Health

SUBSECTORS

Air Quality

Extreme Temperature

Weather and climate play a significant role in our health and well-being. As a society, we have structured our day-to-day behaviors and activities around historical and current climate conditions. Increasing GHGs in the atmosphere are changing the climate faster than any time in recent history.[3] As a result, the conditions we are accustomed to and the environment in which we live will change in ways that affect human health. In addition to creating new problems, changes in the climate can exacerbate existing human health stressors, such as air pollution and disease. Many of the adverse effects brought on by climate change may be compounded by how our society is changing, including population growth, an aging population, and migration patterns that are concentrating development in urban and coastal areas.

HOW ARE PEOPLE VULNERABLE TO CLIMATE CHANGE?

Climate change is projected to harm human health in a variety of ways through increases in extreme temperature, increases in extreme weather events, decreases in air quality, and other factors.[4] Extreme heat events can cause illnesses and death due to heat stroke, cardiovascular disease, respiratory disease, and other conditions. Increased ground-level ozone is associated with a variety of health problems, including reduced lung function, increased frequency of asthma attacks, and even premature mortality.[5] Higher temperatures and changes in the timing, intensity, and duration of precipitation affect water quality, with impacts on the surface water we use. There are a variety of other impacts driven by climate change that are expected to pose significant health hazards, including increases in wildfire activity (see the Wildfire section of this report).[6]

WHAT DOES CIRA COVER?

CIRA analyzes the potential impacts of climate change on human health by focusing on air quality, extreme temperature mortality, labor, and water quality. Analyses of many other important health effects are not included in CIRA; these include, for example, impacts from increased extreme weather events (e.g., injury or death from changes in tropical storms), air pollution from wildfires, and vector-borne disease (e.g., Lyme disease and West Nile virus).

Labor

Water Quality

Air Quality

KEY FINDINGS

1. Unmitigated climate change is projected to worsen air quality across large regions of the U.S., especially in eastern, mid-western, and southern states. Impacts on ozone and fine particulate matter pollution are projected to be especially significant for densely-populated areas. The analysis holds emissions of traditional air pollutants constant at current levels to isolate the climate change related impact on air quality.

2. Global GHG mitigation is projected to reduce the impact of climate change on air quality and the corresponding adverse health effects related to air pollution. Mitigation is estimated to result in significant public health benefits in the U.S., such as avoiding 13,000 premature deaths in 2050 and 57,000 premature deaths in 2100. Economic benefits to the U.S. of avoided premature deaths are estimated at $160 billion in 2050, and $930 billion in 2100.

Climate Change and Air Quality Health Effects

Changes in climate are projected to affect air quality across the U.S. In already polluted areas, warmer temperatures are anticipated to increase ground-level ozone (O_3), a component of smog, and increase the number of days with poor air quality.[7] Changes in weather patterns may also affect concentrations of fine particulate matter ($PM_{2.5}$), a mixture of particles smaller than 2.5 micrograms per cubic meter ($\mu g\ m^{-3}$), emitted from power plants, vehicles, and wildfires. Inhaling ozone and fine particulate matter can lead to a broad range of adverse health effects, including premature mortality and aggravation of cardiovascular and respiratory disease.[8, 9]

Risks of Inaction

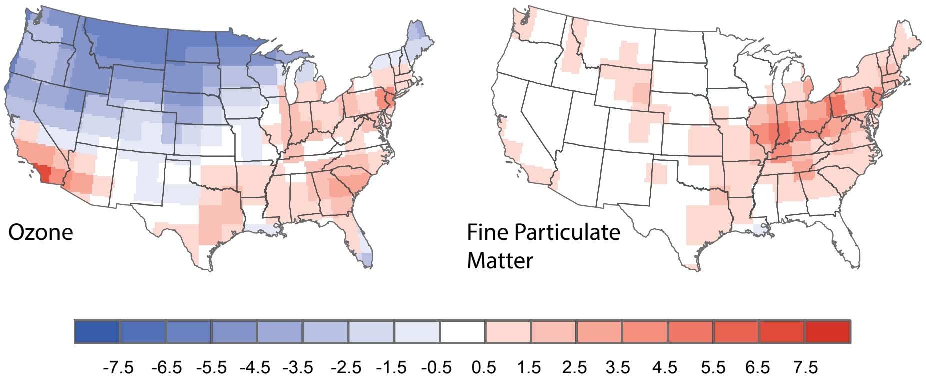
Without global GHG mitigation, climate change is projected to have a substantial effect on air quality across the contiguous U.S., with important regional differences (Figure 1). Ozone concentrations are projected to increase in the Reference scenario in more densely-populated regions, such as the East, Midwest, and South, while some less densely-populated areas experience decreases in ozone concentrations.[10] Although the national annual average ozone concentration is projected to decrease slightly (1.3 ppb +/- 0.2) by 2100, human exposure to ozone is projected to increase, driven by increasing concentrations in densely-populated areas. Climate-driven ozone increases are especially substantial during summer months. By 2100, the U.S.-average 8-hour-maximum ozone concentration in June-August is projected to increase 4.7 ppb (95% confidence interval ± 0.5).[11]

Unmitigated climate change is projected to exacerbate fine particulate matter pollution, especially in the Midwest and East. The annual U.S.-average $PM_{2.5}$ concentrations are projected to increase by 0.3 $\mu g\ m^{-3}$ (± 0.1) in 2050 and 0.7 $\mu g\ m^{-3}$ (± 0.1) in 2100 in the Reference scenario.[12]

Projections that climate change will lead to increased ozone in polluted regions are consistent with the assessment literature. There is less agreement regarding the magnitude of climate change effects on particulate matter, with the exception of increasing wildfire activity on particulates.[13] The results presented in this report add to this emerging area of research.

Figure 1. Projected Impacts of Unmitigated Climate Change on Air Pollution in the U.S.

Estimated change in annual-average ground-level hourly ozone (O_3, ppb) and fine particulate matter ($PM_{2.5}$, $\mu g\ m^{-3}$) from 2000 to 2100 under the Reference scenario.



Reducing Impacts through GHG Mitigation

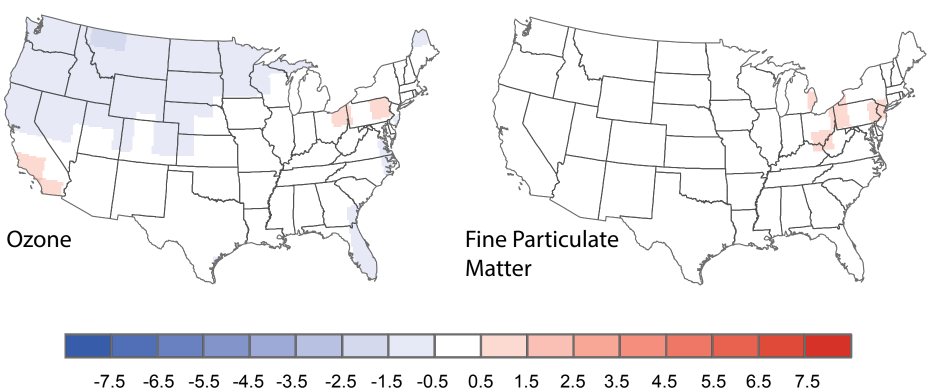
Global GHG mitigation is projected to avoid significant adverse impacts to air quality that would occur under the Reference scenario in densely-populated areas. Figure 2 shows air quality changes in the Mitigation scenario, which are much smaller than those under the Reference (Figure 1). Despite smaller reductions in ozone in some less densely-populated areas, global GHG mitigation is projected to reduce the increase in the annual-average, 8-hour-maximum, population-weighted ozone concentration by approximately 2.6 ppb (95% confidence interval ± 0.3) that would occur in the Reference in the U.S.

Global GHG mitigation is also projected to lessen the adverse effects of climate change on fine particulate matter pollution in the U.S. In 2100, the increase in the annual-average population-weighted $PM_{2.5}$ concentration under the Reference is reduced by approximately 1.2 μg m^{-3} (± 0.1) under the Mitigation scenario.

Reducing the impacts of climate change on air quality through global GHG mitigation is projected to result in significant health benefits across the U.S. For example, the Mitigation scenario is estimated to prevent an estimated 13,000 premature deaths in 2050 (95% confidence interval of 4,800-22,000) and 57,000 premature deaths in 2100 (95% confidence interval of 21,000-95,000) compared to the Reference.[14] Economic benefits to the U.S. of these avoided deaths are estimated at $160 billion and $930 billion in 2050 and 2100, respectively. In addition to reducing premature mortality, global GHG mitigation would result in other health benefits not presented here, including reduced respiratory- and cardiovascular-related hospital admissions.[15, 16]

Figure 2. Projected Impacts on Air Pollution in the U.S. with Global GHG Mitigation

Estimated change in annual-average ground-level hourly ozone (O_3, ppb) and fine particulate matter ($PM_{2.5}$, μg m^{-3}) from 2000 to 2100 under the Mitigation scenario.



Treatment of Co-Benefits

This analysis does not quantify the additional benefits to air quality and health that would stem from simultaneous reductions in traditional air pollutants along with GHG emissions (both are emitted from many of the same sources). Incorporating these "co-benefits," which recent analyses[17] and assessments[18] indicate could provide large, near-term benefits to human health, would result in a more comprehensive understanding of air quality and climate interactions.

APPROACH

The CIRA analysis assesses the impact of climate change on air quality across the contiguous U.S. through changes in ground-level ozone and fine particulate matter ($PM_{2.5}$) concentrations.[19] Future concentrations of these pollutants are simulated in an atmospheric chemistry model, driven by weather patterns from the CIRA climate projections. The analysis projects future concentrations for five initializations of the IGSM-CAM climate model under the Reference and Mitigation scenarios in 30-year periods centered on 2050 and 2100 (with 95% confidence intervals based on the difference in mean across the initializations). Despite assumptions about growth in GHG emissions in the Reference and Mitigation scenarios, emissions of the traditional air pollutants are kept fixed at present-day levels to isolate the climate change-related impact on air quality. Changes in pollution due to projected increases in wildfires and changes in sea salt and dust are not considered. Pollutant concentrations are used to estimate changes in air pollution exposure in people. The Environmental Benefits Mapping and Analysis Program (BenMAP) is applied to estimate health effects (with 95% confidence interval based on concentration response functions in BenMAP).[20] To monetize the effects of changing mortality, a value of statistical life (VSL) of $9.45 million for 2010 (2014$) is used, adjusted to future years by assuming an elasticity of VSL to gross domestic product (GDP) per capita of 0.4.[21]

For more information on the approach, models used, and results for the air quality sector, please refer to Garcia-Menendez et al. (2015).[22]

Extreme Temperature

KEY FINDINGS

1. Without global GHG mitigation, the average number of extremely hot days in the U.S. is projected to more than triple from 2050 to 2100. The projected reduction in deaths from extremely cold days is more than offset by the projected increase in deaths from extremely hot days. This result holds for all reported future years, indicating that unmitigated climate change clearly poses an increasing health risk from extreme temperatures.

2. Global GHG mitigation is projected to result in approximately 12,000 fewer deaths from extreme temperature in the 49 modeled cities in 2100. Inclusion of the entire U.S. population would greatly increase the number of avoided deaths, but accounting for adaptation could decrease the number.

Climate Change and Extreme Temperature Mortality

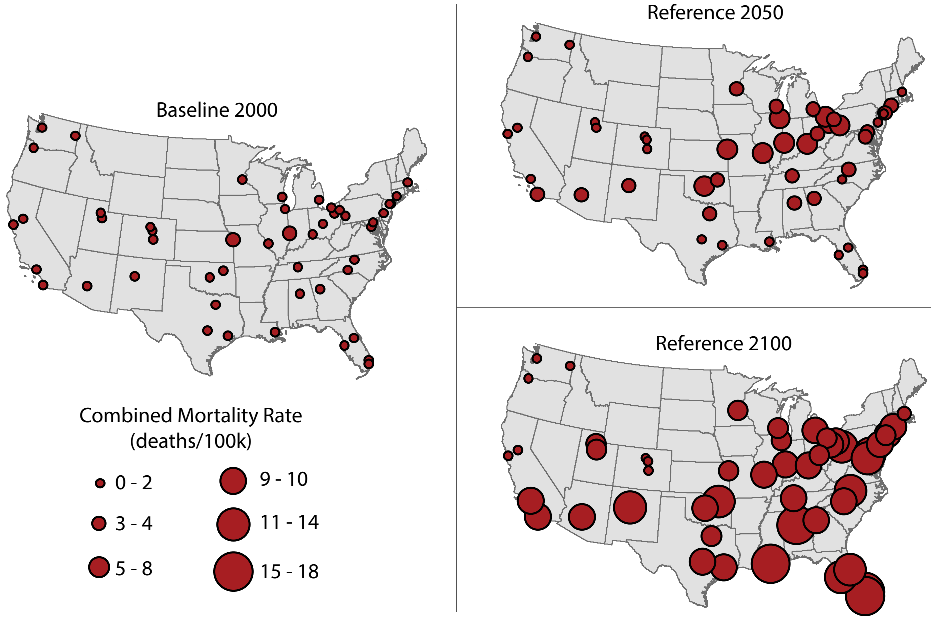
Climate change will alter the weather conditions that we are accustomed to. Extreme temperatures are projected to rise in many areas across the U.S., bringing more frequent and intense heat waves and increasing the number of heat-related illnesses and deaths.[23] Exposure to extreme heat can overwhelm the body's ability to regulate its internal temperatures, resulting in heat exhaustion and/or heat stroke, and can also exacerbate existing medical problems, such as heart and lung diseases.[24] During a 1995 heat wave in Chicago, an estimated 700 individuals died as a result of the extreme heat.[25] Warmer temperatures are also expected to result in fewer extremely cold days, which may also reduce deaths associated with extreme cold.[26]

Risks of Inaction

Climate change poses a significant risk to human health as more days with extreme heat are projected to cause more deaths over time. Without global GHG mitigation, the average number of extremely hot days is projected to more than triple from 2050 to 2100, while the number of extremely cold days is projected to decrease. The projected increase in deaths due to more frequent extremely hot days is much larger than the projected decrease in deaths due to fewer extremely cold days, a finding that is consistent with the conclusions of the assessment literature.[27] Under the Reference, the net increase in projected deaths from more extremely hot days and fewer extremely cold days in 49 cities is approximately 2,600 deaths in 2050, and 13,000 deaths in 2100, but accounting for adaptation could decrease these numbers. Figure 1 shows the net mortality rate from extreme hot and cold temperatures by city in the Reference scenario.

Figure 1. Projected Extreme Temperature Mortality in Select Cities Due to Unmitigated Climate Change

Estimated net mortality rate from extremely hot and cold days (number of deaths per 100,000 residents) under the Reference scenario for 49 cities in 2050 and 2100. Red circles indicate cities included in the analysis; cities without circles should not be interpreted as having no extreme temperature impact.

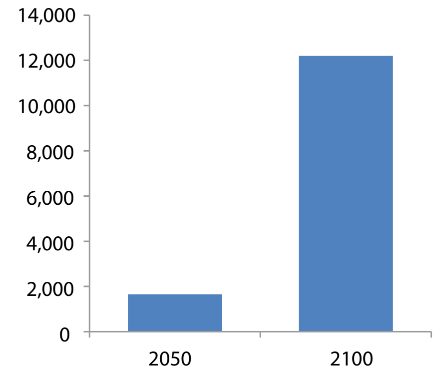


Reducing Impacts through GHG Mitigation

As shown in Figure 2, the projected mortality rates under the Mitigation scenario show small changes through 2100, unlike in the Reference where rates increase substantially. As a result, the net benefits associated with GHG mitigation increase over time. As shown in Figure 3, global GHG mitigation is estimated to result in significant public health benefits across the U.S. by substantially reducing the risk of extreme temperature-related deaths that would occur under the Reference. Under the Mitigation scenario, extreme temperature mortality is reduced by 64% in 2050 and by 93% in 2100[28] compared to the Reference. For the 49 cities analyzed, global GHG mitigation is projected to save approximately 1,700 U.S. lives in 2050, and approximately 12,000 U.S. lives in 2100 (Figure 3).

In 2050, the economic benefits of GHG mitigation are estimated at $21 billion, increasing to $200 billion in 2100 (see the Approach section for more information). It is important to note that these projections reflect only the results for the 49 cities included in this study; corresponding national benefits would be much larger.

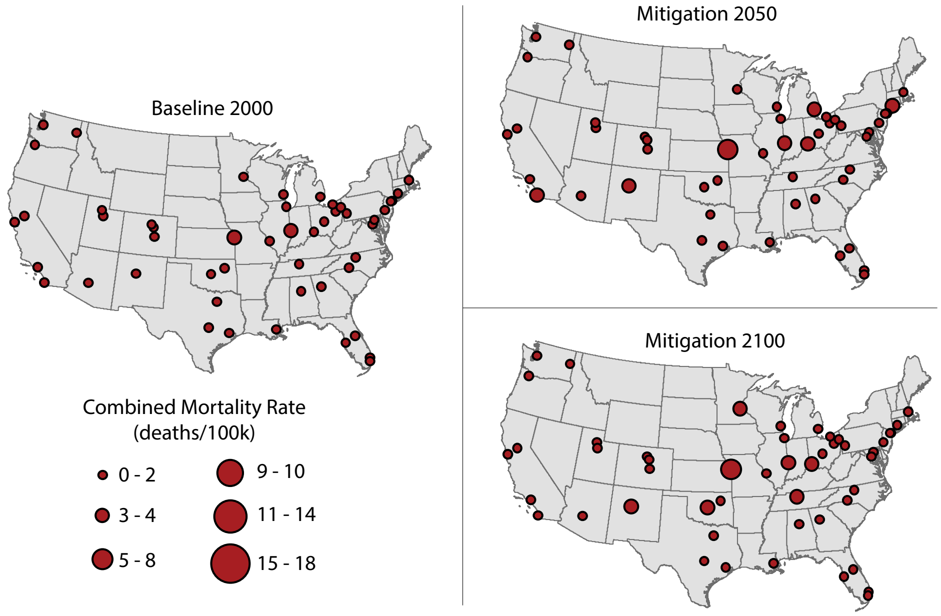
Figure 3. Avoided Extreme Temperature Mortality in 49 U.S. Cities Due to Global GHG Mitigation



The analysis also examines the implications of adjusting temperature thresholds to account for potential adaptation of the human body to warmer temperatures. Specifically, the analysis assumes that the human health response to extreme temperatures in all 49 cities was equal to that of Dallas. Using this approach, results show that mitigation would still save a projected 5,500 lives in 2100 compared to the Reference.

Figure 2. Projected Extreme Temperature Mortality in Select Cities with Global GHG Mitigation

Estimated net mortality rate from extremely hot and cold days (number of deaths per 100,000 residents) under the Mitigation scenario for 49 cities in 2050 and 2100. Red circles indicate cities included in the analysis; cities without circles should not be interpreted as having no extreme temperature impact.



APPROACH

The CIRA analysis estimates the number of deaths over the course of the 21st century attributable to extreme temperatures in 49 cities in the contiguous U.S., which account for approximately one third of the national population. City-specific relationships between daily deaths (of all causes) and extreme temperatures are combined with the IGSM-CAM projections of extremely hot and cold days using city-specific extreme temperature thresholds to estimate future deaths from heat and cold in the Reference and Mitigation scenarios. Extremely hot days are defined as those with a daily minimum temperature warmer than 99 percent of the days in the period 1989-2000. Extremely cold days are defined as those with a daily maximum temperature colder than 99 percent of the days in the period 1989-2000. As a result, the study explicitly addresses the question of the net mortality impact of climate change on future extreme temperature days. The potential impact of future population change is accounted for using an EPA demographic model (ICLUS).[29] To monetize the effects of changing mortality, a baseline value of statistical life (VSL) of $9.45 million for 2010 (2014$) is used, adjusted to future years by assuming an elasticity of VSL to GDP per capita of 0.4.[30] The results presented in this section have been updated since Mills et al. (2014) to include additional cities and more recent mortality rate data.[31] Finally, this analysis did not estimate impacts across ages or socioeconomic status. As these demographics change, they could impact the results presented here.

For more information on the CIRA approach and results for the extreme temperature mortality sector, please refer to Mills et al. (2014).[32]

Labor

KEY FINDINGS

1. Without global GHG mitigation, labor hours in the U.S. are projected to decrease due to increases in extreme temperatures. Over 1.8 billion labor hours are projected to be lost in 2100, costing an estimated $170 billion in lost wages.

2. Global GHG mitigation is estimated to save 1.2 billion labor hours and $110 billion in wages in 2100 in the contiguous U.S. that would otherwise be lost due to unmitigated climate change.

Climate Change and Labor

Climate change may affect labor in a number of ways, but projections of hotter summer temperatures raise a particular concern. Extreme summer heat is increasing in the U.S. and will be more frequent and intense in the future.[33] Heat exposure can affect workers' health, safety and productivity.[34] When exposed to high temperatures, workers are at risk for heat-related illnesses and therefore may take more frequent breaks, or have to stop work entirely, resulting in lower overall labor capacity. This is especially true for high-risk industries where workers are doing physical labor and have a direct exposure to outdoor temperatures (e.g., agriculture, construction, utilities, and manufacturing).[35]

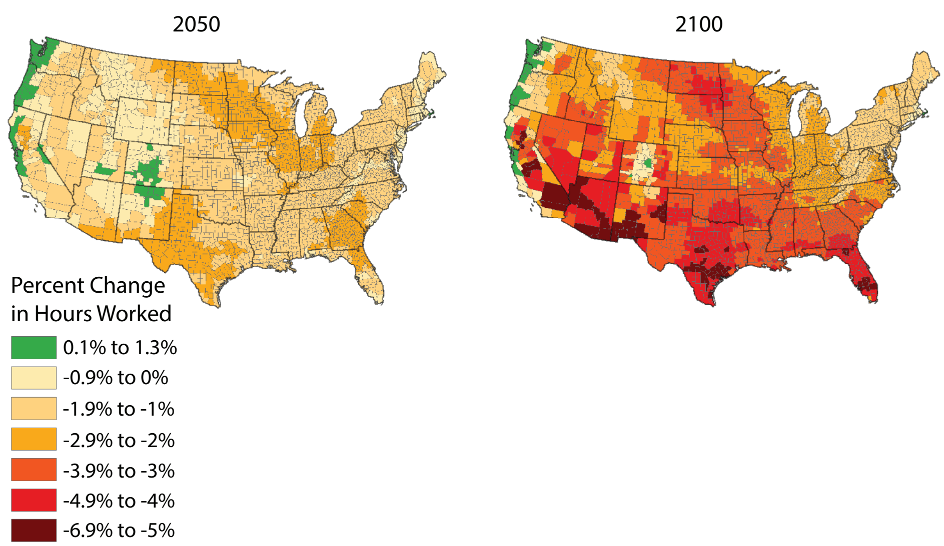
Risks of Inaction

Without global GHG mitigation, an increase in extreme heat is projected to have a large negative impact on U.S. labor hours, especially for outdoor labor industries. In 2100, over 1.8 billion labor hours across the workforce are projected to be lost due to unsuitable working conditions (95% confidence interval of 1.2-2.4 billion). These lost hours would be very costly, totaling over $170 billion in lost wages in 2100 (95% confidence interval of $110-$220 billion).

As shown in Figure 1, the majority of the country is projected to experience decreases in labor hours due to extreme temperature effects. In 2100, parts of the Southwest and Florida are estimated to experience a decrease in hours worked for high-risk industries ranging from -5% to -7%. Although the impacts vary by region, only a limited number of counties are projected to experience increases in labor hours.

Figure 1. Impacts of Unmitigated Climate Change on Labor in the U.S.

Estimated percent change in hours worked from 2005 to 2050 and 2100 under the Reference scenario. Estimates represent change in hours worked at the county level for high-risk industries only, and are normalized by the high-risk working population in each county.



Reducing Impacts through GHG Mitigation

At the national level, impacts to labor under the Mitigation scenario (Figure 2) are substantially smaller compared to the Reference (Figure 1). Counties in the Southwest, Texas, and Florida that are estimated to lose up to 7% of high-risk labor hours under the Reference in 2100 do not experience such losses under the Mitigation scenario.

When comparing the two scenarios (Figure 3), global GHG mitigation is projected to prevent the loss of approximately 360 million labor hours across the workforce in 2050, saving nearly $18 billion in wages. In 2100, the avoided loss of labor hours more than triples, and losses are substantially reduced over a majority of the contiguous U.S. Specifically, mitigation is estimated to prevent the loss of nearly 1.2 billion labor hours and $110 billion in wages in 2100 compared to the Reference.

Figure 2. Labor Impacts in the U.S. with Global GHG Mitigation

Estimated percent change in hours worked from 2005 to 2050 and 2100 under the Mitigation scenario. Estimates represent change in hours worked at the county level for high-risk industries only, and are normalized by the high-risk working population in each county.

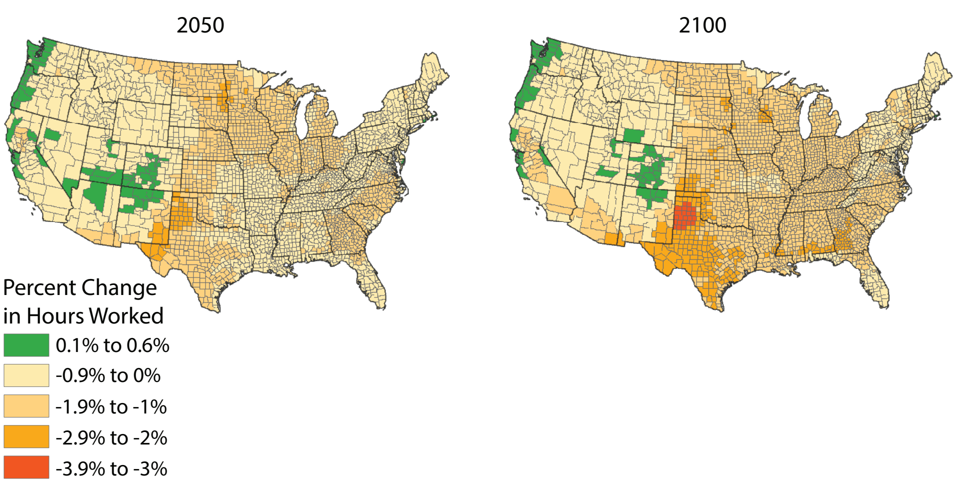
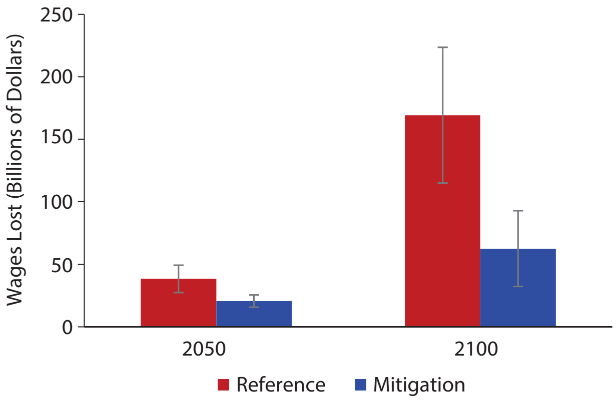


Figure 3. Economic Impacts to Labor with and without Global GHG Mitigation

Estimated wages lost under the Reference and Mitigation scenarios for all labor categories in the contiguous U.S. (billions 2014$). Error bars represent lower- and upper-95% confidence intervals of the dose-response function (see the Approach section for more information).

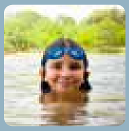


APPROACH

The CIRA analysis focuses on the impact of changes in extreme temperatures on labor supply[36] across the contiguous U.S. Specifically, the analysis estimates the number of labor hours lost due to changes in extreme temperatures using dose-response functions for the relationship between temperature and labor from Graff Zivin and Neidell (2014).[37] Mean maximum temperatures from the IGSM-CAM are projected for two future periods (2050 and 2100, 5-year averages centered on those years) at the county level in the CIRA Reference and Mitigation scenarios. The analysis estimates the total labor hours lost in all categories of the labor force and also for workers in high-risk industries (most likely to be strongly exposed to extreme temperature), taking into account the CIRA county-level population projections from the ICLUS model.[38] The fraction of workers in high-risk industries is calculated using Bureau of Labor Statistics data from 2003-2007 and is assumed to remain fixed over time for each county.[39] A range of estimates for the dose-response function are assessed and used to calculate confidence intervals to show the sensitivity of the results. The dose-response functions are estimates of short-run responses to changes in weather, and as such do not account for longer-term possibilities, such as acclimation of workers, relocation of industries, or technological advancements to reduce exposure.

The analysis estimates the cost of the projected losses in labor hours based on the Bureau of Labor Statistics' estimated average wage in 2005 ($23.02 per hour in a 35 hour work week),[40] adjusted to 2100 based on the projected change in GDP per capita.

For more information on the CIRA approach for the labor sector, please refer to Graff Zivin and Neidell (2014)[41] and Section G of the Technical Appendix for this report.



Water Quality

KEY FINDINGS

1. Unmitigated climate change is projected to have negative impacts on water quality in the U.S., particularly in the Southwest and parts of Texas.

2. Global GHG mitigation is projected to prevent many of the water quality damages estimated under the Reference scenario, primarily by reducing the warming of water bodies across the country.

3. Under the Mitigation scenario, costs associated with decreased water quality are reduced approximately 82% in 2100 compared to the Reference, corresponding to cost savings of approximately $2.6-$3.0 billion.

Climate Change and Water Quality

Climate change is likely to have far-reaching effects on water quality in the U.S. due to increases in river and lake temperatures and changes in the magnitude and seasonality of river flows, both of which will affect the concentration of water pollutants. These physical impacts on water quality will also have potentially substantial economic impacts, since water quality is valued for drinking water and recreational and commercial activities such as boating, swimming, and fishing.[42,43] The analysis presented in this section estimates changes in water quality, but does not quantify the resulting health effects.

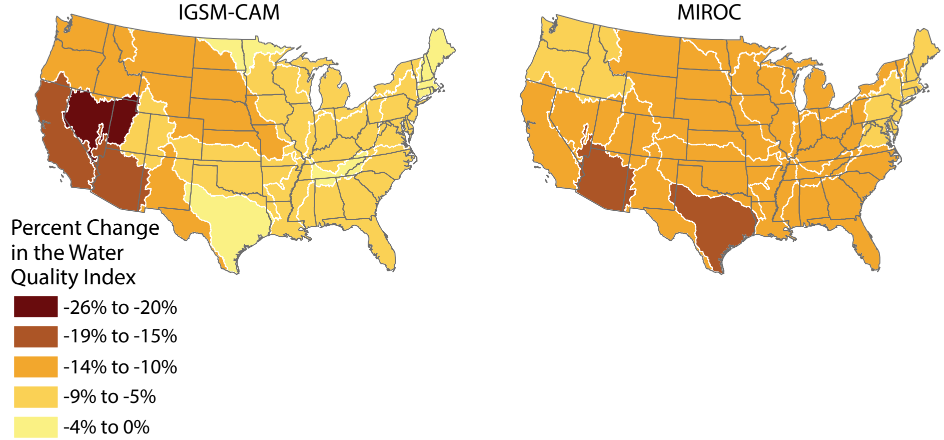
Risks of Inaction

Unmitigated climate change is projected to decrease water quality in the U.S. compared to a future with no climate change. The Water Quality Index (WQI) calculated in the CIRA analysis includes several key water quality constituents, including temperature, dissolved oxygen, total nitrogen, and total phosphorus.[44] The WQI serves as a measure of water quality; the higher the WQI, the higher the water quality.

As shown in Figure 1, the WQI across the U.S. is projected to decline in the Reference scenario in 2100 using both the IGSM-CAM and MIROC climate models. Parts of Texas and the Southwest, in particular, are estimated to experience substantial WQI declines of 15-26% in 2100. Projections that climate change will decrease river and lake water quality are consistent with the findings of the assessment literature.[45]

Figure 1. Effects of Unmitigated Climate Change on U.S. Water Quality in 2100

Percent change in the Water Quality Index in 2100 under the Reference scenario compared to the Control (to isolate the effects of climate change). The WQI is calculated for the 2,119 8-digit hydrologic unit codes (HUCs) of the contiguous U.S., and aggregated to the 18 Water Resource Regions (2-digit HUCs).



Reducing Impacts through GHG Mitigation

Global GHG mitigation is projected to reduce the increase in water temperature that is estimated to occur under the Reference, with corresponding water quality benefits (i.e., avoided degradation) primarily due to better oxygenation. The effects of mitigation on total nitrogen and total phosphorus concentrations vary by region, but the increase in total nitrogen is reduced by up to 80% in some areas of the western U.S. compared to the Reference scenario.

Figure 2 presents the projected change in water quality damages in 2050 and 2100 under the Reference and Mitigation scenarios for the IGSM-CAM and MIROC climate models. As shown in the figure, increases in damages are projected in both scenarios, but most notably in the Reference, where damages are estimated to increase by approximately \$3.2-\$3.7 billion in 2100. Under the Mitigation scenario, damages are reduced by approximately 82% compared to the Reference in 2100, corresponding to approximately \$2.6-\$3.0 billion in avoided costs.

Figure 3 presents the avoided water quality damages in 2100 under the Mitigation scenario compared to the Reference using the IGSM-CAM and MIROC climate models. As shown in the figure, global GHG mitigation is projected to result in economic benefits relative to the Reference across the entire contiguous U.S. California is projected to experience the greatest benefits of mitigation in 2100, ranging from approximately \$750 million to \$1.0 billion.

Figure 2. Change in U.S. Water Quality Damages with and without Global GHG Mitigation

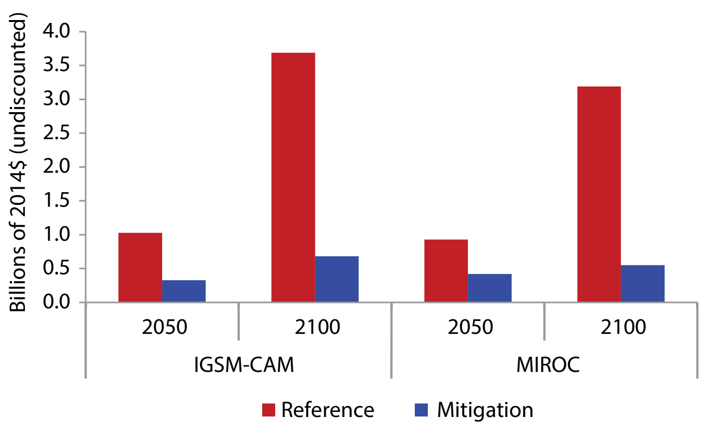
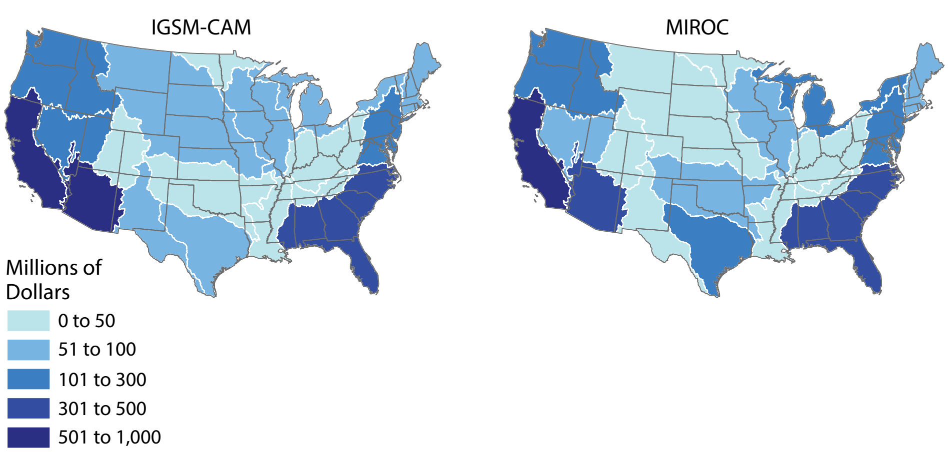


Figure 3. Benefits of Global GHG Mitigation for U.S. Water Quality in 2100

Avoided damages under the Mitigation scenario compared to the Reference in 2100 (millions 2014\$). Damages are calculated for the 2,119 8-digit HUCs of the contiguous U.S., and aggregated to the 18 Water Resource Regions (2-digit HUCs).



APPROACH

The CIRA analysis uses a series of linked models to evaluate the impacts of climate change on water quality in futures with and without global GHG mitigation. The analysis relies upon climate projections from two climate models: IGSM-CAM, which projects a relatively wetter future for most of the U.S., and the drier MIROC model. The CIRA temperature and precipitation projections inform a rainfall-runoff model (CLIRUN-II) that estimates river flow.[46] A water demand model projects water requirements of the municipal and industrial (M&I), agriculture, and other sectors. The runoff and demand projections inform a water supply and demand model that estimates reservoir storage and release, and in turn produces a time series of water allocations for the various demands. After this allocation step, the analysis relies on the QUALIDAD water quality model to simulate a number of water quality constituents in rivers and reservoirs.[47] Changes in overall water quality are estimated using changes in the Water Quality Index (WQI), a commonly used metric that combines multiple pollutant and water quality measures. Finally, a relationship between changes in the WQI and changes in the willingness to pay for improving water quality is used to estimate the economic implications of projected water quality changes.

Results for the CIRA scenarios are compared to a Control to isolate the effect of climate change. See the Water Resources section of this report for information on projected changes in the Inland Flooding, Drought, and Water Supply and Demand sectors. Decreases in water quality due to climate change will likely have an adverse effect on human health due to, for example, the increased risk of harmful aquatic blooms and impacts on sources of drinking water. Human health effects due to decreased water quality are not estimated, but are important considerations to fully understand climate change impacts in this sector. Inclusion of these effects would likely increase the benefits of GHG mitigation.

For more information on the CIRA approach and results for the water quality sector, please refer to Boehlert et al. (2015).[48]