Climate Convexity: The Inequality of a Warming World

AUTHOR

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ABSTRACT

In the past two centuries, global fossil fuel combustion has increased carbon dioxide concentration to unprecedented levels, which has increased Earth's temperatures and the frequency of extreme climate events. If left unaddressed, the climate crisis will not only become more costly to global health and to the global economy, but also will exacerbate inequality within the U.S. and around the world. This chapter describes recent changes in the climate and how scientists predict those changes will evolve in the years ahead. I then describe recent advances in econometric research that, when paired with high-resolution climate models, help us understand the impact of those changes in the climate on society. Finally, I conclude with recommendations for how U.S. policymakers can use this research to address the unequal threat of climate change, both domestically and internationally, and build a more just and sustainable future.

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Disclaimer: The views expressed in this chapter are the author's alone.

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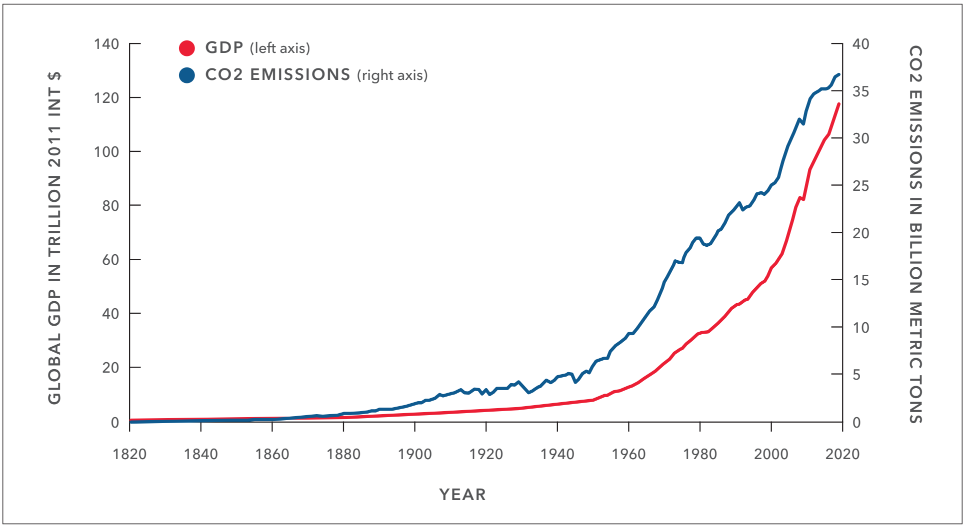
Introduction

Recent research advances at the intersection of climate science and economics make it clear that the cost of inaction on climate change in the United States is not only greater than the cost of action, but that inaction exacerbates income inequality within the United States and around the world. From more frequent heatwaves and wildfires to more destructive hurricanes, an increasingly unstable global climate is already taking a toll on human health and prosperity, and disproportionately impacting the poor. How exposed humans are to future changes will be determined by the actions policymakers take today. Using new research and data, policymakers can counteract the inequality of a warming world.

How did we get here? For the past 12,000 years, a period referred to by geologists as the Holocene, our climate has been the most stable and suitable for human development at any point in Earth's four billion year history. While the first Homo sapiens appeared more than 300,000 years ago in Africa, our early ancestors struggled to thrive through three glacial periods, where ice covered much of North America and Northern Europe. It wasn't until Earth emerged from this last glacial cycle into relatively prolonged stability that humans could move from hunting and gathering to farming. In turn, agricultural production gave rise to early human civilizations in the Fertile Crescent, Ancient India, Ancient China, and Mesoamerica. Continued climate stability has enabled human civilization to undergo dramatic expansion in size, geographic breadth, technological sophistication, and cultural richness, giving us the world we know today.

Measured in economic terms, most human development experienced over the past 12,000 years has occurred in just the last two centuries. Between 0 and 1000 AD, the global economy expanded by only 0.1 percent per decade on average, and per capita GDP declined. Between 1000 and 1820, GDP growth accelerated to 1.8 percent per decade. Over the past 200 years, however, the global economy has grown by almost 30 percent per decade on average. Fossil fuels powered that growth, from coal-fired steel mills and power plants to oil-fueled trains, planes, and automobiles. Carbon dioxide (CO2) emissions from fossil fuel combustion have grown even faster than economic output overall—39 percent per decade, on average, over the past 200 years (Figure 1). This emissions growth is now threatening the very stability in the Earth's climate that made the past 200 years of economic development possible.

Figure 1: Global Economic and Emissions Growth

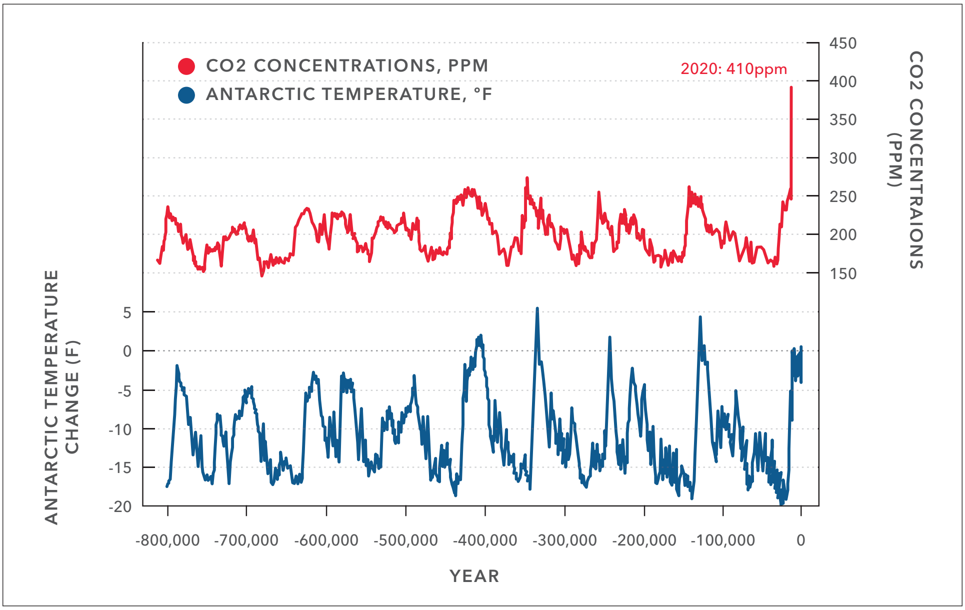


Source: Maddison (2008), Maddison Project Database, version 2018, World Bank, Global Carbon Project, Author's estimates

For the past million years, atmospheric concentrations of carbon dioxide have ranged from 170 to 300 parts per million (ppm), following the Earth's orbit-forced transitions through 100,000 year glacial cycles (Figure 2). For most of the past 12,000 years, atmospheric carbon dioxide concentrations have remained in a tight, comfortable range of 260 to 285 ppm. But fossil fuel combustion over the past two centuries has pushed concentrations above 410 ppm. The last time they were at this level was likely more than three million years ago (Seki et al. 2010).

This rapid growth in carbon dioxide concentrations has already significantly impacted the Earth's climate, both its average temperatures and the frequency and severity of extreme events. The scientific community has studied the relationship between fossil fuel combustion and global climate change for 125 years, and developed increasingly sophisticated climate models to forecast how these changes will unfold in the future under different emissions scenarios. But our understanding of the impact of these changes on society has lagged considerably. Economists only started studying climate change in earnest in the early 1990s. Until recently only a few models existed, each with little empirical basis or geographic detail. A recent explosion of econometric research, mapping climate's relationship to society, is changing that. When paired with high-resolution climate models, this research provides, for the first time, evidence-based estimates of the impact of climate change at a hyper-local level.

Figure 2: Temperature and Carbon Dioxide



Source: American Climate Prospectus (2014) updated with carbon dioxide data from Manua Loa

While this econometric research is still in its early stages, one core insight is abundantly clear: Climate change's impact, whether on economic output or human health, will be extremely varied from place to place. The poor, both within countries and across countries, suffer more than the rich. This insight comes as policymakers grapple with inequality in economic and health outcomes from a pandemic-driven global recession. Recent findings from climate econometrics suggest that if humanity does not address climate change in the next few decades, it will likely drive more devastation and deeper inequality than the current global crisis.

And unlike the current crisis, the inequality of climate change extends to the cause as well as the effect. The carbon dioxide emissions heating the Earth today were emitted over the past two centuries, tied to economic activity that was not evenly distributed around the world. More than half of all global economic output over the past 170 years, and two thirds of all carbon dioxide emissions, have come from countries currently in the top 20 percent of the global income distribution on a per capita GDP basis. These countries are far less vulnerable to the impacts of climate change than the other 80 percent. This is due in large part to their current climate and the convex relationship between temperature and most economic and social outcomes. The climate in rich countries is, on average, colder than in poor countries, and a growing body of climate econometric research shows that a given increase in temperature is much worse for places that are already hot. Compounding this effect is the protective nature of past income growth in richer countries to climate change, made possible by fossil fuel combustion. This inequality exists within national borders as well. Wealthier citizens emit more carbon dioxide and are more protected from the changes in the climate those emissions create, due both to geography and being affluent enough to adapt.

This chapter starts with a description of recent changes in the climate and how scientists predict those changes will evolve in the years ahead. It then describes recent advances in econometric research that, when paired with high-resolution climate models, help us understand the impact of those changes in the climate on society. The chapter concludes with recommendations for how U.S. policymakers can use this research to address the unequal threat of climate change, both domestically and internationally, and build a more just and sustainable future.

1. The State of the Science

Scientific research on the impact of carbon dioxide emissions on the climate dates back almost as far as the combustion of fossil fuels to power industrialization. In an 1856 paper presented to the American Association for the Advancement of Science, New York scientist Eunice Foote argued increasing the amount of carbon dioxide in the atmosphere would increase global temperatures (Foote 1856; Jackson 2019). That year, fossil fuels still played a relatively niche role in the U.S. energy system. Coal accounted for only 14 percent of total consumption, with the rest coming from wood and other forms of biomass (EIA 2020). Commercial oil production would not begin for another three years following the Oil Creek discovery in Titusville, PA.

As fossil fuel production expanded in the late 19th century and early 20th century, climate science continued to improve. In 1894, Swedish scientist Arvid Högbom quantified the amount of carbon dioxide emitted into the atmosphere from the 500 million tons of global coal consumption occurring at the time (Högbom 1894). Two years later, his colleague Svante Arrhenius estimated that a doubling of carbon dioxide concentrations would lead to a 5-6°C increase in global temperatures (Arrhenius 1896). This was the first estimate of what is now known as the "equilibrium climate sensitivity" (ECS). Arrhenius believed, however, that this doubling would take thousands of years to occur, given the rate of carbon dioxide emissions at the time, and could possibly serve as a defense against the Earth entering another glacial cycle.

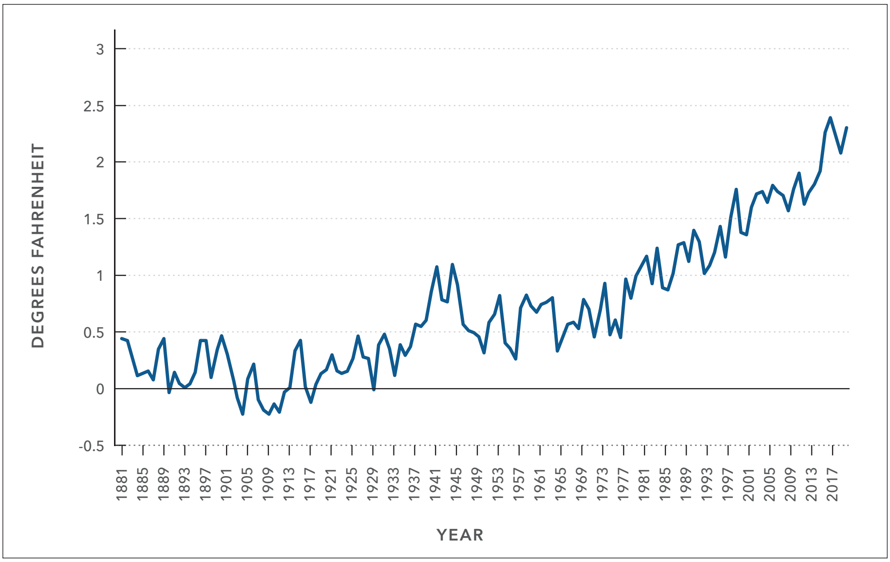
The next major advance in climate change science came in 1938. English steam engineer Guy Stewart Callendar analyzed temperature data and compiled estimates of atmospheric carbon dioxide concentrations from around the world. He estimated atmospheric concentrations of carbon dioxide increased by 6 percent between 1880 and 1935, and that global temperatures had increased by 0.25°C (Callendar 1938). Using a simple model of the climate, Callendar estimated half of the observed increase in temperature was due to 150 billion tons of carbon dioxide from historical fossil fuel combustion. This was the first published empirical evidence of anthropogenic climate change. He wrote:

> *Few of those familiar with the natural heat exchanges of the atmosphere, which go into the making of our climates and weather, would be prepared to admit that the activities of man could have any influence upon phenomena of so vast a scale. In the following paper I hope to show that such influence is not only possible, but is actually occurring at the present time.*

Callendar, like Arrhenius, significantly underestimated future carbon dioxide emissions growth in projecting potential warming. He assumed that fossil fuel production levels in the 1930s would remain constant as efficiency improvements offset rising demand. Instead, global consumption of fossil fuels exploded. In 1938, the word emitted 4.2 million tons of carbon dioxide per year from coal, oil, and natural gas combustion (Global Carbon Project 2019). That number doubled by 1958, and more than doubled again by 1978. In 2019, the world emitted 36.8 billion tons, a nine-fold increase from the year in which Callendar's article was published. As a result of that growth in emissions, global average temperatures have increased by 1.28°C, or 2.31°F, relative to pre-industrial levels (Figure 3).

Figure 3: Change in Global Average Temperatures

Degrees Fahrenheit relative to pre-industrial (1850-1900) levels



Source: NOAA

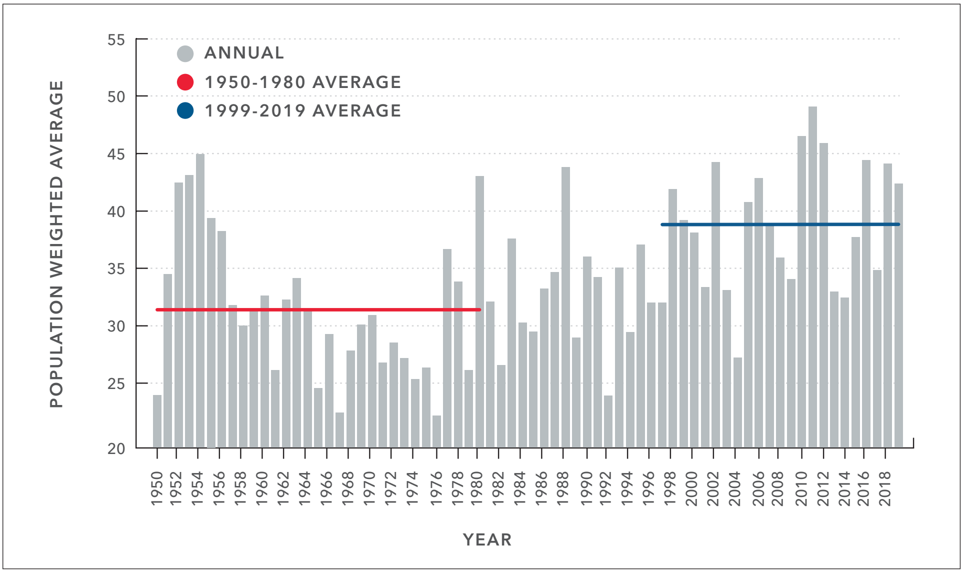
1.a. How Climate Change Is Felt

Statistics on changes in global average temperatures do a poor job of communicating the significance of the shift in the climate that's occurred over the past few decades. A relatively modest increase in *average* temperatures is accompanied by a much larger increase in temperature *extremes*. In the United States, for example, average annual temperatures were 3 percent higher between 1999 and 2019 than between 1950 and 1980. But the number of days above 90°F the average American experienced rose by 23 percent between those two time periods (Figure 4).

Heat alone is not nearly as threatening as the combination of increased heat and humidity (referred to as "wet-bulb temperature"). Humid heat limits the human body's ability to cool itself through perspiration. Body temperatures can rise rapidly when heat stress occurs, damaging the brain and other vital organs. Heat stroke, the most severe heat-related illness, can kill or permanently disable its victims without emergency treatment. At wet-bulb temperatures above 79°F (26°C), strenuous physical activity can be dangerous. If wet-bulb temperatures rise above 91°F (33°C), even during rest fit health individuals will have difficulty controlling their core temperature. During the Chicago heat wave of 1995, which resulted in more than 600 excess deaths and 3300 excess emergency room visits (Dematte et al. 1998), wet-bulb temperatures reached 85°F. The highest wet-bulb temperature every recorded on earth was 95°F (35°C), temperatures even very healthy people cannot survive for more than a few hours. Researchers estimate that recent changes in the climate have already expanded the number of people who experience at least one day a year with wet-bulb temperatures above 91°F from 97 million to 275 million, and those exposed to wet-bulb temperatures above 95°F at least once a decade from 0 to 9 million (Li et al. 2020).

Warmer temperatures expand the water-holding capacity of the atmosphere. As the climate grows more unstable some parts of the United States and the world are getting dryer, other regions are getting wetter, and a greater share of annual rainfall is occurring during extreme precipitation events. The frequency of extreme precipitation events in the United States, as tracked by the National Centers for Environmental Information (NCEI), was 60 percent higher over the past 20 years than between 1950 and 1980 (Figure 5). This increases the frequency and severity of surface flooding (pluvial), by overwhelming urban drainage systems, and flooding along streams or rivers (fluvial).

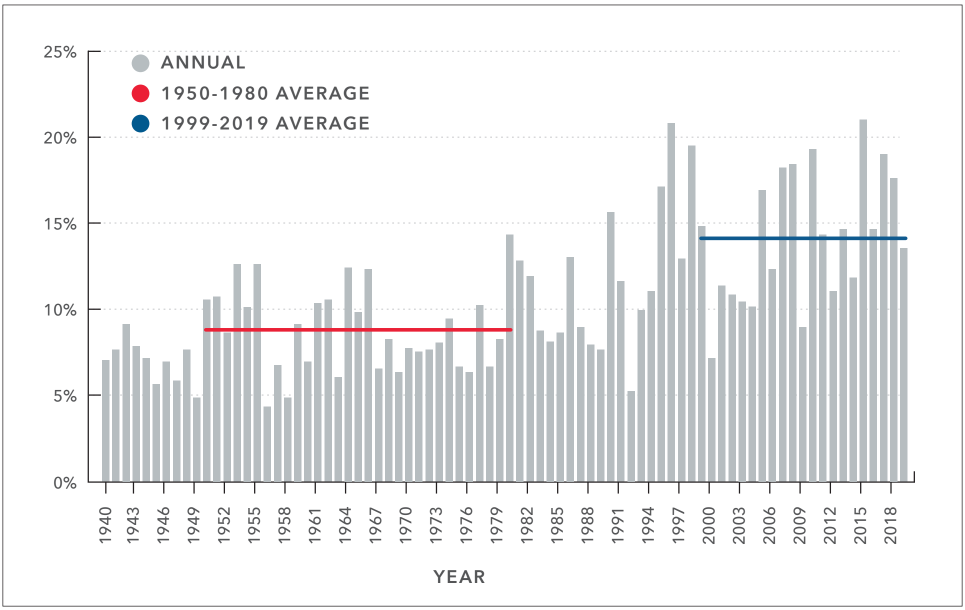
Figure 4: Number of Days above 90F Experienced by the Average American



Source: Rhodium Group

Figure 5: Extreme 1-Day Precipitation Events

Percent of contiguous United States with significant portion of total annual rainfall coming from extreme single-day precipitation events



Source: NOAA U.S. Climate Extremes Index, Step 4

A warmer atmosphere means warmer oceans. That leads to sea level rise both through thermal expansion of the oceans and melting ice sheets around the world. Global average sea levels have risen by 8 to 9 inches since pre-industrial levels, and by more than 3 inches since 1993 alone.[1] In parts of the United States, sea levels are rising at rates three to four times as fast as the global average.[2] As sea levels increase, so do the number of tidal flooding events. Nationally, the number of "High-Tide Flooding events," as defined by NOAA, were 350 percent greater between 2015 and 2019 than between 1995 and 1999.[3]

Higher sea levels also result in more flooding during hurricanes. Climate change has also increased the frequency and severity of the most extreme storms. Over the past 40 years, the probability that any given hurricane will become a Category 3-5 storm has grown by 8 percent per decade globally, and even higher in the North Atlantic (Kossin et al 2020). The amount of rainfall associated with any given hurricane has increased as well. For example, scientists estimate that warming over the past four decades increased the probability of the amount of rainfall experienced during Hurricane Harvey in 2017 six-fold (Emanuel 2017).

1.b. What's in Store in the Future

How will the changes in the climate we've witnessed over the past few decades evolve in the future? Since we only have one Earth and cannot run controlled experiments, scientists rely on increasingly sophisticated, computerized climate models. First developed in the 1960s through the 1980s, climate models use mathematical formulas to simulate atmospheric and oceanic dynamics. More recent models incorporate biogeochemical cycles as well.

Projections made by some of the earliest climate models have done a remarkably good job of predicting the increase in global average temperatures witnessed over the past few decades (Hausfather et al 2019). Even projections using Callendar's model, one of the very earliest, come within 15 percent of actual temperature increases experienced between 1938 and 2000, when adjusted for the growth in emissions that actually occurred (Anderson, Hawkins, and Jones 2016). Early climate models, however, had very little temporal or geographic granularity. But over the past couple

1 Lindsey, Rebecca. 2020. "Climate Change: Global Sea Level." Retrieved from https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level.

2 NOAA. n.d. "Sea Level Trends - NOAA Tides & Currents." Retrieved from https://tidesandcurrents.noaa.gov/sltrends/.

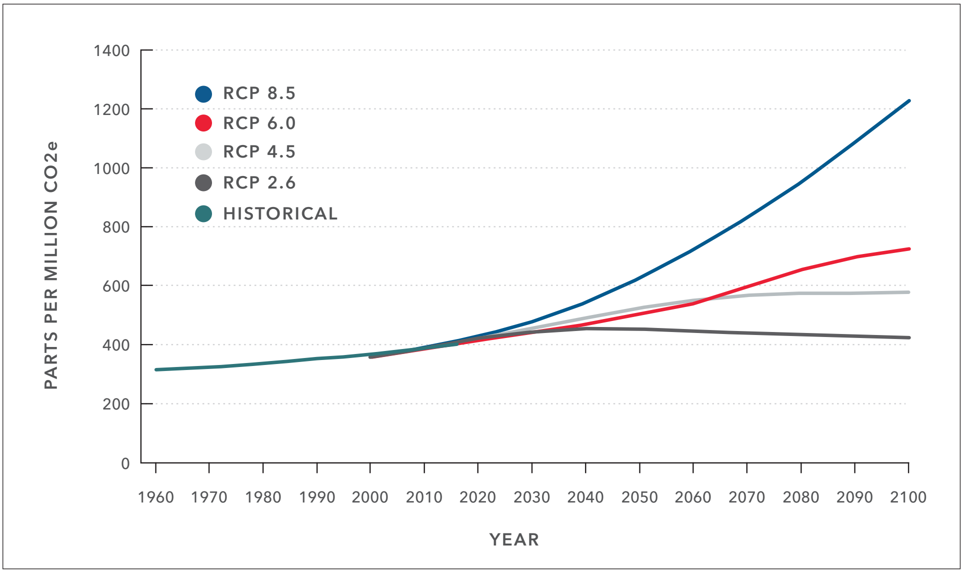
3 NOAA. 2020. "2019 State of U.S. High Tide Flooding with a 2020 Outlook." Technical Report. NOAA. Retrieved from https://tidesandcurrents.noaa.gov/publications/Techrpt_092_2019_State_of_US_High_Tide_Flooding_with_a_2020_Outlook_30June2020.pdf.

of decades, more than 20 high-quality research teams around the world, from NOAA's Geophysical Fluid Dynamics Laboratory in the United States to the Met Office in the United Kingdom to the Meteorological Research Institute in Japan, have invested millions of person hours and trillions of CPU hours each year, improving the ability of climate models to project changes in temperature, precipitation, storm patterns, sea levels, and other climate variables at increasingly high levels of resolution.

Every six to eight years, these research groups model a harmonized set of emissions scenarios. This work is coordinated through the Coupled Model Intercomparison Project (CMIP) and feeds into the Intergovernmental Panel on Climate Change (IPCC's) big assessment reports. The last round of this modeling (known as CMIP5) focused on four emissions scenarios, or "representative concentration pathways," defined in terms of total radiative forcing—a cumulative measure of human emissions of greenhouse gases (GHGs) from all sources expressed in Watts per square meter. In the high-emissions scenario (RCP 8.5), atmospheric concentrations of carbon dioxide and other GHGs exceed 1,200 ppm by the end of the century. In the more moderate RCP 6.0 and RCP 4.5 scenarios, concentrations reach 728 and 581 ppm respectively by 2100. In the low-emissions RCP 2.6 scenario, concentrations peak at just over 450 ppm in 2040, and then decline to 427 ppm by 2100.

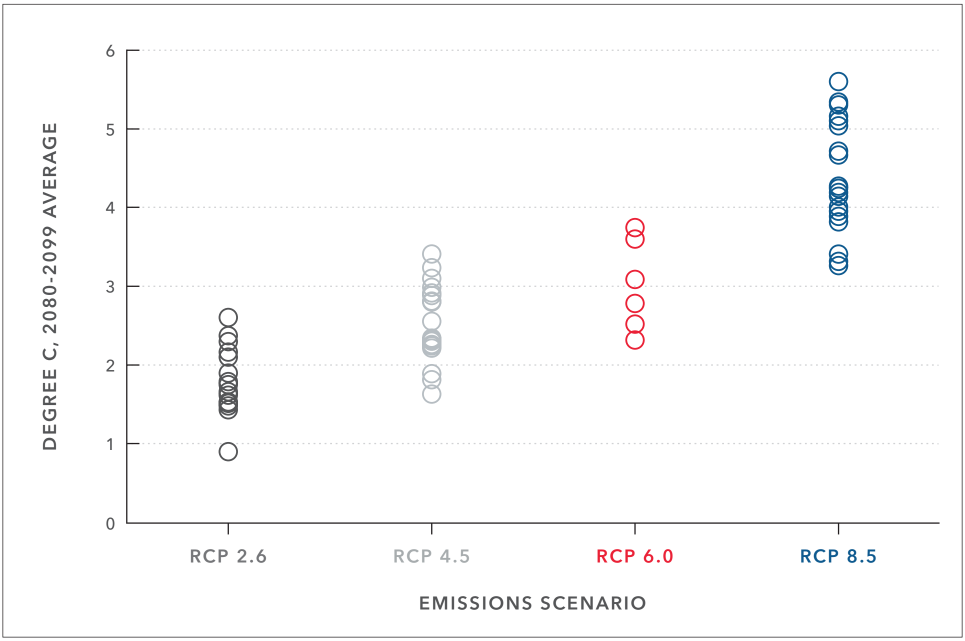
There remains considerable uncertainty around the ECS—how much global average temperatures will increase if carbon dioxide concentrations double. Arrhenius estimated a 5-6°C increase. Callendar's model implies 1.6°C. In 1979, a group of leading scientists estimated a likely range of 1.5° to 4.5°C in the landmark study known as the Charney Report (Charney et al. 1979). That spread has remained roughly the same across climate models over the past 40 years, and can be seen in the range of end-of-century temperature projections from CMIP5 model output in Figure 7 (though new research may have narrowed the range) (Sherwood et al. 2020). In a high-emissions scenario, this collection of models predict global average temperature increases of anywhere between 3.3° and 5.6°C relative to pre-industrial levels (or a 2° to 4.3°C increase relative to where we are today). Under a more moderate-emissions scenario (RCP 4.5), that range falls to 1.6° to 3.4°C.

Figure 6: Atmospheric Concentrations of all Greenhouse Gas Emissions



Source: Integrated Assessment Modeling Consortium

Figure 7: Increase in Global Mean Surface Temperature Relative to Pre-industrial Levels



Source: Rhodium Group analysis of CMIP5 GCM output

How will these changes in average temperatures manifest in the day-to-day weather we experience? Given changes in the climate that have already occurred, the average American is expected to experience between 42 and 51 days above 90°F each year. Under a high-emissions scenario, this likely grows to 56 to 80 days by 2050 and 77 to 126 days by the end of the century (assuming geographic allocation of the population remains at current levels). Under a moderate-emissions scenario, the number of extremely hot days experienced by the average American likely grows to between 52 and 67 days per year by 2050, and to 56 to 82 days by the end of the century.

Dangerously high levels of humidity are also projected to increase as well. Under a high-emissions scenario, researchers estimate that an additional 2.3 billion people around the world will experience at least one day a year where wet-bulb temperatures exceed 91°F by the end of the century (Li, Yuan, and Kopp 2020), even without any population growth. The number of people projected to experience at least one day with wet-bulb temperatures exceeding 95°F is projected to grow by 1.5 billion. Even under a moderate-emissions scenario the number or people exposed to 91°F wet-bulb temperatures annually is expected to grow by 950 million, and the number of those exposed to 95°F wet-bulb temperatures at least once a decade is projected to grow by 700 million.

Global sea levels will likely rise 9 to 13 inches by midcentury under a high-emissions scenario, and 24 to 40 inches by the end of the century relative to year 2000 levels (Kopp 2014). The center point of this range would put the current homes of 120 million people globally below high tide (Kulp and Strauss 2019). If ice sheets melt more quickly, this could grow to 43 to 83 inches (Kopp 2017). The center point of this range would put the current homes of 230 million people globally below high tide. Under a moderate-emissions scenario, sea levels will likely rise by 8 to 12 inches by mid-century, and 17 to 31 inches by the end of the century (putting 90 million current homes below high tide). With faster ice sheet melt, this could grow to 26 to 49 inches (putting 140 million current homes below high tide).

Higher sea levels will make tropical cyclones more damaging, and the frequency of the most severe storms is also projected to continue increasing. Under a moderate-emissions scenario, the frequency of major tropical cyclones is expected to increase by 11 percent globally between 2016 and 2035, relative to 1986–2005 averages, growing to 20 percent by the end of the century (Bhatia et al. 2018). Under a high-emissions scenario the frequency of major tropical cyclones is projected to grow by 40 percent (Emanuel 2013).

1.c. All Climate Is Local

The national or global average projections outlined above mask stark variation across local geographies. For example, Houston, Texas will experience 21 to 29 more extremely hot days annually over the next 30 years, while Portland, Maine will only experience 1 to 6 more. Meanwhile, Portland will likely experience 13 to 22 fewer days below freezing over that period of time, while Houston will only experience 3 to 4 fewer. Globally the vast majority of those exposed to dangerously hot and humid days will be in India and the Middle East, along with parts of China, Australia, North and West Africa, the Midwest and Gulf Coast of the United States, and parts of Latin America.

While the overall amount of precipitation globally increases as the climate warms, some parts of the United States and of the world are projected to get drier, increasing the risk of drought, wildfires, and water scarcity, while others get wetter, increasing the risk of flooding. Sea level rise projections vary dramatically around the world as well. Under a high-emissions scenario (but with more moderate ice sheet melt), local mean sea level will likely rise by 28 to 54 inches in the Chesapeake Bay by the end of the century. Meanwhile, in Juneau, Alaska local mean sea levels will likely *decline* by 27 to 45 inches.

Projected changes in the frequency and severity of tropical cyclones vary around the world as well. Under a moderate-emissions scenario, the frequency of major tropical cyclones is projected to increase by 14 percent in the Atlantic Ocean between 2016 and 2035 relative to 1986–2005 averages (Bhatia et al 2018), by 12 percent in the South Indian Ocean and by 41 percent in the South Pacific. By the end of the century, this grows to 29 percent, 28 percent, and 66 percent respectively.

This local variation in how changes in the global climate manifest is a major factor in shaping the economic impact of climate change around the world.

2. Understanding the Economic Impact of Climate Change

It is only in the past few decades that economists have developed tools to measure and document the economic ramifications of the climate changes that are happening as a result of human activity. It is important to understand the basics of these research advances, in order to understand both the nature of the risks we face without policy action as well as how to design the policy response to climate change in an effective and equitable manner.

Compared to the 160-year history of climate science scholarship, research on the economic impact of climate change is still in its infancy. The first significant contributions were made in the early 1990s by Yale professor William Nordhaus (1991) and Peterson Institute for International Economics fellow William Cline (1992)—more than a half century after Callendar proved fossil fuel combustion was warming the climate. As Nordhaus said in his 1991 article for *The Economic Journal*, "we now move from the terra infirma of climate change to the terra incognita of the social and economic impacts of climate change." Nordhaus divided U.S. economic sectors into three groupings based on their expected sensitivity to warmer temperatures, and offered a rough estimation of how much aggregate economic activity might decline if global temperatures increased by 3°C—0.25 percent. Acknowledging this was likely an underestimate, he rounded up to 1 percent, noting, "it is not possible to give precise error bounds around this figure, but my hunch is that the overall impact upon human activity is unlikely to be larger than 2% of total output." Cline's estimates for the United States were broadly similar—1.1 percent of GDP loss for a 2.5°C increase in global temperatures.

With this early work, Nordhaus and Cline launched the field of climate economics (for which Nordhaus was awarded the Nobel Prize in 2018). The field's initial focus was on developing simplified "integrated assessment modes" (IAMs) that could be used to compare the cost of reducing GHG emissions to the cost of continued warming of the climate. The first IAMs were developed by Nordhaus (1992), University of Cambridge professor Chris Hope (1993), and University of Sussex professor Richard Tol (1995). These three models continue to be among the most often used, though others have been developed.

Simplified IAMs have provided the economics community and policymakers with a useful framework for understanding the relationship between economic activity and the global climate, but relatively little progress has been made since the 1990s in improving their estimate of the economic impact of warming, known as the "damage function." As the National Academies of Sciences, Engineering, and Medicine noted in 2017, "much of the research on which they are based is dated" with the majority coming from the 1990s and early 2000s. The IAMs also have very little geographic resolution, which limits their utility in understanding the distribution of climate damages around the world or their ability to inform investments in resilience that would reduce future climate damages. The DICE model developed by Nordhaus has one global region, the PAGE model developed by Hope has eight regions, and the FUND model developed by Tol has 16 regions. Finally, both the IAMs and the studies on which they are based look at the impact of changes in average annual temperature only, which misses the effects of climate-driven changes in the frequency and severity of extreme events.

2.a. The Empirical Revolution Comes to Climate Economics

In the late 2000s, a new approach to researching the economic impacts of climate change emerged—"climate econometrics" (Hsiang 2016). Exploiting natural variability in the climate, econometricians began developing statistical models of the relationship between temperature, precipitation, storm activity, and other weather variables and social and economic outcomes of interest. Early empirically based damage functions were developed for agricultural production (Deschênes and Greenstone 2007; Schlenker and Roberts 2009), human mortality (Deschênes and Greenstone 2011; Barreca et al. 2015), labor productivity (Hsiang 2010; Graff Zivin and Neidell 2014), crime rates (Jacob, Lefgren, and Moretti 2007; Ranson 2014), electricity demand (Auffhammer and Aroonruengsawat 2011), and other climate impact categories.

One of the powerful features of this "bottom-up" econometric research, the volume, scope and sophistication of which has exploded over the past 15 years, is that it can be combined with increasingly high-resolution global climate models to provide evidence-based projections of the impact of climate change at a hyper-local level. This requires interdisciplinary collaboration between climate scientists and economists, and significant computational resources. The first comprehensive attempt at this was made by a group of researchers at the University of California at Berkeley, Rutgers University, and Rhodium Group in 2013. The team combined output from 33 global climate models with sector-specific empirical damage functions and detailed process models.

Published in book form in 2015 (Houser et al.) and as a research article in Science in 2017 (Hsiang et al.), this work (dubbed the "American Climate Prospectus") provided the first detailed estimate of the economic impact of climate change across the United States. At the national level, combined damage from the six impact categories quantified (energy, mortality, commodity agriculture, coastal property, and crime) is estimated to be roughly 1.2 percent of GDP per 1°C of warming. That's considerably higher than projections from FUND or PAGE of the total cost of climate change for the United States (DICE only includes global damages), even though it is a decidedly conservative estimate (it only covers six impact categories, and only the direct effect of single-year climate shocks).

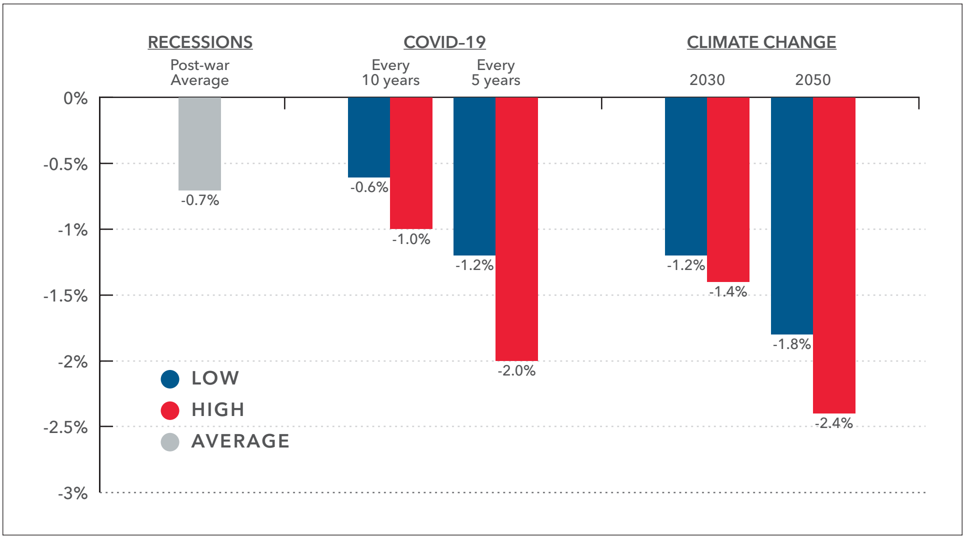
Complementing bottom-up climate econometrics is "top-down" research that develops empirically based models of how overall macroeconomic performance responds to changes in temperature or tropical cyclone activity. Top-down research provides a more holistic measure of market damages, but without knowledge of the underlying mechanisms generating those losses (and without capturing non-market damages like impacts to human health or ecosystem services). For example, Deryugina and Hsiang (2017) find a strong statistical relationship between per capita income and daily temperatures. Hsiang and Jina (2014) find that tropical cyclones have a large and persistent impact of GDP.

2.b. Climate Change Compared to Other Economic Risks

Combining these top-down damage functions with the same high-resolution probabilistic climate model projections used in the American Climate Prospectus, my colleagues and I estimate the impact of both recent and projected changes in the climate on U.S. GDP. We find that around 2030, climate-driven changes in temperature and hurricane activity cost the U.S. economy 1.2 percent of GDP in a moderate-emissions scenario (RCP 4.5, median estimate), rowing to 1.8 percent of GDP by mid-century. In a high emissions scenario (RCP 8.5, median estimate) we estimate climate change costs the U.S. 1.4 percent of GDP by 2030, growing to 2.4 percent of GDP by mid-century.

These are not one-time events, but the annual average of shocks that will be higher in some years and lower in others. They also exclude the compounding effects of shocks in previous years. If measured on a cumulative basis, the impacts would be even higher. To put these numbers in context, we calculate the impact of post-war U.S. recession in the same way. We measure the impact of each recession as the reduction in output during the period in which the recession occurred (as defined by the National Bureau of Economic Research) relative to what it would have been at the pre-recession growth rate. We then average the economic impact during quarters with recessions over the full 1947–2019 period, but exclude any effects on economic growth that persist after the recession ends. The result is an average annual cost of U.S. recessions of 0.7 percent of GDP (Figure 8). To draw another comparison, economists currently project that COVID-19 will cost the U.S. economy between 6 percent and 10 percent of GDP in 2020. That means by 2030, the economic cost of climate change to the United States could be on par with a COVID-19-style disruption once every 10 years, and every five years by mid-century.

Figure 8: Economic Impact of Climate Change versus COVID-19 and Post-War Recessions
Average annual impact on US GDP



Source: NBER, CBO, Bloomberg and Rhodium Group estimates

Note: For climate change, "Low" is RCP 4.5 median estimates and "High" is RCP 8.5 median estimates.

2.c. Estimating the Global Impacts of Climate Change

While it began focused on the United States, climate econometrics research has expanded globally. Top-down studies were the first to achieve global coverage, because of the relative ease of obtaining historical macroeconomic outcome data for a wide range of countries. For example, Hsiang and Jina's 2014 hurricane research was global in scope, analyzing the impact of 6,700 historical storms on aggregate economic output over time. Burke, Hsiang, and Miguel (2015) develop an empirical model of the relationship between temperature and GDP growth, and found that under a high-emissions scenario, global GDP declines by 23 percent (median estimate) by the end of the century relative to a "no climate change" counterfactual. That's considerably higher than what's projected by traditional IAMs. Employing a slightly different top-down econometric model, Kalkhul and Wenz (2020) estimate global economic damage of 14 percent by the end of the century in the same emissions scenario.

Bottom-up, global climate econometrics is more challenging due to the need to collect and harmonize granular social and sector-specific outcome data from a wide range of countries. The Climate Impact Lab (the team behind the American Climate Prospectus, expanded to include the University of Chicago) has been leading the charge on this effort. The Lab's model has just under 25,000 geographic regions around the world, each sized to have the rough population equivalent of a U.S. county. Research underway quantifies the impact of climate change on energy costs, agricultural production, labor productivity, manufacturing output, infectious disease, wind, flood, and wildfire damage to property and infrastructure, and other impact categories.

Initial output from the Lab's global research was published this summer, providing the first ever empirically based estimate of the impact of temperature on mortality rates at a hyper-local level around the globe (Carleton et al. 2020). To do this research, the team had to start by compiling the largest sub-national vital statistics database in the world, detailing 399 million deaths across 41 countries accounting for 55 percent of the global population. Lab researchers exploited the heterogeneity in income and climate within and across these countries to estimate mortality damage functions for those parts of the world where subnational mortality statistics are not available. The mortality model also captures the potential for reducing temperature-driven deaths through adaptation, as well as the cost of those adaptive measures. Under a high-emissions scenario, the cost of climate-driven changes in death rates, along with the cost of adaptive measures in prevent further deaths, totals 3.2 percent of GDP by the end of the century (median estimate). That's equivalent to the estimated global cost of all climate impact categories under the same emissions scenario in the current DICE model (Nordhaus 2018).

3. The Inequality of Convexity

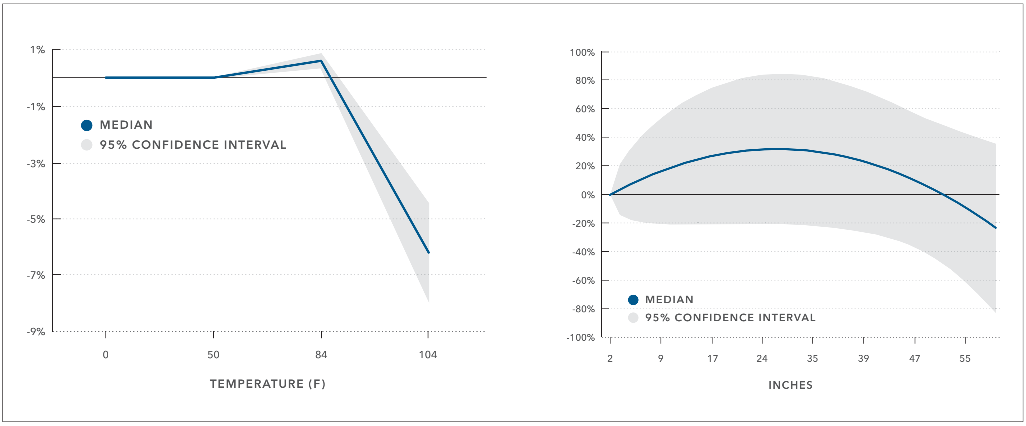
The most significant insight from coupling high-resolution climate models with econometric damage functions isn't the magnitude of the economic and damage at a global level, but just how unequally that damage is distributed, both within the United States and around the world. This is due to two factors. First, in both the bottom-up and top-down literature, most of the damage functions are convex, meaning that the directional impact of warming on various social or economic outcomes depends on the starting climatology of a given place. Second, the ability to adapt to these changes, at an individual, community, or country level, is dependent on income. The richer you are, the more protected you will be from a changing climate.

3.a. Impacts Are Unequal within the United States

Take, for example, the response of U.S. corn yields to changes in temperature and precipitation shown in Figure 9 from the American Climate Prospectus. There is an optimal temperature and level of precipitation for growing corn. If the place you live is below that optimal today, and climate change makes it warmer and wetter, than yields will likely increase. If you are at or above the optimal level today, then the same percent increase in temperature and precipitation will likely lead to a decrease. Humans have an optimal temperature as well. Warming leads to a net decline in mortality rates in colder parts of the country, because the decrease in cold-related deaths outweighs the increase in heat-related deaths, and a net increase in warmer parts of the country. The same dynamic plays out in energy costs. Warming reduces heating costs and increases cooling costs. Homeowners and renters in colder parts of the country will likely see a net reduction their total energy bill due to climate change, while those in warmer parts of the country will likely see a net increase. There are other reasons why climate damages are geographically dependent as well. Sea level rise and changes in hurricane activity impact coastal communities much more than inland communities. Location-specific wildfire risk is a function both of climatology and the type and supply of forest fuels.

Figure 9: U.S. Corn Production Damage Functions

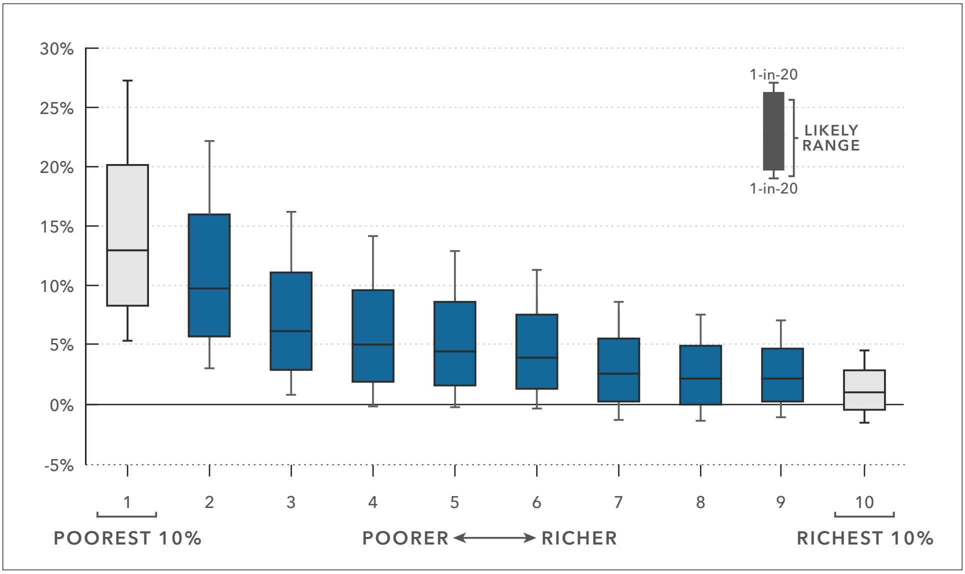
Change in yields as a function of daily temperature (left) and as a function of seasonal precipitation (right)



Source: Hsiang et al. (2017), Schlenker and Roberts (2009), and McGrath and Lobell (2013)

The combined bottom-up economic cost of all six impact categories in the American Climate Prospectus varies by an order of magnitude across states, based on their current climate and their proximity to the coast. For example, under a high-emissions scenario, the combined cost is likely 10 to 24 percent of Gross State Product in Florida by the end of the century, while Vermont sees a 1 to4 percent gain. Because hotter counties tend to be poorer in the United States, climate change exacerbates income inequality as well. The poorest 10 percent of counties in the United States face likely damages of 9 to 20 percent of income, while the richest 10 percent see between a 3 percent loss and 0.4 percent gain (Figure 10).

Figure 10: Poorest U.S. Counties Are Most at Risk from Climate Change
Damage as a percent of county income under RCP 8.5, 2080-2099



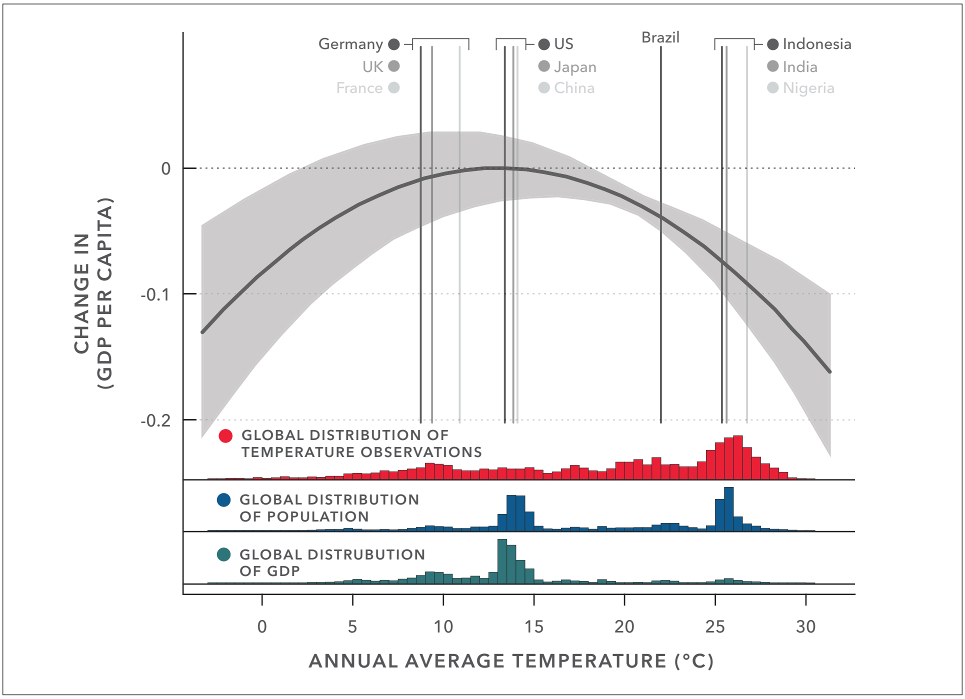
Source: Hsiang et al. (2017)

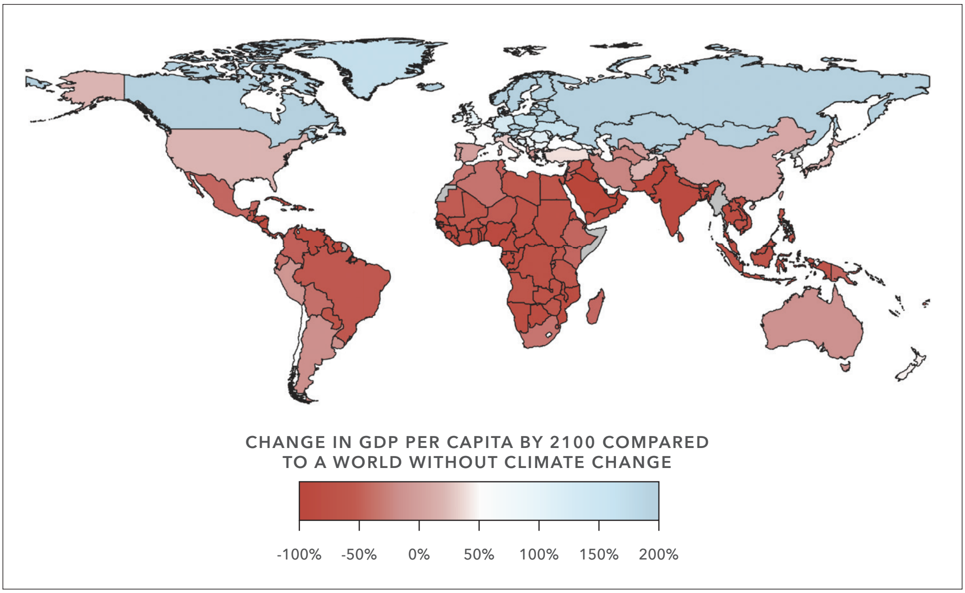
Geography is not the only factor that drives inequality in climate impacts. Even within the same place, poor Americans are often more vulnerable to changes in the climate. Factors include less access to insurance to protect against increasingly frequent and severe weather events, or less access to federal emergency support in the wake of a storm. Income is a major determinant of the likelihood of dying from a heat wave, something demonstrated empirically in Carleton et al. (2020).

3.b. But Even More Unequal across the World

The equity implications of climate convexity are even more profound at a global level. Take, for instance, Burke, Hsiang, and Miguel's top-down estimate of the relationship between temperature and GDP growth rates around the world (Figure 11). Up to a certain average starting temperature, warming increases economic output. Beyond that, it decreases output. This has a similar shape to the top-down, income damage functions in the United States. In general, today's developed countries are currently colder than developing countries. That results in dramatic growth in global income inequality as warming occurs. Burke, Hsiang, and Miguel estimate that while global GDP declines by 23 percent in a high-emissions scenario on average (median estimate), for the poorest 40 percent of the global population it falls by 75 percent (Figure 11). Kalkuhl and Wenz (2020) find similar geographic distribution of temperature-driven economic damages.

Figure 11: Temperature-GDP Damage Function and Projected Decline in Per Capita GDP





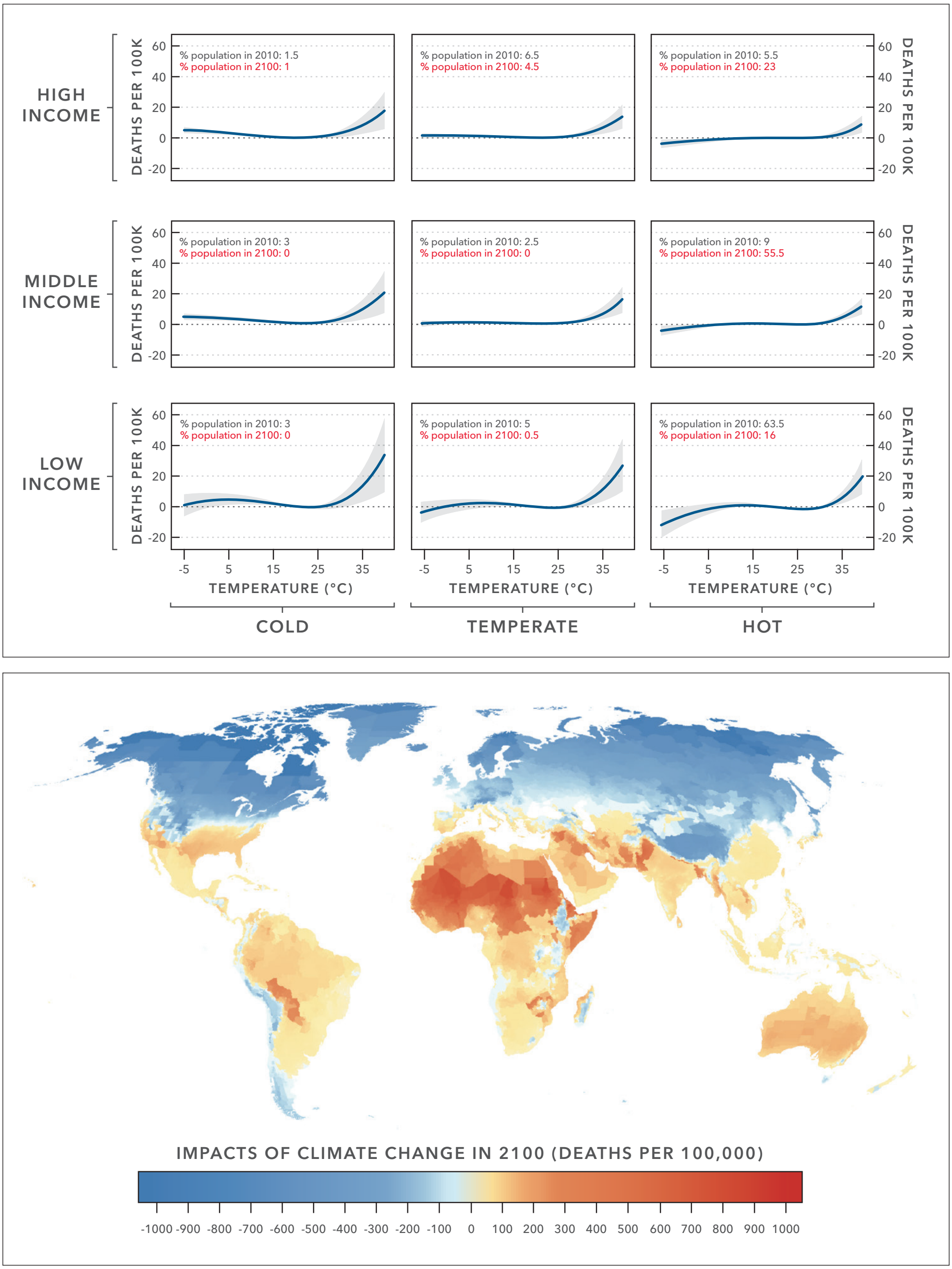
Source: Burke, Hsiang, and Miguel (2015)

Note: High-emissions scenario, end of century.

GDP is a narrow and sterile measure of human welfare. The inequality in climate-driven mortality rates around the world is much more stark. Carleton et al. (2020) find that in a high-emissions scenario, climate-change-driven increases in temperature raise global death rates by roughly 74 per hundred thousand by the end of the century. This is after accounting for the reduced vulnerability that comes from projected income growth and adaptive measures. Seventy-four deaths per hundred thousand is on par with the current death rate for all infectious diseases—including tuberculosis, HIV, malaria, dengue, yellow fever, and diseases transmitted by ticks, mosquitos, and parasites—combined.

As with GDP, climate-driven changes in mortality rates vary dramatically around the world with poor countries bearing most of the impact. Hotter places suffer more than colder places, and as already mentioned, developed countries tend to be colder than developing countries. But wealth itself is also protective against temperature-driven mortality, through greater access to air conditioning, indoor service sector employment, and other adaptive measures (Figure 13). Because of these two factors combined, the poorest 20 percent of the world's population sees an increase in death rates of 142 per 100,000 by the end of the century (twice the global average), while the richest 20 percent see their death rates decline.

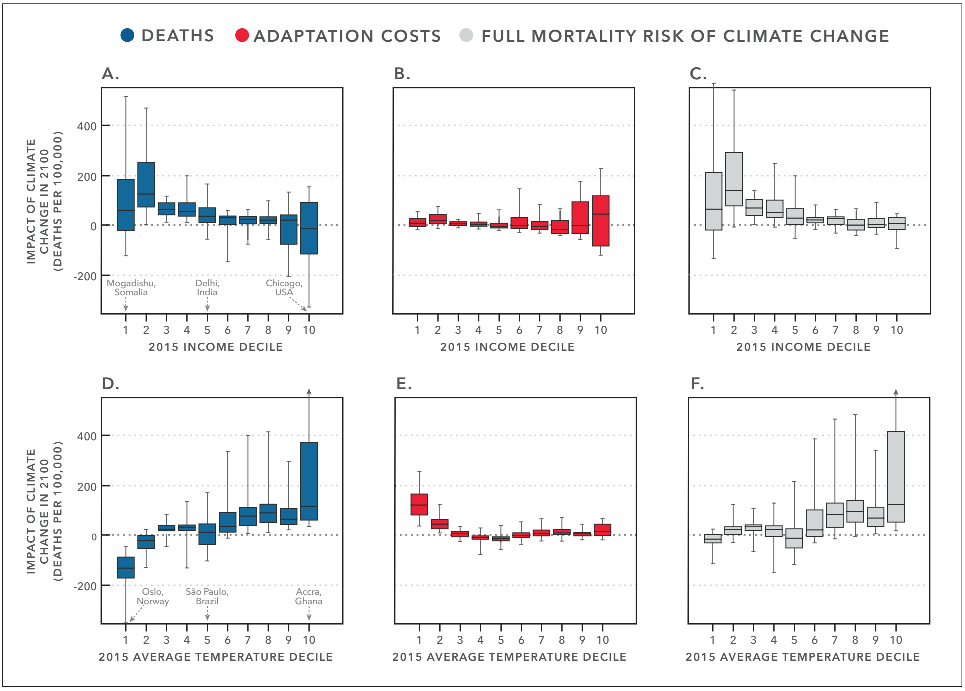
Figure 12: Mortality Damage Function and Projected Change in Death Rate



Source: Carleton et al. (2020)

Note: High-emissions scenario, end of century.

Figure 13: Climate Change Mortality Impacts by Current Income Decile



Source: Carleton et al. (2020)
Note: High-emissions scenario.

3.c. Inequality in Both Cause and Effect

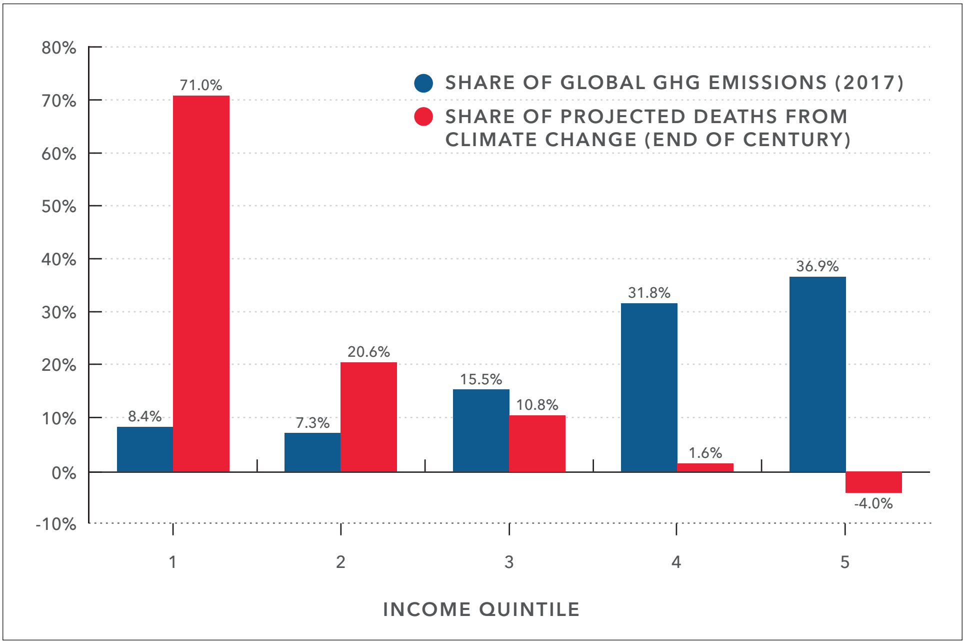
Climate change is obviously not unique in the unequal way in which it impacts human society. COVID-19 has highlighted stark differences in health outcomes within the United States, both by race and income. Globally, the deadliest infectious diseases—tuberculosis, HIV, and malaria—kill far more people in developing countries than in developed countries. But for very few other large-scale threats to human health and welfare is there such a stark difference between those creating the problem and those directly impacted by it.

Within the United States, carbon dioxide emissions from residential energy consumption are 25 percent higher for high-income households than low-income households, due primarily to larger house size (Goldstein, Goundaridis, and Newell 2020). Accounting for all sources of emissions, Song et al. (2019) find that carbon footprint of the wealthiest U.S. households is nearly five times that of the poorest households. These more affluent households are more likely to be protected from the changes in the climate their emissions help create due both to geography and the greater adaptive capacity higher income levels create.

The disparity is even starker internationally. People currently living in countries in the bottom fifth of the global income distribution emit 2.8 metric tons of GHG emissions per year on average and account for 8.4 percent of total emissions globally (Figure 14). In contrast, those living in countries in the top fifth of the global income distribution emit five times that amount—12.6 metric tons per year on average (Figure 14). Americans emit 17.8 metric tons per person. Yet for those countries in the top fifth of the global income distribution, climate change will likely reduce temperature-driven mortality rates on average (though some countries and some parts of others will see net increases). In contrast, countries in the bottom fifth of the global income distribution account for 71 percent of projected increases in all temperature-driven mortality around the world.

Figure 14: Those Least at Fault Are Most at Risk

Countries' share of current GHG emissions and projected increases in mortality from climate change by income quintile



Source: Rhodium Group and Carleton et al. (2020). Income quintiles are based on national per capita GDP and binned by combined population.

The same disparity exists for climate change's impact on economic output. Under Burke, Hsiang, and Miguel's (2015) model of the relationship between temperature change and economic growth, a disproportionate share of global economic damage occurs in countries that account for a very small share of global emissions.

3.d. Indirect Risks for Higher Income Countries and Communities

More affluent countries and communities have a moral obligation to mitigate climate damage caused by their emissions in lower-income countries and communities. But doing so is in their self-interest as well. Extreme weather events are already the leading cause of forced human displacement around the world (Yayboke et al. 2020). Increasingly frequent and severe heat waves, storms, and wildfires will only increase this in the years ahead. In addition to this temporary displacement, climate change will drive permanent displacement as well, whether from cities inundated by rising seas, long-term agricultural failure from rising temperatures, or communities crossing wet-bulb thresholds that make safe inhabitation impossible.

Displacement within the United States will disproportionately impact lower-income households, but will impose costs—both fiscal and economic—on all Americans. Federal government spending on disaster relief is growing due to climate change, a cost borne by all taxpayers. Forced displacement puts strains on state and local government services and erodes local tax bases. Abandoned homes and other capital stock create a drag on economic growth, not just in the community in which they exist but in the country more broadly.

Forced displacement in developing countries will increase refugee flows into the United States and other developed countries. Econometric research quantifying the impact of climate change on human migration is still in its early stages, but one of the early areas of focus is on the impact of climate change on conflict, and the impact of that conflict on migration patterns. Through a meta-analysis of more than 50 existing quantitative studies, Burke, Hsiang, and Miguel (2015b) find that higher temperatures meaningfully elevate the risk of both interpersonal and intragroup conflict. Analyzing the relationship between weather variations in source countries and asylum applications in the European Union, Missirian and Schlenker (2017) estimate that climate-related increases in conflict could raise EU asylum applications by between 28 percent and 188 percent by the end of the century.

Forced displacement is only one way in which conflict made more likely by a changing climate will impact the United States and other developed countries. In 2015, the U.S. Department of Defense (DoD) published a report on the risks to U.S. national security and found "a changing climate increases the risk of instability and conflict overseas, and has implications for DoD on operations, personnel, installations, and the stability, development, and human security of other nations."[4]

4 "National Security Implications of Climate-Related Risks and a Changing Climate." 2015. Department of Defense. https://archive.defense.gov/pubs/150724-congressional-report-on-national-implications-of-climate-change.pdf.

4. Policy Recommendations

Recent advances in climate econometric research make it clear that the cost of inaction on climate change in the United States is greater than the cost of action. The more important insight from this research for American policymakers, however, is how unequally the cost of climate change is distributed, both within the United States and around the world. There are four concrete ways to incorporate this knowledge into domestic and international climate policymaking that will help create a more just and sustainable future, both within the United States and around the world.

4.a. On the Path to Zero, Remember Every Ton Counts

The most significant step the United States can take to reduce the impact of climate change on human health and economic welfare in developing countries is taking aggressive steps to move quickly to reduce GHG emissions at home, and reengage other developed and emerging economies in efforts to do the same, both bilaterally and multilaterally.[5]

Because of the length of time carbon dioxide emissions remain in the atmosphere, the only way to ultimately stabilize global concentrations is to reduce the net addition from human activities to zero (or very near zero). That means reducing the amount of carbon dioxide and other GHGs added to the atmosphere from fossil fuel combustion and other activities as much as possible, and increasing the amount removed from the atmosphere (whether through technical or natural sequestration) to cover the rest.

In 2018, the IPCC published a major report indicating that to limit global temperature increases to 1.5°C (an aspiration set out in the 2015 Paris Agreement), the world will likely need to achieve net-zero carbon dioxide emissions on a global basis between 2045 and 2055, along with deep reductions in other GHG emissions (IPCC 2018). Following this report, a number of U.S. states adopted goals of achieving net-zero emissions by mid-century. The House Select Committee on the Climate Crisis has set a similar goal at a national level, as has Vice President Joe Biden's presidential campaign.

As officials at both the federal and state level develop policies to achieve a net-zero target, its important to remember that in avoiding climate damage, the path to zero matters as much as the end point. A non-linear damage function means the first tons reduced have the most benefit, and the sooner they are reduced the better. This is particularly true for low-income communities and countries.

5 For examples of emission reducing policy and technology options, see Keith and Deutch (2020) and Metcalf (2020)

4.b. Address Inequality in Mitigation Policy Design

Inequality can also be directly addressed in policies designed to reduce emissions. Regulations to reduce pollution in the United States require benefit-cost analysis (BCA), where the benefits of the regulation are compared to its costs. This includes regulations to reduce GHG emissions, where the benefits of avoided climate damage are measured using the Social Cost of Carbon (SCC). To date, the U.S. government has used the DICE, FUND, and PAGE IAMs to estimate the SCC. Because of their regional aggregation, these models value future climate damages based on their average impact. For example, let's say climate change will lead to a 1 percent increase in income for nine communities, but a 9 percent decrease in income for one community, these IAMs would indicate that climate change has no cost. Policymakers are often rightly interested in avoiding such unequal outcomes, and the adoption of high-resolution climate econometric models in developing the SCC will help them do so in the regulatory process.

Climate change is not the only negative externality from fossil fuel production. Sulfur dioxide, mercury, particulate matter, and other air pollutants from coal, oil, and gas combustion impose billions of dollars in public health costs each year. These costs are not evenly spread, and as with climate impacts, disproportionately impact low-income households. In 2015, the Environmental Protection Agency (EPA) developed the EJSCREEN database, which tracks exposure to these and other environmental hazards at the census tract level. These data are used by the EPA and other agencies to comply with Executive Order 12898, which directs federal agencies to "identify and address the disproportionately high and adverse human health or environmental effects of their actions on minority and low-income populations, to the greatest extent practicable and permitted by law." Incorporating high-resolution climate econometric data into this tool will help legislators and regulators design policy that addresses environmental inequalities more holistically.

Finally, the opportunities for addressing inequality in U.S. mitigation policy design extend beyond America's borders. The United States and other developed and emerging economies had the luxury of relying on fossil fuels to power industrialization, something less available to low-income countries now, if the world is going to limit global temperature increases to less than 2°C or 1.5°C. U.S. investment in bilateral and multilateral efforts to support clean energy deployment, low-GHG agriculture, and other emission-reducing activities in these countries can help provide them with an alternative pathway to industrialization, while having material benefits for the United States through reduced warming and avoided climate damages.

4.c. Improve Resilience, Both at Home and Abroad

No matter how successful the world is in reducing GHG emissions, some level of continued warming of the climate is already baked in. For example, even in a low-emissions scenario with modest ice sheet melt, global sea levels will still likely rise by 14 to 26 inches by the end of the century, putting the current homes of 90 million people around the world below high tide. Improving the resilience of our communities and economy to those climate impacts that are certain to occur, as well as preparing for those that might occur if emission-reductions fall short, is a critical task facing policymakers around the world. Some level of adaptation will happen automatically, but much less than people often assume and at much higher cost. The fact that climate change is expressed through increased frequency and severity of extreme events creates behavioral barriers to adaptation, as do existing policy regimes that incentivize living and working in high-risk areas. Adaptation is even more challenging for low-income communities and countries, which often lack the resources to make the kind of up-front investment in protective measures required.

Within the United States, there are four priority areas of policy focus. The first is to make coastal communities more resilient to rising seas and more intense storms. This includes updating Federal Emergency Management Agency (FEMA) maps to more accurately reflect current flood risk, reforming the National Flood Insurance Program to reduce incentives to live in high-risk areas while offsetting the impact of such changes on low-income households currently in flood zones, and more federal funding for municipal and state-level investments in coastal resilience. The second is to make low-income households and those with co-morbidities less vulnerable to increasingly frequent heat waves. This includes expanding access to efficient and low-cost air conditioning, particularly in those parts of the country that are currently systematically under-air-conditioned relative to what's required for health and safety in the years ahead, given current climate projections. The third is support for agricultural communities in the South and lower Midwest, where climate change is threatening the viability of the crops on which they traditionally rely. This includes changes to federal crop insurance to remove incentives for maladaptation and investment in economic diversification, both into other crops and other sectors. The fourth is reducing wildfire risk in the western United States. Research suggests that half of the growth in wildfire burn area over the past 30 years was due to climate change. Policy action is required both to reduce the amount of burn area in the years ahead, and to mitigate risk to homes and businesses when burns occur.

There are important steps the United States can take to improve resilience in vulnerable countries around the world, through United States Agency for International Development (USAID), bilateral credit agencies, and multilateral development banks and organizations. The economies of the Least Developed

Countries (LDCs) are far more reliant on agriculture than the global average, and many of these countries have climates where global warming will significantly reduce, rather than increase, yields. In the 1960s and 1970s, international collaboration on agricultural technology and practices helped increase rice and wheat yields around the world to accommodate rapid population growth while avoiding mass famine. Similar collaboration today can help make agricultural production more resilient to changes in the climate.

A key component of this will be better water management, both in parts of the world getting drier as a result of climate change and in parts of the world getting wetter, which may experience more extreme precipitation events. The benefits of better water management extend beyond agriculture as well. Many urban centers in developing countries are facing severe ground water shortages, made worse by changes in the climate. Flooding is the largest single source of forced displacement around the world, and it will only get worse in the years ahead.

Sea level rise is an enormous risk for many developing countries, and an existential threat for Small Island Developing States (SIDS). Under a high-emissions scenario, but with modest ice sheet melt, the current homes of 27 million people in Bangladesh will be submerged by high tide by the end of the century, compared to 1.3 million in the United States. The U.S. Army Corp of Engineers has expertise in coastal and structural defenses that can be deployed to help keep the seas at bay, along with development assistance to finance new infrastructure projects.

International development assistance aimed at access to affordable, high-efficiency air conditioning in those developing countries most vulnerable to extreme heat could save thousands of lives around the world, as could increased funding for conflict prevention through the State Department, USAID, international governmental organizations, and non-governmental organizations (NGOs).

With interest rates at record lows and unemployment at record highs, this is a unique opportunity to invest in climate resilience both in the United States and around the world. Such investments will accelerate economic recovery and deliver financial dividends through avoided climate damage in the future.

4.d. Prepare for Climate Displacement

No matter how successful the United States and other major economies are in reducing emissions and improving resilience, large amounts of climate-driven, forced displacement will occur in the years ahead. Domestically we have existing programs, through FEMA and other channels, that help provide those displaced by extreme weather events with temporary housing and assistance. These will need to be significantly strengthened and expanded to effectively respond to climate-driven increases in temporary displacement in the years ahead. There is no policy framework in place, however, for those who could be permanently displaced in the future, whether from sea level rise, widespread agricultural failure, or uninhabitable temperatures. Effective and equitable resettlement will require significant fiscal resources and extensive federal-state coordination.

Internationally, climate migrants currently have little protection under the United Nations frameworks that govern refugee resettlement or U.S. immigration law. If someone is displaced from their home due to a conflict made more likely by climate change, they may be eligible for refugee status or able to claim asylum within the United States. But those directly displaced, either temporarily by extreme weather events or permanently by sea level rise or temperature increases that make continuing to live in their community impossible, have very few pathways for protection.

Yayboke et al. (2020) identify a number of legal changes the United States should make to resettle climate migrants in the United States and provide them with legal protections. This includes Climate Temporary Protective Status for those displaced by a storm, flood, or wildfire made significantly worse by climate change, but who are ultimately interested in returning home, and a Climate Migrant Resettlement Program for those permanently displaced by climate change. Yayboke et al. also recommend the United States take a leadership role in strengthening protections for climate migrants within existing international frameworks and organizations.

Embracing climate migrants is our moral responsibility, but it also helps us build a stronger country in line with our founding ideals. Immigration is not only an intrinsic feature of America's national identity, but has been essential to the country's economic success. Many past waves of immigrants were fleeing disasters at home, and found both refuge and opportunity in the United States. Thanks to our wealth of land and natural resources, a growing population has been a source of economic dynamism rather than scarcity. This continues to be the case with this coming wave of migrants seeking refuge, and from a storm we helped create.

Conclusion

As climate scientist Kate Marvel often notes, we are living in "the good place."[6] The odds of a planet forming the right distance from a star and with the right atomic composition to support life are extremely low. And even once that planet is formed, there is no guarantee it will develop a climate suitable and stable enough to support

6 Klein, Ezra. n.d. "We Live in The Good Place. And We're Screwing It up." The Ezra Klein Show. Retrieved from https://www.stitcher.com/s?eid=64883521.

robust human development. For Earth, that has only occurred in the last 12,000 years—roughly 0.00002 percent of the planet's existence. Over the past 200 years, economic growth and technological progress have created dramatic improvements in our life expectancy and daily living conditions. These gains have been fastest among developed and emerging economies, but over the past few decades, low-income, developing countries have also experienced meaningful improvements.

Unfortunately, one of the primary engines of our past economic success—fossil fuel combustion—is threatening the benign and stable climate that has enabled human progress. Most of this combustion occurs in developed and emerging economies, but the growing body of research outlined in this brief shows that the costs of continuing on our current path will fall disproportionately on poor countries, and poor households within rich countries. The magnitude of the threat is large enough to significantly slow, if not halt, the pace of human development in the most vulnerable countries and communities, with spillover effects around the world.

This future is not set in stone. Quick action to reduce emissions can save millions of lives per year and dramatically improve the economic development prospects for billions of people around the world. Large-scale investment in resilient agriculture, buildings, infrastructure, and social systems will help protect vulnerable populations from those changes in the climate that do occur. And reforming domestic immigration law and international migration frameworks can help ensure those who are displaced still have a chance at safety and prosperity. U.S. leadership is essential for this to succeed, and with it we have a fighting chance of preventing the benefits of a stable climate from being lost, particularly to those who haven't yet had the opportunity to fully thrive and develop.

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