risk in terms of events that are not predictable in specific instances (i.e., heat waves) rather than as a gradually increasing threat (i.e., generally rising temperatures). And risk transfer instruments may need to support both short-term response actions and long-term investments in resilience, with each representing a different financial incentive structure.

Finally, the cost of the risk transfer instrument must be affordable and must offer a greater value proposition than investing exclusively in mitigation and/or response. For a local government (or coalition of government and private actors) to invest in risk transfer premium payments, the investment must be likely to deliver payouts that either reduce long-term response costs or minimize the variability of those costs by providing a baseline of funding to address them. Research on coastal resilience risk transfer measures (combining proactive reef restoration with insurance) suggests that a premium-reduction structure that fully accounts for a mitigation investment's reduction in annual average loss (AAL) can generate insurance savings of over 40 percent of the cost of that investment, and total long-term risk-reduction benefits that exceed total costs (mitigation and insurance).[235] However, crafting a similar structure for the extreme heat context may prove particularly complex—because mitigation investments are multi-faceted, data on risk-reduction are compelling but nascent, and effective public response includes both long-term and immediate actions.

FIGURE 2: Risk transfer cost savings



These analyses identify a number of barriers to crafting an effective and feasible risk transfer framework. At the same time, they highlight the key criteria for feasibility and yield a potential framework for further analysis.

A FRAMEWORK FOR FEASIBLE EXTREME HEAT RISK TRANSFER

Research on the impacts of extreme heat, the mechanisms and plans being developed to address it, and existing climate-related risk transfer instruments, together with expert interviews, highlights a set of factors that may determine the feasibility of risk transfer for extreme heat mitigation and response. As demonstrated in prior sections of this report, extreme heat risks will likely call upon a range of investments across mitigation (natural and built infrastructure), response (social and communications infrastructure), and long-term planning and zoning measures (planning infrastructure); they will rely on multiple, coordinated government (and potentially private) capacities; and they will require new funding streams. Crafting a risk transfer framework that addresses extreme heat risk, while interacting with one or more of these areas of investment, in a form that is cost-effective for the buyer/insured and actuarially sound for the seller/insurer, is a complex task. As noted in the prior section, valuable components of extreme heat risk transfer may include parametric triggers; incorporation of response plans; public-private partnership; multi-jurisdictional risk pooling; ongoing monitoring of mitigation and response; premium discounts and/or repayment moratoria; and direct links to natural infrastructure. An effective risk transfer mechanism would likely match one or more of these components to a specific local environment and response plan.

The following diagram outlines baseline conditions for such an instrument to be feasible, which may include:

JURISDICTION/COMMUNITY	Identify a target jurisdiction, community, or local population with distinct exposure to extreme heat-related risk *Need: jurisdiction-specific data on heat risk and vulnerability*
FINANCIAL IMPACT	Quantify financial impact of risk exposure, including public health, infrastructure, and government and private response costs Identify financial inflection point at which costs will exceed jurisdiction's capacity to respond/mitigate *Need: data on public health, infrastructure, business, and other impacts and response costs*
RISK REDUCTION BENEFIT	Quantify risk reduction benefit from creating, maintaining, implementing, and/or protecting a given intervention or set of interventions across natural, built, social, communications, and planning infrastructure *Need: data and modeling on cooling and benefits across potential risk and intervention categories*

RISK PARAMETER	Identify and agree on a discrete parameter related to occurrence of the extreme heat event *Need: consensus framework for declaring heat events (and the parameter/trigger) at local level*
STRUCTURED INTERVENTIONS	Structure a suite of interventions to mitigate or respond to urban heat risk Tie interventions to the risk parameter *Need: locally appropriate, comprehensive heat mitigation and response plan including immediate, medium, and long-term measures*
RISK TRANSFER INSTRUMENT	Structure a risk-transfer mechanism linked to the risk parameter and the suite of interventions, with payout that can be used to fund immediate response actions and/or investments in risk-reducing infrastructure/programs Reduce premiums in exchange for further risk-mitigation actions *Need: private partner with direct incentive linked to one or more heat risks, mitigation investments, or response actions*

This feasibility framework underscores a range of outstanding needs, including data on jurisdiction-specific risks, costs, and benefits of extreme heat; comprehensive heat management plans including locally appropriate measures across immediate response and long-term mitigation; and multi-party, potentially multi-jurisdiction cooperation to achieve scale and align incentives. Increasingly robust data on extreme heat risk and response may need to be met with detailed and regular analysis of new heat events and decision calendars to map local response timelines.[236] And financial support from government, private, or philanthropic sources may be necessary, at least at the pilot stage, as risk transfer providers and local governments seek to overcome the 'customer' challenge identified earlier in this report.

Progress in each of these areas will be necessary to develop risk transfer mechanisms that can support extreme heat response. A pilot project to pioneer an extreme heat insurance model for a local government or individual industry could begin to spark the data, policy, and financial innovations needed to address these gaps, though multiple efforts will ultimately be necessary to develop the beginnings of a risk transfer market. While this report identifies significant challenges to the feasibility of extreme heat risk transfer, the scale of the need in a warming climate is far greater.

VI.

DEVELOPING AN EXTREME HEAT RISK TRANSFER MODEL

The previously discussed feasibility factors and outstanding needs across data and analysis, mitigation and response, and financial support present a potentially challenging case for extreme heat risk transfer. At the same time, the urgency and scale of extreme heat risks, the development of comprehensive heat plans, and the innovative risk transfer mechanisms being used to address other climate and environmental risks suggest that a feasible path may be available. This section offers three potential models for extreme heat risk transfer.

INSURANCE FOR COMPREHENSIVE LOCAL EXTREME HEAT RESPONSE

A leading local government could collaborate with an insurer to implement a risk transfer mechanism premised on comprehensive heat response planning and a parametric insurance instrument. Drawing on the best-fit components of existing risk transfer models and the developing area of comprehensive heat response, such a mechanism could include:

1. *Development of a comprehensive local extreme heat plan* including appropriate components across the categories of natural, built, social, communications, and planning infrastructure. A local (city or county) government with one or more particularly vulnerable communities, as indicated by data on urban heat island effects, public health outcomes, and/or access to air conditioning, would be an ideal candidate. Examples like the Resilient Los Angeles plan offer potential models for such an approach, and community engagement processes, like those used to develop Maricopa County's neighborhood-specific heat action plans, could help deliver solutions that are targeted to community needs.

2. *Analysis of financial implications of heat plan implementation* including the cost of long-term mitigation investments and immediate responses; anticipated temperature reductions from infrastructure investments; expected health impact of social and communications investments; and estimated financial savings (public and private) generated by these measures. Synoptic analysis and tools such as

the C40 Cities Heat Resilient Cities tool could help estimate these costs and savings with local specificity. By documenting the cost savings of heat interventions, the government could attract financial contribution from stakeholders like hospital systems, multifamily housing owners, outdoor employers, and utilities.

3. *Certification of the heat plan through a model "performance contract"* that identifies necessary plan components and monitors achievement of key milestones and adherence to recurring plan elements. A leading insurance regulator, such as the California Department of Insurance, or an independent third-party entity (similar to the US Green Building Council) could conduct review and certification. California's Wildfire Fund, which requires electric utilities to submit wildfire mitigation plans for certification by the Public Utilities Commission, could also serve as a model.[237]

4. *Establishment of a local heat vulnerability index* including multiple trigger points at different daytime and overnight temperatures (and other related factors including demographic and public health profiles) and time periods in multi-day extreme heat event. The insurer or other financial institution could work with local government and public health leaders to identify or develop vulnerability indicators for different stakeholders.

5. *Creation of an insurance policy with payouts linked to escalating heat triggers and vulnerability indicators and appropriate responses from the heat plan,* to provide financial support where and when it is most needed. For example, the mechanism could provide funding to support communications interventions or air conditioner loans in the period immediately prior to an expected heat event; additional funding for cooling centers, subsidized access to privately owned cool spaces like movie theaters, or utility bill relief as the event progresses; and for additional staff at public hospitals after multiple days of impact. Provision of the policy could be dependent on certification of the local heat plan.

6. *Provision of premium reductions or other subsidies* for investment in and maintenance of long-term heat mitigation infrastructure, including natural infrastructure like tree canopy and build infrastructure like shading and cool roofs, similar to the community review system for federal flood insurance. As an alternative, maintenance of such investment could serve as a requirement for eligibility to participate.

By providing a financial and monitoring structure to support a comprehensive heat response plan, this model could accelerate the development and implementation of such plans, which will be essential to protect vulnerable populations from increasingly extreme heat. And a participating local government could leverage its capacity as an aggregator of public and private interests—as did the State of Quintana Roo in assessing a fee on resorts to fund an insurance-buying trust—to bring together relevant, disparate stakeholders in a community-based approach to insurance. In addition, as noted above, private stakeholders that see a direct financial benefit in comprehensive extreme heat planning (such as hospital systems, outdoor employers, and utilities) may be willing to contribute a portion of the cost of a risk transfer mechanism, or to carry out individual response or mitigation efforts that form part of the plan.

INSURANCE FOR TARGETED EXTREME HEAT RESPONSE

As a precursor to the comprehensive approach outlined above, a pilot risk transfer mechanism could instead target a single stakeholder or 'customer' with a particular financial interest in mitigating extreme heat impacts. This mechanism could take the same structure as the comprehensive approach but incorporate only a single trigger and response element focused on that stakeholder's particular extreme heat vulnerability point. Potential examples include:

- A ***public hospital system*** or insurer with a localized network could invest in a risk transfer instrument that triggers a payout for public communications efforts upon an early indicator of extreme heat and for surge staffing and equipment after multiple days of heat, based on the anticipated cost of increased hospitalizations during that event.
- A ***university campus*** with a resident population, range of facilities and operations, on-site power generation, and control of a significant quantity of infrastructure could develop a comprehensive extreme heat plan and partner with an insurer to cover a particular element of response, such as immediate funds to provide resident students access to cool facilities.
- An ***electric utility*** could purchase an instrument that pays out for grid repair and local backup generators in the case of an extreme heat event that threatens grid stability, with premium discounts for documented grid maintenance and resilience investments (including demand-management technologies to minimize the risk of rolling blackouts and public safety power shutoffs).
- ***A heat-impacted business*** could use a risk transfer mechanism to address potential business interruption during extreme heat events. Potential private parties could include agricultural or construction entities subject to work disruptions, logistics entities subject to supply chain disruptions, and outdoor entertainment entities subject to event cancellations.

While this model would not provide the full response and mitigation incentive structure of the comprehensive model, it could help prove basic feasibility for risk transfer and extreme heat by initiating relationships between insurers and stakeholders, building a record of heat indices and trigger events, testing premium levels and the viability of longer-term structures, and building connections between policy payouts and mitigation efforts. Each example would help build more robust heat impact data sets and serve as a test case for the comprehensive, fully public approach outlined above.

EXTREME HEAT IMPACT BOND

As an alternative to the insurance-based mechanism, local governments could consider a "pay for success" environmental impact bond focused on extreme heat mitigation investments. Such an approach might include the following components:

1. *Issuance of impact bonds to finance investment in heat mitigation and response*, potentially including both long-term investments in natural and built infrastructure and investments in social and communications programs and staff to carry out immediate response. The investments would target discrete vulnerable communities or districts within a larger city or county that experiences extreme heat stress.

2. *Assessment of the mitigation and response infrastructure's performance* relative to neighboring areas, measuring both ambient temperatures and public impacts (such as hospitalizations). The local government and investors would need to identify in advance the expected benefits of the measures selected, and select a third party to conduct ongoing evaluation and monitoring of the project to ensure it is operated and maintained adequately.

3. *Additional payments for over- or under-performance of the infrastructure* as a risk-sharing mechanism. The local government would owe an additional amount if temperature and hospitalization reductions exceed expectations, and could withhold a portion of payment from investors if the reductions are less than expected.

This model could help local governments finance their extreme heat investments by amortizing cost over the term of the bond, while providing an influx of response funding if the investments under-perform, reducing the government's risk. Insurance regulators could participate by convening the government, financial, and insurance actors that would support the model, and insurers could potentially participate as bond investors, based on the value of incentivizing risk-reducing investments.

At present, the financial risk model that would enable an insurer to engage in extreme heat risk transfer under traditional insurability criteria is unclear. Given the number of outstanding questions about the financial costs and benefits of extreme heat risk and response, and the lack of a clear insurance 'customer' at this stage, a pilot project would be the most viable means to launch an insurance-based instrument, in particular to help identify appropriately diverse risk pools and time scales to address heat risk. Such a pilot could include either a limited-scope version of the comprehensive model, with corporate or philanthropic support to provide start-up funding and expand the stakeholder group; or an industry-specific, targeted response model. In either case, the pilot could test key feasibility requirements and establish greater scientific, financial, and policy coordination in extreme heat management. And the disproportionate impact of extreme heat on disadvantaged communities and other vulnerable populations, the clear need to support and incentivize comprehensive response in a warming future, and the success of other pilot projects such as the Quintana Roo reef insurance program highlight the value of private and philanthropic support for this type of innovation.


AHEAD
STOP

VII.

CONCLUSION: AN AGENDA FOR EXTREME HEAT RISK TRANSFER: POLICY, RESEARCH, AND INNOVATION

Leaders in local government, risk transfer, and climate and public health science can collaborate on data, policy, and business model innovations needed to develop a market for extreme heat risk transfer. The urgent need for comprehensive heat mitigation and response makes the value of this innovation clear.

The potential extreme heat risk transfer models identified in this report highlight a number of opportunities for governments, businesses, and insurers to align incentives and resources to advance extreme heat mitigation and response efforts. At the same time, they highlight a number of open questions that will be central to their long-term feasibility, focused on the divergence between the incentives of risk transfer and the disparate nature of extreme heat impacts and responses. Addressing these questions will require collaboration between policymakers, local governments, insurers, and the private sector to develop the data and tools to support innovation in risk management. These needs include, but are not limited to:

- *Climate modelers and public health experts could collect comprehensive data on the costs of extreme heat events and the benefits of mitigation investments* to allow public and private actors to accurately assess their exposure and determine appropriate responses. The data would ideally be regional in scope and cover not only declared extreme heat events but also the increasingly warm days that surround them. Building on existing synoptic climate analysis efforts to cover the full range of heat threats (mortality, morbidity, productivity and education losses, infrastructure impacts) mitigation measures (natural and built infrastructure), and assessment frameworks such as the Heat Resilient Cities tool, will be key to this effort.
- *Government and risk transfer leaders could identify emerging financial incentives and opportunities* to draw private capital to extreme heat mitigation and response. Corporate leaders in outdoor sectors, goods movement/logistics, and utility operations may all have financial incentives to support long-term heat resilience in the communities in which they operate. Potential settlements in climate-related litigation

by local governments against fossil fuel companies could include heat resilience insurance concepts. Local governments and insurers can track and leverage these opportunities as they develop more nuanced understanding of their heat risk profiles.

- ***State and local government leaders could create new public heat management authorities*** with mandates and directives specifically to address extreme heat risks and response, empowered to craft and implement comprehensive heat resilience plans and to purchase or participate in related community insurance mechanisms. California's Geologic Hazard Abatement Districts, which have statutory authority to manage property and make contractual arrangements for the specific purpose of preventing, mitigating, or abating geologic hazards, could serve as a model.[238] San Francisco's Urban Forestry Council could offer a model for urban vegetation-specific entities.
- ***State and local government leaders could develop new policies to protect vulnerable populations from extreme heat*** and create more incentives to address it. As extreme heat impacts grow in scope, severity, and recognition, policymakers will need to craft regulatory responses—such as mandating cooling in schools and housing, enforcing work stoppage and break requirements, and ensuring adequate shade cover at public transit stations—to protect the most vulnerable residents. These policies, in turn, would create greater incentives to invest in mitigation and risk transfer.
- ***Government and risk transfer leaders could craft innovative applications of public financing structures*** to manageably pool risks and promote mitigation. For example, a multi-hazard CAT bond like the Extreme Climate Facility could incorporate heat risks alongside other climate risks—covering a diverse group of jurisdictions (for example in northern, southern, coastal, and inland California) across multiple years—to provide parametric trigger-based payouts for mitigation investments. Or a new property tax, with assessments based on a property's heat-resilient cover (similar to proposed Measure W for water resources in Los Angeles County), could be used to finance new public investments in heat-mitigating infrastructure while incentivizing private property owners to make similar investments.[239]
- ***Insurance sector leaders could build innovative applications of existing insurance structures*** to address the disparate costs of, and solutions to, extreme heat risk. For example, a cohort of local governments could finance a captive insurer specifically to address extreme heat risk, pooling resources to build an asset base capable of supporting immediate response to catastrophic heat events, based on mutual agreements to invest in appropriate long-term heat mitigation infrastructure.

Progress in each of these areas will be necessary to develop risk transfer mechanisms that can support extreme heat response. A pilot project to pioneer an extreme heat insurance model for a local government or individual industry could begin to spark the data, policy, and financial innovations needed to address these gaps, though multiple efforts will ultimately be necessary to develop the beginnings of a risk transfer market. While this report identifies significant challenges to the feasibility of extreme heat risk transfer, the scale of the need in a warming climate is far greater.

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