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EXTREME HEAT
The Economic and Social Consequences for the United States

Adrienne-Arsht Rockefeller Foundation Resilience Center

The **Adrienne Arsht-Rockefeller Foundation Resilience Center**, housed at the Atlantic Council, was founded in 2019 with the ambitious goal of reaching one billion people with Resilience solutions to climate change, migration and security by 2030.

In 2020, the Center launched the Extreme Heat Resilience Alliance (EHRA), a coalition of more than 30 global city and county leaders and experts in public health, finance, humanitarian assistance, disaster management, climate science, risk, insurance and public infrastructure, committed to protecting lives and livelihoods, particularly vulnerable people and communities, from the dangers of extreme heat. City Champions for Heat Action (CCHA), a cornerstone program of EHRA, was launched in 2021 to bring together elected leaders of major cities and counties around the world to reduce heat risk for their citizens. The initiative has spurred climate-forward cities such as Miami-Dade County, Athens, Greece and Freetown, Sierra Leone to commit to naming Chief Heat Officers and accelerating vital heat interventions. The Center is also spearheading a global movement to name and categorize heatwaves to help sound the alarm for approaching emergencies and build a culture of preparedness around extreme heat. For more information please visit https://www.onebillionresilient.org/ or follow us on Twitter at @ArshtRock.

Vivid Economics

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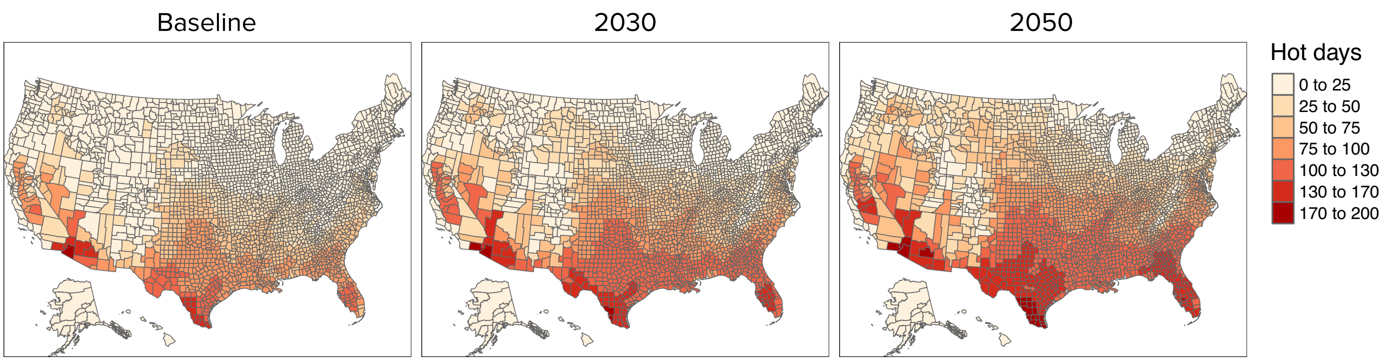
1 Introduction

The United States has historically faced periods of extreme heat, but climate change over the next 30 years could make these events more frequent, widespread, and severe. Under prevailing late-twentieth-century climate conditions, around 5 percent of the current population—roughly 16.5 million people—could expect to experience 100+ days per year where the daily maximum temperature is above 90°F. Without concerted action to limit emissions, this could increase to around 30 percent of the population by 2050. Many more people face extreme heat in unusually warm years: the recent heat wave in the Pacific Northwest provides stark evidence of how even relatively cool parts of the country can be exposed to high-severity heat events.

The economic and societal consequences of extreme heat are pervasive. Impacts encompass reductions in GDP, as workers and infrastructure systems become less productive, as well as wider detrimental effects on well-being, as healthcare outcomes worsen and people are unable to access outdoor space. Impacts include transitory ones, from people enduring uncomfortable conditions and workers taking sick leave, and enduring losses, for example, due to interruptions to education or property damage from wildfires which can be more severe due to extreme heat's effect on the environment. Tourism and other leisure activities are also affected as temperatures rise, making walking, shopping, and sightseeing uncomfortable and potentially dangerous.

This paper quantifies some of the likely socioeconomic impacts of heat in the United States under current and possible future conditions. It provides new, quantitative evidence of the economic importance of heat for policy makers and investors and shows how impacts are disaggregated across regions, socioeconomic groups, and sectors of the economy. As Table A1 in the Annex highlights, this paper considers only a subset of the ways in which extreme heat can impact the US economy and society and appraises impacts only in "normal"—as opposed to unusually warm—years, meaning it provides a conservative view of the overall significance of the issue.

Figure 1: Number of Days Where Daily Maximum Temperature Exceeds 90°F, by County



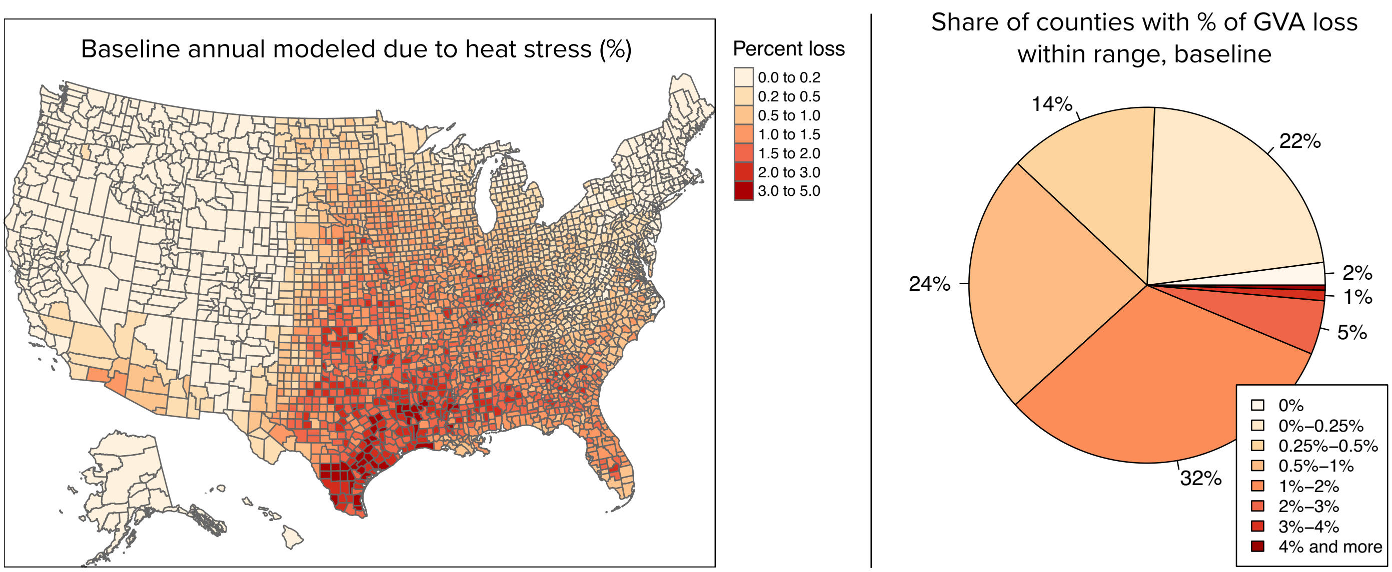
Note: Baseline based on historical climate data from 1986 to 2005. Future outlooks for 2030 and 2050 are based on an ensemble mean of 10 CMIP5 climate models run under the RCP 8.5 emissions scenario for 2021 to 2040 and 2041 to 2060, respectively. See methodology document for further details.

Source: County-level analysis conducted by Vivid Economics.

2 Impact on Labor Productivity

Extreme heat-related labor productivity losses already affect all regions and sectors of the US economy. Under baseline climate conditions, the United States could lose on average approximately $100 billion annually from heat-induced lost labor productivity—approximately the annual budget for the Department of Homeland Security ($51.7 billion) and the Department of Housing and Urban Development ($44.1 billion) combined (US Government Publishing Office 2019).[1] By comparison, the "record-breaking" 2020 Atlantic hurricane season caused an estimated $60 billion to $65 billion in loss and damages, including physical damages, lost economic activity, and health impacts (Puleo 2020). Damages significantly affect most localities of the United States—in a typical year, annual heat-related losses amount to more than 0.5 percent of economic activity (gross value added; GVA) in 62 percent of counties (they exceed $5 million in a similar share of counties) and only in a small number of counties in Alaska are they zero.[2] By comparison, in fiscal year 2020 Harris County, Texas, spent approximately 0.5 percent of its budget on mental health support and 0.8 percent on public libraries (Harris County 2019). Losses are proportionally steepest in sectors such as agriculture and construction where outdoor work is prevalent but are greatest overall in services (~$600 million), the most valuable sector of the economy, which remains vulnerable to heat due to limited air-conditioning.[3] The services sector covers a wide range of industries and occupations with varying exposure, from

Figure 2: Distribution of Economic Losses from Reduced Worker Productivity Due to Heat Stress, Baseline Scenario



Note: Gross value added lost across all sectors of the economy in 2020, based on historical climate data from 1986 to 2005.

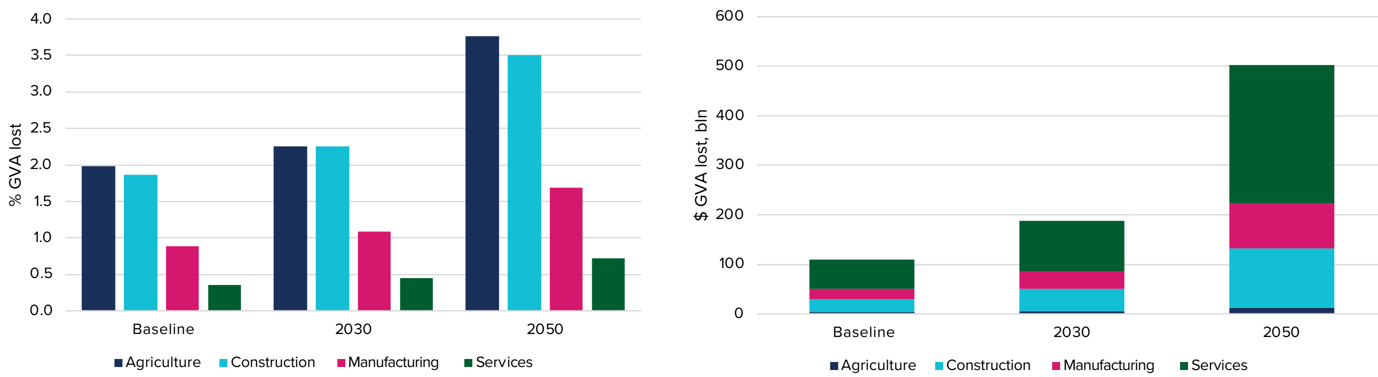
Source: Vivid Economics. Data on workability (share of productive working hours lost due to human heat stress) from Woodwell Climate Research Center (WCRC).

1 2020 results based on the "baseline" climate scenario using historical data from 1986 to 2005. See the methodology document for further details. The effect of heat stress on work comes through two channels: the need to take breaks to rest, hydrate, or seek cooling in a less exposed environment, and a natural self-limiting response of an overheated body reducing effort to maintain function. See (Dunne et al. 2013).

2 Measured as lost gross value added (GVA), the measure of the value of goods and services produced in an area, industry, or sector of an economy.

3 "Services" includes a wide range of industries, including white-collar services, restaurants and hospitality, transportation, education, retail and wholesale trade, healthcare, and more. See the methodology document for further details.

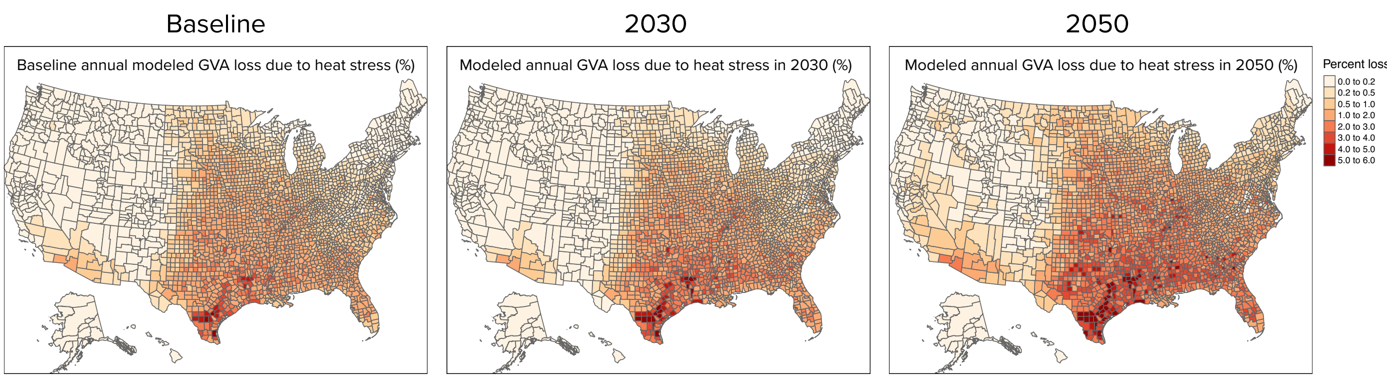
Figure 3: Estimated Economic Losses from Reduced Worker Productivity Due to Heat Stress, Baseline, by Major Sector



Note: Based on historical climate data from 1986 to 2005 and 2020 economic data for baseline and projections for 2030 (2021 to 2040) and 2050 (2041 to 2060) under RCP 8.5 and SSP5. See methodology document for more details.

Source: Vivid Economics. Data on workability (share of productive working hours lost due to human heat stress) from Woodwell Climate Research Center (WCRC).

Figure 4: Evolution of Modeled Economic Losses from Reduced Worker Productivity Driven by Human Heat Stress, Baseline, 2030, and 2050



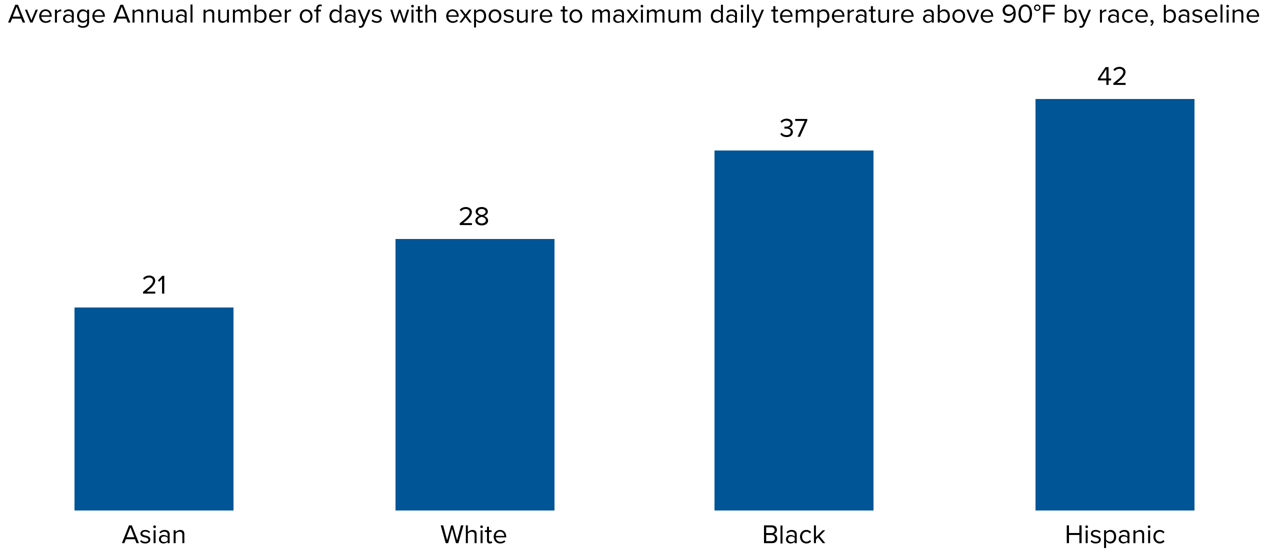
Note: Based on historical climate data from 1986 to 2005 and 2020 economic data for baseline and projections for 2030 (2021-2040) and 2050 (2041-2060) under RCP 8.5 and SSP5. See methodology document for more details.

Source: Vivid Economics. Data on workability (share of productive working hours lost due to human heat stress) from Woodwell Climate Research Center (WCRC)

office jobs which are largely air-conditioned to work in transportation and warehousing which largely takes place outside or in environments that are not air-conditioned.

Without meaningful action to reduce emissions and/or adapt to extreme heat, labor productivity losses could double to nearly $200 billion by 2030 and reach $500 billion by 2050. Losses mount not only in dollar terms but also affect a larger share of the economy, amounting to an estimated ~0.5 percent of projected GDP by 2030 and ~1 percent of GDP by 2050. Texas, Mississippi, and Alabama are already among the states facing the highest heat stress-related economic losses and could also face the greatest increase in losses as a share of output. By 2050, 80 percent of the counties in the United States could lose more than 0.5 percent of their GVA due to heat-related

Figure 5: Exposure to Heat by Race, Baseline Climate Conditions



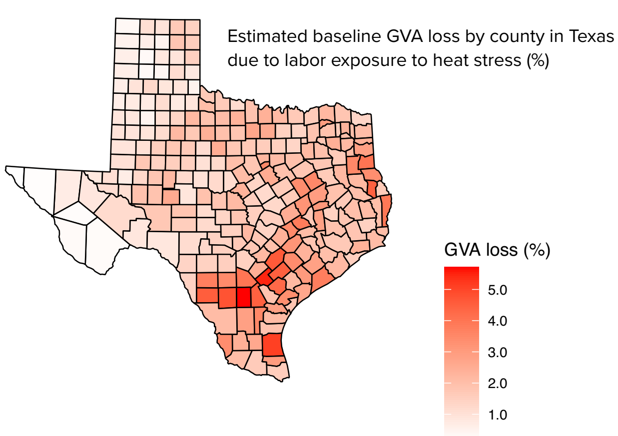
Note: Based on historical climate data from 1986 to 2005 and demographic details from the 2019 American Community Survey.

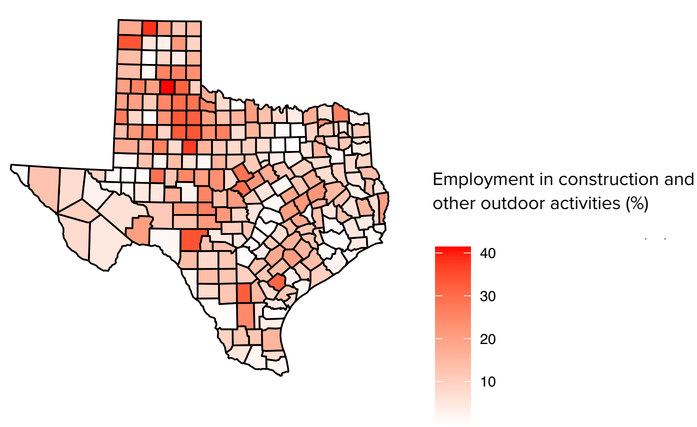
Source: Vivid Economics.

Box 1: Texas Accounts for Almost a Third of National Labor Productivity Losses

Texas is exposed to the greatest labor productivity losses due to heat stress under baseline conditions, and, without adaptation, this will remain the case in 2050. Without adaptation or action to reduce emissions, losses are projected to mount in absolute and relative terms, from ~$30 billion or ~1.5 percent of GVA on average in the baseline period to ~110 billion or ~2.5 percent of GVA by 2050. High Texan losses can be explained by both the level of heat and composition of economic activity, with relatively high levels of outdoor work.

Figure B1.1





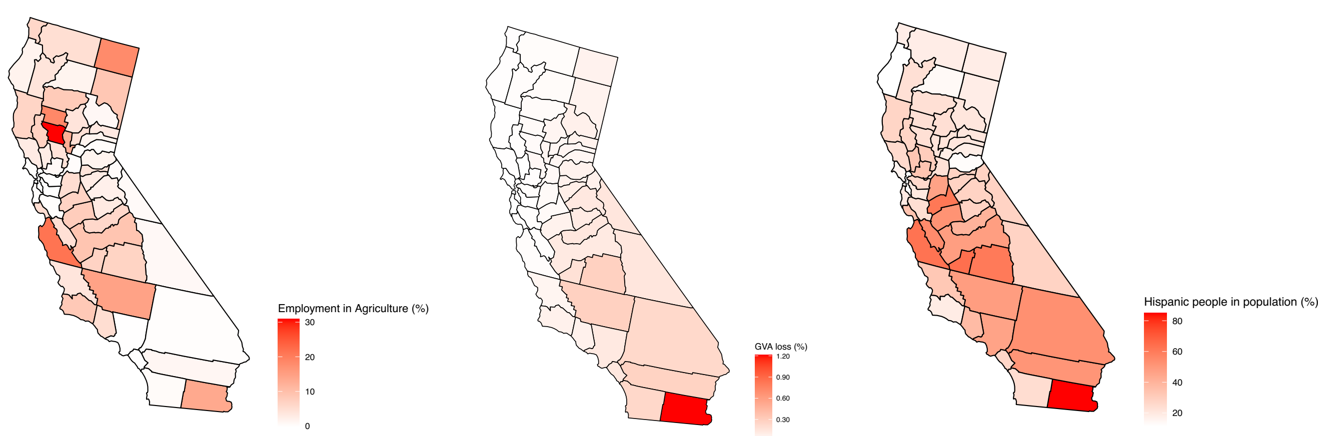
Box 2: Hispanic Workers Are Likely to Be Disproportionately Affected by Heat Stress in Southern California

California is exposed to significant losses from heat-induced labor productivity impacts under baseline climate conditions, worth around $3 billion. By comparison, the 2019-2020 state budget allocated $2.75 billion in emergency investments for housing and homelessness (State of California 2019, 67). These losses are concentrated in counties in Southern California, which are hotter and often more dependent on agriculture. For example, Imperial County has desert conditions but, due to irrigation supplied by the Colorado River, is one of the most productive farming regions in the state, with 9.2 percent of workers in the county employed in agriculture.

Imperial County borders Mexico and 85 percent of its population is Hispanic. Hispanic workers are disproportionately represented in the demographics of agricultural workers (Isaacs 2020). As such, Hispanic workers are likely to experience heat-related losses equivalent to ~2.0 percent of their productivity in Imperial County, relative to ~1.7 percent for White workers.

In 2005, California became the first state to establish a statewide occupational heat illness prevention directive that applies to all outdoor workers, requiring employers to provide water, rest, shade, and training. Although studies have found farms comply with the standards, the measures are not sufficiently effective to eliminate heat-related illness among farmworkers (Mitchell et al. 2018).

Figure B2.1: Baseline % Employment in Agriculture, % GVA Lost, and Percentage of Hispanic Working Population in California



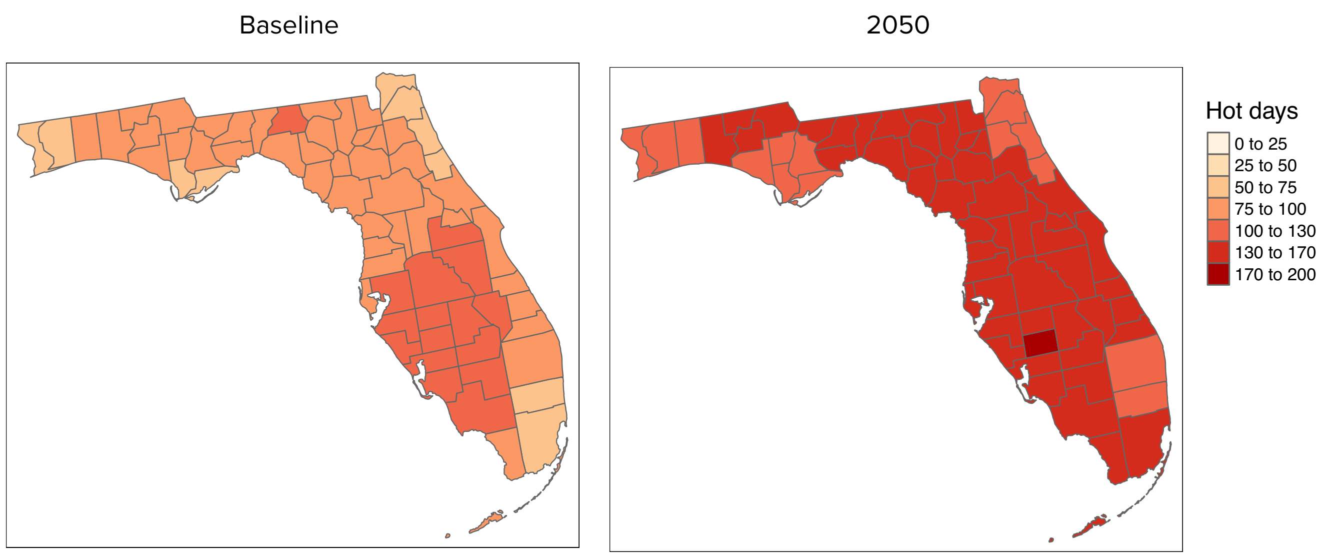
productivity losses, and 86 percent of the counties in the United States may face losses of at least $5 million per year.

Black and Hispanic workers face proportional productivity losses 18% percent greater than non-Hispanic White workers. Black and Hispanic workers tend to live and work in more heat-exposed regions of the country. On average, a Black worker is likely to experience ~35 to 40 days with maximum temperature above 90°F, and a Hispanic worker is likely to experience ~40 to 45 such days. White and Asian workers typically live in cooler areas and are exposed to approximately ~25 to 30 and ~20 to 25 days, respectively, with temperatures above 90°F. Greater exposure to this heat stress means Black and Hispanic workers tend to face worse working conditions and, on average, lose ~1.3 percent of their productivity. In contrast, an average non-Hispanic White worker tends to face a lower average productivity loss of ~1.1 percent.

Box 3: Florida's Hot and Humid Conditions Threaten Its Service-Driven Economy

Hot and humid conditions in Florida result in high labor productivity losses. At $11 billion in a typical year, labor productivity losses in Florida are second only to Texas and are expected to increase more than fourfold to $52 billion by 2050. Florida is a services-driven economy, a sector which accounts for 89 percent of employment, with leisure and hospitality alone accounting for 11 percent (US Bureau of Labor Statistics 2021). Disney World is a major employer in the sector, with the resort employing 77,000 workers before the COVID-19 pandemic, and has expressed concern about the risk of extreme heat associated with climate change. In its disclosure to CDP, Disney outlined that rising temperatures are already affecting "the comfort and health and well-being of customers" and "if measures are not taken to ensure low cost alternatives for cooling and managing extreme temperatures, this will not only negatively impact our customers experience, it will also impact our ability to attract and retain visitor numbers" (Flavelle 2019). The impact of heat on tourism has been found in empirical analysis. For example, a study of an outdoor tourist attraction in California (the Living Desert Zoo and Botanical Gardens in Palm Desert) found that visitor attendance declined at temperatures of 86°F and higher (Yañez et al. 2020). In Orange and Osceola Counties, where Disney World Resort is based, the number of hot days is expected to increase by 50 percent between now and 2050, reaching 151 and 156 days, respectively. The tourism sector offers particular adaptation challenges due to the outdoor nature of many activities.

Figure B3.1



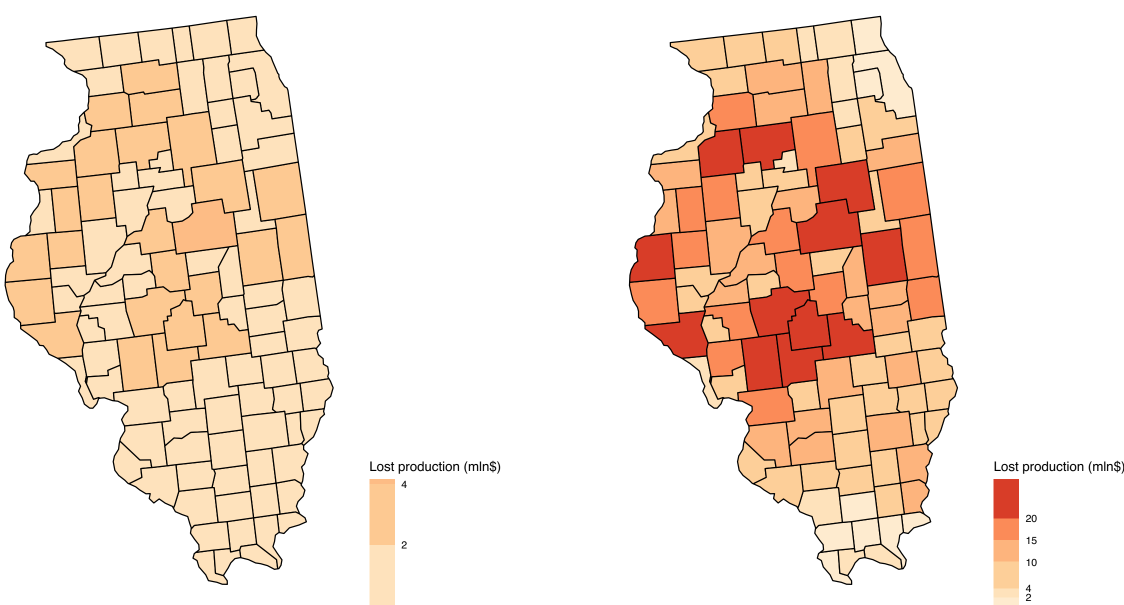
3 Impact on Agricultural Yields

Physical impacts on crop yields can compound with reduced labor productivity in US agriculture: without adaptation, corn yields in key regions could fall by ~10 percent by 2050. Many key crops are vulnerable to extreme heat: corn, soy, and wheat, which collectively covered approximately 62 percent of harvested area in the United States in 2010, could face significant losses during growing seasons without adaptation (Schauberger et al. 2017). In the Midwest, yield losses associated with heat for corn and soy, whose growing seasons are in the spring and summer, could grow from ~2 percent to 13 percent and ~1 percent to 11 percent, respectively. Wheat, whose earlier growing season means losses are minimal under baseline conditions, could experience yield losses of up to 11 percent by 2050. With the United States accounting for nearly a third of global corn exports, the economic consequences could be internationally significant (US Department of Agriculture 2020). Reduced corn supply could cause prices to rise, resulting in higher prices for foods and fuels that use corn as a major input (Forbes 2021).

Box 4: Illinois' Agricultural Prowess Is Vulnerable to a Changing Climate

Illinois is a leading producer of soybeans, corn, and pork products in the United States. The sale of Illinois' agricultural commodities generates $19 billion each year, of which corn accounts for 54 percent and soybeans 27 percent, and agriculture accounts for 6 percent of employment (Illinois Department of Agriculture 2021). Under baseline climate conditions, the analysis suggests that Illinois loses ~$200 million on average each year from heat-damaged major crops.[1] Absent adaptation, this number could increase to ~$1.6 billion by 2050, driven primarily by projected losses in corn (67 percent) and soybeans (32 percent). A separate study found that Illinois could lose up to ~$13 billion each year from crop losses by the end of the century (Gordon et al. 2015).

Figure B4.1: Estimated Lost Corn Production in Baseline and Modeled 2050 Climate Scenarios in Illinois (in $ millions)



1 Corn, cotton, soybeans, and wheat.

4 Impact on Health Outcomes

Extreme heat is already a leading cause of mortality in the United States, but without adaptation, deaths could increase more than sixfold. Under baseline climate and current demographic conditions, more than 8,500 deaths would be expected in a typical year as a consequence of daily average temperatures above 90°F, concentrated in the country's hottest areas. This is projected to increase more than sixfold to ~59,000 by 2050, with increases projected to be concentrated in already hot areas in southwestern Arizona, Southern California, and southwest Texas, as well as becoming more widespread. Estimated increases in heat-related mortality are affected by climate change and population growth, as well as demographic shifts from an aging population. People aged 65 and older are more than twenty times more likely to die from heat-related events compared to people aged 1 to 44 years.

These projections do not account for factors that could increase future mortality. Access to air-conditioning is a critical mitigant of health risks from heat. More widespread heat episodes could affect areas where access is least well established at present, including in lower-income communities, while increased demand for air-conditioning

Box 5: Arizona's Hot Conditions Could Increase the Risk of Heat-Related Deaths

Arizona averaged approximately 50 dangerous heat days (above 90°F average temperature) per year during the baseline period. This figure is likely to increase to ~80 by 2050. Arizona accounts for 45 percent of the modeled heat-related deaths in the baseline period, but as extreme heat becomes more widespread across the United States, other states will see relative increases. By 2050, Arizona will account for only 22 percent of the modeled heat-related deaths, while Texas will account for 30 percent.

In 2020, officials in Arizona reported 520 heat-related deaths, of which 315 were in Maricopa County (where Phoenix is located) and 155 were among the homeless population (James 2021). Although the Phoenix metropolitan area experiences the most deaths by number, there is growing concern about the rural western part of the state, which experience high rates of heat-related illness attributed to energy poverty and inaccessibility of public services (Stone 2021). In Arizona, mobile homes account for 11 percent of housing units and can present a particular risk (Segedy 2018). The poor design of mobile homes means that residents tend to spend a high proportion of their income on energy bills (Jessel et al. 2019). Low-income, elderly people living in these types of housing with limited access to cool, indoor public space are highly vulnerable to heat-related illness. In 2019, rural Yuma County's heat illness rate was nearly three times higher than the state average (Stone 2021). Exposure to dangerous high temperatures may be mitigated by increasing tree canopy cover, where appropriate in the environment. Tree canopy cover reduces not only the surface temperature outdoors by as much as 45°F but can also cool buildings and reduce indoor cooling energy costs (US Environmental Protection Agency 2021)

Figure B5.1: Heat-related excess mortality, baseline

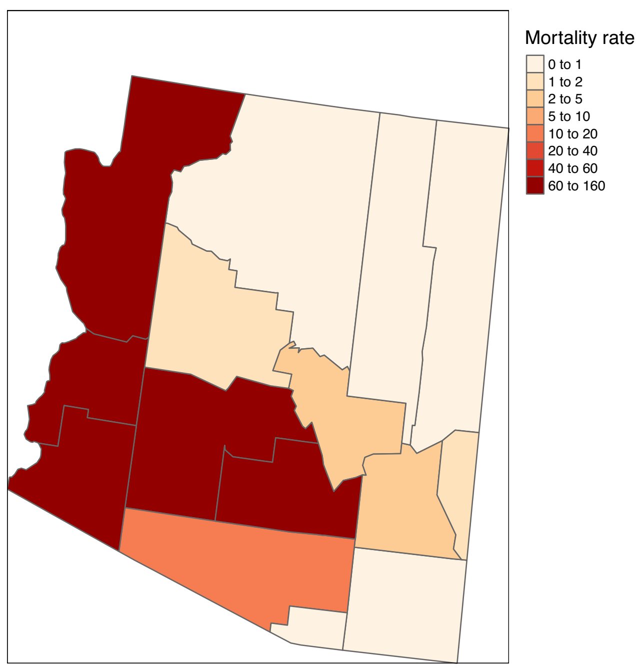
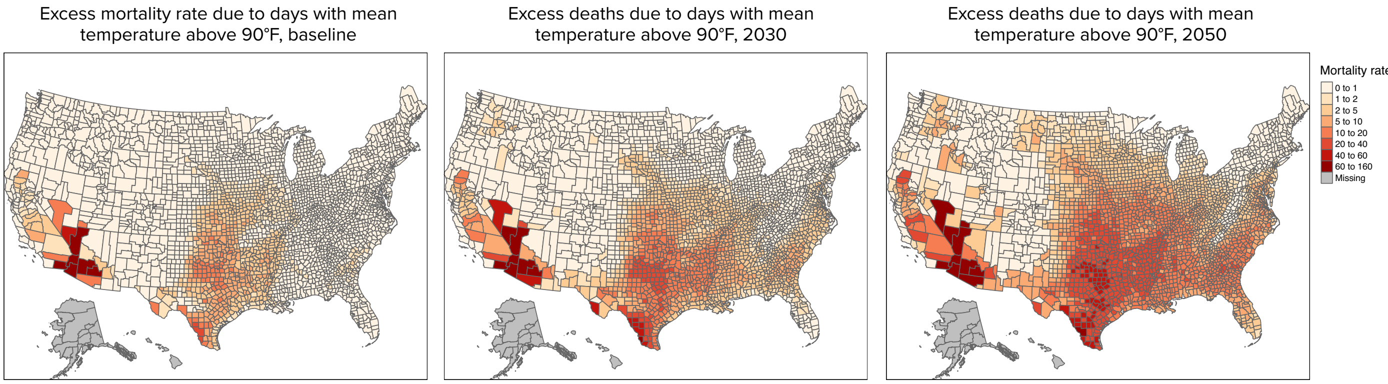


Figure 6: Estimated Mortality Due to Extreme Heat Days (Above 90°F Mean Daily Temperature), Baseline, 2030, and 2050



Note: Baseline based on historical climate data, 1986 to 2005. Future outlook for 2030 and 2050 is based on an ensemble mean of 10 CMIP5 climate models run under the RCP 8.5 emissions scenario for 2021 to 2040 and 2041 to 2060, respectively. See methodology document for further details.

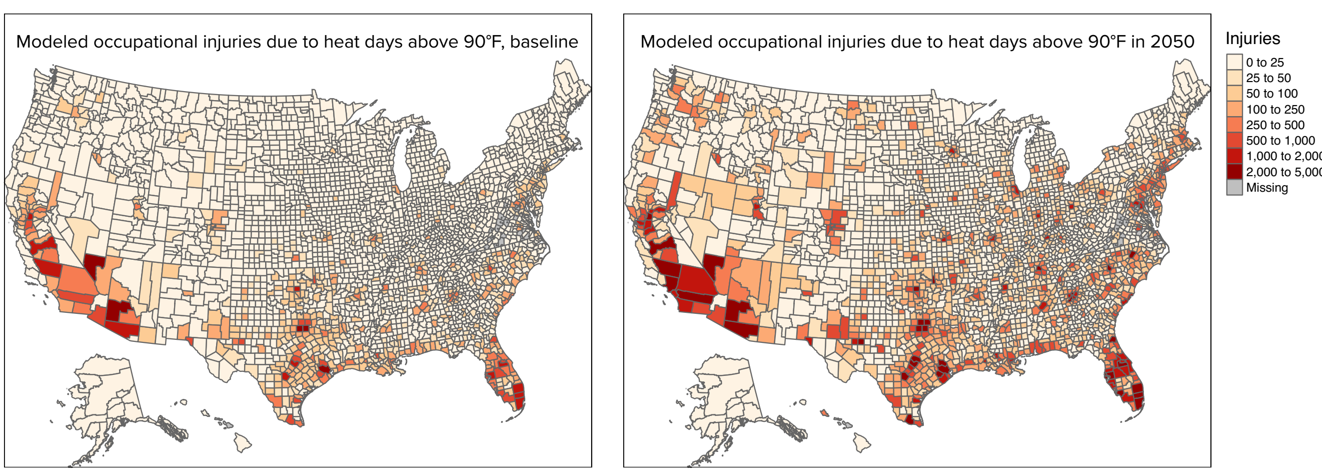
Source: County-level analysis conducted by Vivid Economics.

Box 6: Occupational Injuries

In addition to impacts on mortality, there is evidence that extreme heat can lead to higher rates of occupational injuries. This can have effects on both health outcomes and productivity. Park et al. 2021 found that hot days increase occupational injuries for outdoor and indoor activities, even those not directly related to heat such as falls, slips, and trips (Park et al. 2021).

Extreme heat is estimated to explain around 120,000 occupational injuries on average per year during the baseline period. Without adaptation, this number could increase nearly fourfold to ~450,000.

Figure B6.1



strains grid capacity, risking outages.[4] Additionally, climate change could increase the likelihood of heat events coinciding with other physical hazards that can cause power outages. The 2020 Atlantic hurricane season caused millions of Americans to lose power during the summer months when heat was most intense. Tropical Storm Isaias alone left 35 percent of households in New Jersey without power in August 2020, and more than 90,000 households in Connecticut were left without power for over a week, leading the governor to declare a state of emergency (Mersereau 2020; Scinto 2020).

4 California regularly faces grid stress due to peak demand for air-conditioning on hot days. The grid operator issues “Flex Alerts” to request voluntary reductions in energy use by consumers (California ISO 2021; Ormseth 2021).

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Annex

Table A1: Socioeconomic Impact Channels of Extreme Heat in the United States			
Category	**Mechanism**	**Explanation**	**Analysis**
Productivity losses	Labor productivity	Heat stress reduces labor productivity, as workers slow down work and take extra breaks to prevent overheating.	Annual heat stress-related gross value added loss across the economy, grouped into four major sectors, estimated by county for baseline, 2030, and 2050.
	Mechanical failures	Extreme heat can cause machinery to overheat and fail, including vehicles, computers, and cooled production processes, for example.	Not estimated in analysis
	Infrastructure system failures	Transport infrastructure (for example, runways) can become unusable in extreme heat.	Not estimated in analysis
	Absenteeism	Workers who are ill or injured due to extreme heat could be unable to work.	Not estimated in analysis
	Agricultural yield loss	Heat stress during key stages of crop development during the growing season could lead to reduced crop yields.	Annual heat-related yield loss for corn, soy, wheat, and cotton estimated by county for baseline, 2030, and 2050.
Health impacts	Mortality	Extreme heat places stress on body systems and can lead to premature death.	Annual heat-related deaths estimated by county and age group for baseline, 2030, and 2050.
	Occupational injures	Exposure to extreme heat at work can increase not only heat-related illness, but also accidental injury.	Annual heat-related occupational injuries estimated by county for baseline, 2030, and 2050.
	Morbidity	Heat stress can lead to both acute heat-related illness and exacerbation of chronic illness, especially cardiovascular, pulmonary, and renal.	Not estimated in analysis

Category	Mechanism	Explanation	Analysis
Health impacts	Healthcare costs	Hospital admissions and ongoing treatment can increase costs both to the healthcare system and the individual.	Not estimated in analysis
Asset damages	Wildfires	Dry conditions, driven in part by heat, can contribute to increases in the likelihood of wildfire occurrence and wildfire severity.	Not estimated in analysis
Other socioeconomic impacts	Education	Heat can reduce learning and human capital development when students must learn in environments without air-conditioning.	Not estimated in analysis
	Outdoor activities	Outdoor activities can become less enjoyable and less safe when temperatures are very high. Active transport modes (walking, cycling) could be reduced.	Not estimated in analysis
	Domestic activities	Normal household activities may suffer in extreme heat; comfort and time spent on these activities are likely to be reduced.	Not estimated in analysis
	Tourism	Exposure to extreme heat may reduce tourism to locations which currently receive significant income from tourist activities.	Not estimated in analysis
	Price effects	Impacts on productivity can increase prices for essential commodities such as food.	Not estimated in analysis

Source: Vivid Economics.

Methodology

This methodology document accompanies the August 2021 report "Extreme Heat: Economic and Social Consequences for the United States" and provides additional detail into the assumptions of the main report and the sources relied on to support and develop those assumptions.

Read the methodology document here.

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