United States Government Accountability Office

Report to Congressional Requesters

September 2017

# CLIMATE CHANGE

# Information on Potential Economic Effects Could Help Guide Federal Efforts to Reduce Fiscal Exposure

Accessible Version

GAO-17-720

# GAO Highlights

Highlights of GAO-17-720, a report to congressional requesters

September 2017

# CLIMATE CHANGE

## Information on Potential Economic Effects Could Help Guide Federal Efforts to Reduce Fiscal Exposure

## Why GAO Did This Study

Over the last decade, extreme weather and fire events have cost the federal government over $350 billion, according to the Office of Management and Budget. These costs will likely rise as the climate changes, according to the U.S. Global Change Research Program. In February 2013, GAO included *Limiting the Federal Government's Fiscal Exposure by Better Managing Climate Change Risks* on its High-Risk List.

GAO was asked to review the potential economic effects of climate change and risks to the federal government. This report examines (1) methods used to estimate the potential economic effects of climate change in the United States, (2) what is known about these effects, and (3) the extent to which information about these effects could inform efforts to manage climate risks across the federal government. GAO reviewed 2 national-scale studies available and 28 other studies; interviewed 26 experts knowledgeable about the strengths and limitations of the studies; compared federal efforts to manage climate risks with leading practices for risk management and economic analysis; and obtained expert views.

## What GAO Recommends

GAO recommends that the appropriate entities within the Executive Office of the President (EOP), including the Office of Science and Technology Policy, use information on potential economic effects to help identify significant climate risks and craft appropriate federal responses. EOP entities and the Environmental Protection Agency did not provide official comments on the report.

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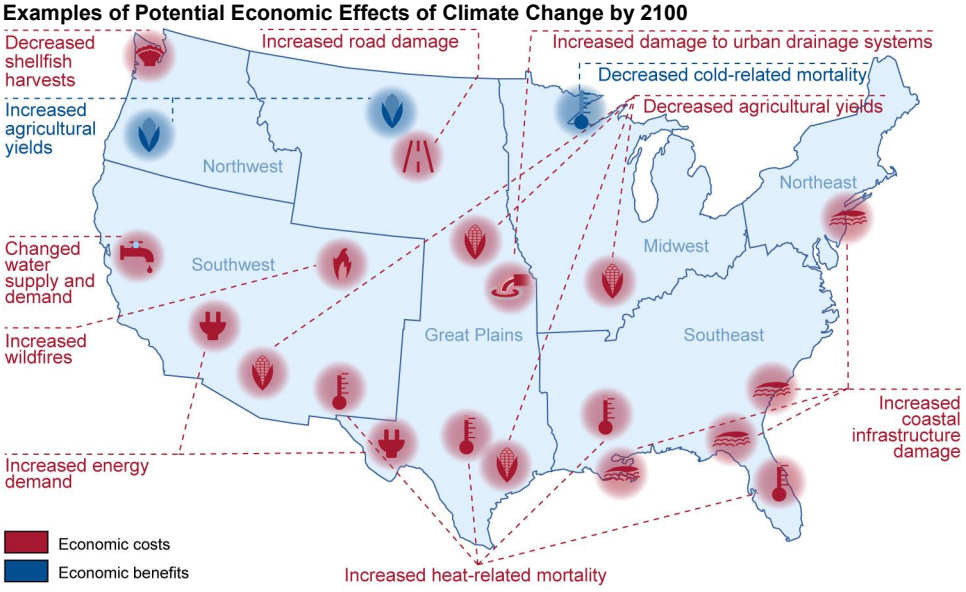
## What GAO Found

Methods used to estimate the potential economic effects of climate change in the United States—using linked climate science and economics models—are based on developing research. The methods and the studies that use them produce imprecise results because of modeling and other limitations but can convey insight into potential climate damages across sectors in the United States.

The two available national-scale studies that examine the economic effects of climate change across U.S. sectors suggested that potential economic effects could be significant and unevenly distributed across sectors and regions. For example, for 2020 through 2039, one study estimated between $4 billion and $6 billion in annual coastal property damages from sea level rise and more frequent and intense storms. Also, under this study, the Southeast likely faces greater effects than other regions because of coastal property damages (see figure).

**Examples of Potential Economic Effects of Climate Change by 2100**




Sources: GAO analysis of Environmental Protection Agency, *Climate Change Impacts in the United States: Benefits of Global Action* (Washington, D.C.: 2015), and Solomon Hsiang et al., "Estimating Economic Damage from Climate Change in the United States," *Science,* vol. 356 (2017); Map Resources (map). | GAO-17-720

Information about the potential economic effects of climate change could inform decision makers about significant potential damages in different U.S. sectors or regions. According to several experts and prior GAO work, this information could help federal decision makers identify significant climate risks as an initial step toward managing such risks. This is consistent with, for example, National Academies leading practices, which call for climate change risk management efforts that focus on where immediate attention is needed. The federal government has not undertaken strategic government-wide planning to manage climate risks by using information on the potential economic effects of climate change to identify significant risks and craft appropriate federal responses. By using such information, the federal government could take an initial step in establishing government-wide priorities to manage such risks.

# Contents

**Abbreviations**

| | |
|---|---|
| CGE | Computable General Equilibrium |
| DOD | Department of Defense |
| EOP | Executive Office of the President |
| EPA | Environmental Protection Agency |
| IPCC | Intergovernmental Panel on Climate Change |
| OMB | Office of Management and Budget |
| SCC | social cost of carbon |
| USGCRP | U.S. Global Change Research Program |

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September 28, 2017

The Honorable Maria Cantwell
Ranking Member
Committee on Energy and Natural Resources
United States Senate

The Honorable Susan Collins
United States Senate

According to the President's budget proposal for fiscal year 2017, over the last decade, the federal government has incurred direct costs of more than $350 billion because of extreme weather and fire events, including $205 billion for domestic disaster response and relief; $90 billion for crop and flood insurance; $34 billion for wildland fire management; and $28 billion for maintenance and repairs to federal facilities and federally managed lands, infrastructure, and waterways.[1] According to a May 2014 assessment by the U.S. Global Change Research Program (USGCRP), the impacts and costs of extreme events—such as floods, drought, and other events—will increase in significance as what are considered rare events become more common and intense because of climate change.[2] A November 2016 assessment by the Office of Management and Budget (OMB) and the Council of Economic Advisers found that recurring costs that the federal government incurred as a result of climate change could increase by $12 billion to $35 billion per year by mid-century and by $34 billion to $112 billion per year by late-century, the equivalent of $9 billion to $28 billion per year in today's economy.[3] For example, according to this

[1]Office of Management and Budget, *Budget of the U.S. Government, Fiscal Year 2017* (Washington, D.C.: Feb. 9, 2016) and *Analytical Perspectives, Budget of the United States Government, Fiscal Year 2017* (Washington, D.C.: 2016).

[2]Jerry M. Melillo, Terese (T.C.) Richmond, and Gary W. Yohe, eds., *Climate Change Impacts in the United States: The Third National Climate Assessment*, (Washington, D.C.: U.S. Global Change Research Program, May 2014). USGCRP coordinates and integrates the activities of 13 federal agencies that research changes in the global environment and their implications for society. The Office of Science and Technology Policy within the Executive Office of the President oversees USGCRP.

[3]According to this assessment, these ranges are projections of costs that the federal government would incur across four program areas—wildland fire suppression, crop insurance, air quality-health care, and coastal disaster relief—given a set of assumptions that form the scenarios modeled. Office of Management and Budget, *Climate Change: The Fiscal Risks Facing the Federal Government* (Washington, D.C.: November 2016).

assessment, wildland fire suppression costs have increased as fire seasons have grown longer and the size and severity of wildland fires have increased, in part because of climate change.[4]

Reflecting such observed and projected climate-related costs to the federal government, in February 2013 we placed *Limiting the Federal Government's Fiscal Exposure by Better Managing Climate Change Risks* on our list of agencies and program areas that are high risk because of their vulnerabilities to fraud, waste, abuse, and mismanagement or are in most need of transformation.[5] In that report, we identified a number of areas in which the federal government faces fiscal exposure from climate change risks, including its role as (1) the owner and operator of extensive infrastructure and federal property vulnerable to climate impacts, (2) the insurer of property and crops vulnerable to climate impacts, and (3) the provider of aid in response to disasters.[6] As an example illustrating the government's fiscal exposure because of its ownership of infrastructure, in May 2014, we reported that the Department of Defense's (DOD) 2010 and 2014 Quadrennial Defense Reviews stated that climate change poses risks to defense infrastructure, particularly on the coasts.[7] This defense infrastructure consists of more than 555,000 defense facilities and 28 million acres of land, with a replacement value of close to $850 billion.

As reported in our 2015 High-Risk update, climate change adaptation—defined as adjusting natural or human systems in response to actual or expected climate change—is one way for the federal government to manage climate risks.[8] Adaptation can help protect vulnerable sectors and communities that might be affected by changes in the climate. Adaptation measures to protect infrastructure, for example, include raising river or coastal dikes to protect infrastructure from sea level rise,

[4]Office of Management and Budget, *Climate Change: The Fiscal Risks Facing the Federal Government*.

[5]GAO, *High-Risk Series: An Update,* GAO-13-283 (Washington, D.C.: Feb. 14, 2013).

[6]For a discussion of the concept of fiscal exposures and sources of risks that create such exposures, click here.

[7]GAO, *Climate Change Adaptation: DOD Can Improve Infrastructure Planning and Processes to Better Account for Potential Impacts*, GAO-14-446 (Washington, D.C.: May 30, 2014).

[8]GAO, *High-Risk Series: An Update,* GAO-15-290 (Washington, D.C.: Feb. 11, 2015).

building higher bridges, and increasing the capacity of storm water systems. According to a 2010 National Academies report, choices regarding how and when to adapt vary greatly, and priorities for addressing climate risks through adaptation need to be set relative to other important priorities. Setting such priorities for the federal government would require an understanding of relative risks across economic sectors, such as agriculture, health, and energy.[9] To more effectively understand such risks and the range of options for managing them, the National Academies, in its 2016 review of USGCRP's strategic plan update, reported that social science research, including economic research, is needed to support effective decision-making processes.[10]

You asked us to review the potential economic effects of climate change impacts and resulting risks to the federal government. This report examines (1) what is known about methods used to estimate the potential economic effects of climate change in the United States, (2) what is known about the potential economic effects of climate change in the United States, and (3) to what extent have leading practices and experts found that information about the potential economic effects of climate change could inform efforts to manage climate risks across the federal government.

To address these objectives, we reviewed reports and studies and interviewed experts and knowledgeable stakeholders. First, we conducted a literature review to determine what has been reported about methods used to estimate the economic effects of climate change in the United States and what estimates have been produced.[11] As a part of this work, we reviewed 30 studies published in 2005 or later and identified the only

[9]National Research Council of the National Academies, America's Climate Choices: Panel on Adapting to the Impacts of Climate Change, *Adapting to the Impacts of Climate Change* (Washington, D.C.: 2010).

[10]National Academies, Committee to Advise the U.S. Global Change Research Program, Board on Atmospheric Sciences and Climate; Division on Earth and Life Studies; Board on Environmental Change and Society; Division of Behavioral and Social Sciences and Education, *Review of the U.S. Global Change Research Program's Update to the Strategic Plan Document* (Washington, D.C.: 2016).

[11]This report focuses on adaptation to climate change and does not include the economic costs of emissions reduction policies. The social cost of carbon (SCC), an economic metric quantifying the marginal global benefit of reducing one ton of carbon dioxide, is beyond the scope of this report. We have examined SCC in prior work: GAO, *Regulatory Impact Analysis: Development of Social Cost of Carbon Estimates,* GAO-14-663 (Washington, D.C.: July 24, 2014).

2 available studies that provide national-scale information about the economic effects of climate change across multiple sectors and regions in the United States. We then reviewed these studies using standard economic principles, including a review of objective and scope, methodology, analysis of effects, sensitivity analysis, and documentation.[12] Second, we interviewed 26 selected experts, including agency officials, researchers, and consultants. We identified these experts through our literature search and snowball sampling based on, among other things, their expertise related to our objectives, such as knowledge of the strengths and limitations of methods used to estimate the economic effects of climate change.[13] Finally, we compared government-wide efforts to manage climate risks with leading practices for risk management and economic analysis and the views of experts. For additional details on our scope and methodology, see appendix I.

We conducted this performance audit from December 2015 to September 2017 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

# Background

Agencies across the federal government, such as the National Oceanic and Atmospheric Administration and the National Aeronautics and Space Administration, collect and manage many types of climate information, including observational records from satellites and weather monitoring stations on temperature and precipitation; projections from complex climate models; and other tools to make this information more meaningful to decision makers. Such information includes the following:

[12]We used standard economic principles similar to those embodied in federal and agency guidance. See app. I for more details on our scope and methodology.

[13]To quantify the number of experts, of the 26 interviewed, who expressed particular views, we use the following modifiers throughout the report: "some" represents 2 to 3 experts, "several" represents 4 to 7 experts, "many" represents 8 to 13 experts, and "most" represents 14 or more experts. The specific areas of expertise varied among the experts we interviewed, so not all of the experts commented on all of the interview questions.

- **Information and analysis about observed climate conditions.** This includes information on, for example, temperature, precipitation, drought, storms, and sea level rise and how they may be changing in the local area. This type of information can be most easily conveyed by graphs and maps with some statistics on trends, variability, and data reliability.
- **Information about observed climate impacts and vulnerabilities.** This includes site-specific and relevant baselines of environmental, social, and economic impacts and vulnerabilities, resulting from observed changes in the climate against which past and current decisions can be monitored, evaluated, and modified over time.
- **Projections of what climate change may mean for the local area.** This includes, for example, projections based on easily understandable best- and worst-case scenarios with confidence intervals and probability estimates and examples of potential climate impacts. The projections may need to be downscaled from complex global-scale climate models to provide climate information at a geographic scale relevant to decision makers.[14] Then, the information would need to be translated into impacts at the local level, such as how increased streamflow for a particular river may increase flooding.
- **Information on the economic and health impacts of climate change.** Observed and projected local impacts must be translated into costs and benefits, as this information is needed for many decision-making processes.

Entities within the Executive Office of the President, such as the Council on Environmental Quality and the Office of Science and Technology Policy,[15] have led specific government-wide climate information efforts,

[14]According to a 2012 National Research Council report on climate models, the fundamental science of greenhouse gas-induced climate change is simple and compelling. However, genuine and important uncertainties remain, such as how clouds affect the climate system, and these uncertainties need to be considered in developing scientifically based strategies for societal response to climate change—especially those related to "downscaled" climate information. For more information, see National Research Council of the National Academies, *A National Strategy for Advancing Climate Modeling* (Washington, D.C.: 2012).

[15]The Council on Environmental Quality coordinates federal environmental efforts and the development of environmental initiatives. The council was established within the Executive Office of the President by the National Environmental Policy Act of 1969, and additional responsibilities were provided by the Environmental Quality Improvement Act of 1970. The Office of Science and Technology Policy was established by statute in 1976 to serve as a source of scientific and technological analysis and judgment for the President with respect to major policies, plans, and programs of the federal government, among other things.

such as USGCRP's May 2014 Third National Climate Assessment, which summarizes the impacts of climate change on the United States, now and in the future.[16]

# Methods Used to Estimate the Potential Economic Effects of Climate Change in the United States Are Based on Developing Research, Are Complex, Produce Imprecise Results, and Can Convey Useful Insight

Methods used to estimate the potential economic effects of climate change in the United States are based on developing research from a small but growing number of researchers. These methods are complex because they link different types of complicated climate and economic models to assess how projected changes in the climate could affect different sectors and regions. They produce imprecise results because of information and modeling limitations associated with (1) climate modeling uncertainty; (2) limited information on which to base models for specific economic sectors; (3) incomplete coverage of sectors, interactions among sectors, and climate change impacts; and (4) challenges of modeling over long time frames. Nonetheless, according to several experts we interviewed, the methods can convey useful insight into broad themes about potential climate damages across sectors in the United States.[17]

## Methods Are Based on Developing Research

Methods used to estimate the potential economic effects of climate change in the United States are based on developing research being undertaken by a small but growing number of researchers, according to

[16]A team of several hundred experts guided by a 60-member federal advisory committee produced the report, which was extensively reviewed by the public and experts, including federal agencies and a panel of the National Academy of Sciences. In addition, a large stakeholder network was developed in support of the May 2014 National Climate Assessment.

[17]According to the National Academies, damages from climate change are the monetized value of the net impacts associated with climate change. See National Academies of Sciences, Engineering, and Medicine, *Valuing Climate Damages: Updating Estimation of the Social Cost of Carbon Dioxide* (Washington, D.C.: 2017).

the literature we reviewed and several experts we interviewed. Researchers began developing methods to understand the economics of climate change starting in the early 1990s. These original methods—primarily designed to analyze the economic benefits and costs of reducing greenhouse gas emissions—typically assess the economic effects of climate change at a global or multinational scale, with little detailed information about specific regions or sectors within a country.[18] As a result, some experts said that these original methods produce limited information about the economic effects of climate change within different sectors in the United States.

Since the early 2000s, researchers have developed new methods that provide more detailed information about the economic effects of climate change in the United States. Advances in knowledge about the historical relationships between changes in temperature, precipitation, and other climatic variables and the economy; access to data and information about the physical impacts of climate change; and a growth in computing power, among other things, have enabled the development of methods to assess economic effects in specific sectors and regions of the United States, according to literature we reviewed. To date, the new methods have been used primarily to quantify the economic effects of climate change on certain economic sectors, such as agriculture, health, and energy, but the research has been expanding to include additional sectors, such as infrastructure and water resources.

Only recently have studies analyzed the economic effects of climate change using frameworks that can compare effects across different sectors and regions within the United States on a national scale. According to many experts we interviewed, the following are the only two such national-scale research studies:[19]

- ***American Climate Prospectus:*** This study was published in October 2014 by the Rhodium Group and assessed the economic effects of

[18]According to literature we reviewed, these methods use an aggregated class of integrated assessment models, which quantify climate change economic effects through "damage functions" that estimate the economic impacts of climate change—typically as a percentage of gross domestic product—associated with different increases in global average temperatures. Some aggregated integrated assessment models can produce national-level estimates as well as global or multinational estimates.

[19]These studies were developed for different purposes and use different analyses. Neither of the studies assesses the costs of reducing greenhouse gas emissions and therefore, neither provides a cost-benefit assessment of climate policies.

potential changes in temperature, precipitation, sea level, and extreme weather events on six sectors of the U.S. economy—coastal property, health, agriculture, energy, labor productivity, and crime—within different regions of the country.[20] According to the study, its intent was to provide information on the probability, timing, and scope of a set of economically important climate change impacts comparable across sectors, rather than a conclusive answer about how much climate change will cost the United States. The study's authors noted that they designed a research framework that could expand and improve as the climate science and economics fields continue to develop.[21]

- ***Climate Change Impacts and Risks Analysis:*** This is an ongoing research project coordinated by the Environmental Protection Agency (EPA), which published a summary study in 2015.[22] The goal of the study was to assess the extent to which reducing global greenhouse gas emissions may help avoid or reduce climate change impacts and adverse economic effects on six U.S. sectors—health, infrastructure, electricity, water resources, agriculture and forestry, and ecosystems—and enabled the comparison of climate risks across these sectors. According to the authors of the *Climate Change Impacts and Risk Analysis* study, the study estimated the benefits to the United States of global action on climate change. As such, the analysis presented in the report did not inform on alternative actions

[20]Rhodium Group, LLC., *American Climate Prospectus: Economic Risks in the United States* (New York: October 2014). The *American Climate Prospectus* was funded by the Risky Business Project, a project funded by Bloomberg Philanthropies, the Paulsen Institute, and TomKat Charitable Trust; the Skoll Global Threats Fund; and the Rockefeller Family Fund. The Rhodium Group, LLC, a research consultancy and advisory company, coordinated the effort, which involved authors from universities and the private sector. This study was later published by the Columbia University Press in 2015: Trevor Houser et al., *Economic Risks of Climate Change: An American Prospectus* (New York: Columbia University Press, 2015).

[21]An update to this analysis was published in *Science* in June 2017: Solomon Hsiang et al "Estimating Economic Damage from Climate Change in the United States," *Science*, vol. 356 (2017).

[22]Environmental Protection Agency, Office of Atmospheric Programs, *Climate Change in the United States: Benefits of Global Action*, EPA 430-R-15-001 (Washington, D.C.: 2015). The detailed methods and results of the project were published in a 2014 special issue of the peer-reviewed journal, *Climatic Change* entitled, "A Multi-Model Framework to Achieve Consistent Evaluation of Climate Change Impacts in the United States." The project is coordinated by EPA's Office of Atmospheric Programs – Climate Change Division, with contributions from national laboratories and the academic and private sectors.

and did not constitute a benefit-cost assessment of actions to address climate change. In addition, EPA officials stated that the report was meant to convey broad themes about climate damages across sectors of the United States based on peer-reviewed data and methods. Like the authors of the *American Climate Prospectus* study, the authors of the *Climate Change Impacts and Risk Analysis* study noted in the report that the breadth and depth of the project, including the number of sectors covered, will expand in future work as the fields of climate science and economics continue to develop. According to EPA officials, this expanded research will contribute physical and economic information to USGCRP's next National Climate Assessment.[23]

## Methods Are Complex Because They Link Complicated Scientific and Economic Models

Methods used to estimate the potential economic effects of climate change in the United States are complex because, according to literature we reviewed and many experts we interviewed, they use different types of complicated climate and economic models that are linked together in a sequential framework that uses the results of one model as input to another. The different types of climate and economic models include the following:

- **Climate models:** Climate models are mathematical representations of physical, chemical, and biological processes in Earth's climate system, including the atmosphere, land surface, ocean, and sea ice. These models use scenarios of future greenhouse gas emissions as input, such as a scenario in which current trends in greenhouse gas emissions continue or a scenario in which future emissions are reduced. Based on these scenarios, the models simulate future changes in climate variables, such as changes in temperature and the amount of precipitation. In the United States, global-scale climate models are developed at federally funded institutions, such as the National Center for Atmospheric Research. The *American Climate Prospectus* and *Climate Change Impacts and Risk Analysis* studies

[23]The Global Change Research Act of 1990 requires that a scientific assessment—which, among other things, analyzes the effects of global change on the natural environment, agriculture, and energy production and use—be provided to the President and Congress not less frequently than every 4 years. USGCRP conducts this National Climate Assessment, the most recent of which was released in May 2014. According to USGCRP, development of the next National Climate Assessment is underway, with anticipated delivery in late 2018.

both used climate models from the National Center for Atmospheric Research, including the Model for the Assessment of Greenhouse-gas Induced Climate Change and the Community Atmosphere Model.

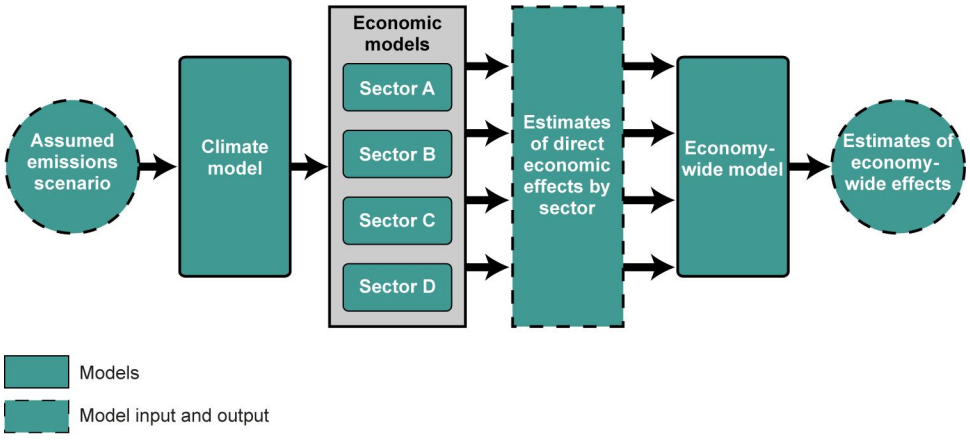
- **Economic models for individual sectors:** These models estimate the direct economic effects in certain sectors from changes in climate variables, such as temperature, and related climate impacts, such as sea level rise. Some economic models for individual sectors are based on relatively new econometric research that uses historically observed relationships between climate variables and economic effects to assess the potential economic effects of climate change on certain segments of the economy. For example, the *American Climate Prospectus* study used analyses of the historical relationships among temperature and changes in mortality, labor productivity, and violent crime, among other things, to project the economic effects of climate change. Other types of sector-specific models use known or theoretical relationships among climate variables and economic effects to make projections. These types of process-based models include, for example, the Forest and Agricultural Sector Optimization Model, used in the *Climate Change Impacts and Risks Analysis* study, which estimates changes in market outcomes associated with projected impacts of climate change on U.S. crop and forest yields.[24] The 2015 *Climate Change Impacts and Risks Analysis* report included 18 process-based models and 2 econometric models, according to EPA officials. Also, a version of the U.S. Energy Information Administration's National Energy Modeling System, maintained by the Rhodium Group and used in the *American Climate Prospectus* study, models the impact of changes in temperature on energy demand, power generation, and electricity costs.
- **Economy-wide models:** These models—called Computable General Equilibrium (CGE) models—can help assess how the entire economy, including individual sectors or regions, might react to the impacts of climate change and how their reactions can have implications for other sectors and regions. For example, as a result of changes in climate (e.g., higher temperatures), increases in energy demand and costs can increase the price of a wide range of goods, and decreases in crop yields in Iowa can affect food prices nationwide. As they encompass multiple sectors in a model of the U.S. economy, CGE models can more fully account for interactions between sectors than individual sector models can, potentially affecting findings on the

[24]The Forest and Agricultural Sector Optimization Model was developed for the U.S. Department of Agriculture.

effects of climate change.[25] The *American Climate Prospectus* used a CGE model to examine how these types of interactions among sectors affect the magnitude and regional variation of effects on the sectors analyzed in the study.[26] According to EPA officials, although the *Climate Change Impacts and Risk Analysis* study did not use a CGE model to analyze interactions among sectors, some interaction between sectors was analyzed. For example, water supply and availability projections from the water balance model were used to inform irrigation supply in the agricultural sector.

Figure 1 provides an example of how climate models, economic models for specific sectors, and economy-wide models can be linked together sequentially in a framework to estimate the economic effects of climate change.

**Figure 1: Example of Linked Models Used to Estimate Economic Effects of Climate Change**




Source: GAO analysis. | GAO-17-720

[25]For example, as found in the *American Climate Prospectus,* by allowing capital and labor to move from one economic sector to another in response to changes in relative prices as a result of the economic effect of climate change, the economic effect of climate change may be lower, all else the same. On the other hand, if substitution possibilities are limited, changes in relative prices (e.g., higher energy prices) may increase economic effects.

[26]The *American Climate Prospectus* study's CGE model assumed that labor would not be able to move between economic regions, effectively limiting the economy's flexibility in responding to climate change.

**Text for flow chart**

1. **Assumed scenario**
2. **Climate model**
3. **Economic models (sector a,b,c,d)**
    a. **Estimates of direct economic effects by sector**
4. **Economy-wide model**
5. **Estimates of economy-wide effects**

While the two national-scale studies of the economic effects of climate change across sectors in the United States use sequential modeling frameworks similar to the one shown in figure 1, other methods—referred to by several experts we interviewed as complex integrated assessment models—also incorporate feedback between the different climate and economic modeling components.[27] Such models include the Integrated Global System Model, developed at the Massachusetts Institute of Technology, and the Global Change Assessment Model, developed at the Pacific Northwest National Laboratory. Some experts we interviewed noted that these complex integrated assessment models have traditionally been used to analyze the effects of different policies on the energy sector. The models currently have limited capability to quantify economic effects on individual sectors, according to some experts we interviewed. For example, some experts we interviewed said that the Integrated Global System Model can roughly quantify the economic effects of climate change in the health and agriculture sectors.

## Methods, and the National-Scale Studies That Use Them, Produce Imprecise Results Because of Information and Modeling Limitations

According to the literature we reviewed and many experts we interviewed, methods used to estimate the potential economic effects of climate change in the United States, and the national-scale methods that use the methods, produce imprecise estimates of economic effects because of data and modeling limitations associated with (1) climate modeling

[27]According to several experts we interviewed, complex integrated assessment models differ from so called “aggregate” integrated assessment models that analyze economic effects of climate change on a global or multinational scale to assess metrics such as the social cost of carbon. Specifically, complex integrated assessment models include much more detailed representations of the climate, individual sectors, and the overall economy and can produce information on a smaller geographic scale than aggregate integrated assessment models.

uncertainty; (2) limited information on which to base models for specific economic sectors; (3) incomplete coverage of sectors, interactions among sectors, and climate change impacts; and (4) challenges of modeling over long time frames.[28]

## Climate Modeling Uncertainty

According to a 2012 National Academies report, climate models have advanced over the decades to provide much information that can be used for decision making today, but there are and will continue to be large uncertainties associated with climate modeling.[29] According to literature we reviewed, future greenhouse gas emissions are one key source of uncertainty because they will depend on factors that are extremely challenging to predict decades into the future, such as rates of economic and population growth, technological developments, and policy decisions. Climate models use as input different scenarios that represent a range of potential future greenhouse gas emissions. These scenarios are based on various actions that could be taken to reduce future emissions, such as particular policies initiated by the international community. For example, the *Climate Change Impacts and Risk Analysis* study used a scenario based on significant global action being taken to reduce future emissions.[30] The study does not specify what significant global action would cost the United States, or what it would entail, and such action may or may not occur.

According to literature we reviewed, another key source of uncertainty is how much global temperatures will rise in response to a change in carbon

[28]EPA officials stated that these models are not meant to provide "precise" estimates and focusing on the level of precision in the modeling results would reflect a misunderstanding of the purpose and use of such models. They said that models provide an indication of direction and relative magnitudes, not an absolute truth, and should be considered as one tool among many in the policymaker's toolbox. Rather than striving for precision, modelers aim to provide a robust characterization of uncertainty, according to these officials.

[29]National Academies, Committee on a National Strategy for Advancing Climate Modeling, Board on Atmospheric Studies and Climate, Division on Earth and Life Sciences; *A National Strategy for Advancing Climate Modeling*.

[30]Specifically, EPA compared a significant global action scenario representing emissions reductions with a business-as-usual emissions future. Although the *American Climate Prospectus* study analyzed the economic effects of several emissions reduction scenarios, it did not estimate the cost of those alternatives. Both studies acknowledged that emissions reductions costs were not considered and that this information can be found elsewhere.

dioxide concentrations, a factor known as climate sensitivity.[31] The climate models include assumptions about climate sensitivity that have an effect on the model results, with higher values for climate sensitivity resulting in greater warming for a particular level of emissions and therefore the potential for greater economic effects from climate change. Conversely, lower values of climate sensitivity would result in less warming for a particular level of emissions, and therefore the potential for lower economic effects from climate change. The *American Climate Prospectus* study incorporated a range of values for climate sensitivity in its analysis, and the *Climate Change Impacts and Risk Analysis* study generally used a single value to represent the sensitivity of the climate to rising greenhouse gas concentrations.[32]

## Limited Information on Which to Base Sector-Specific Models

The methods rely on limited information that can be used to model the relationships between climate and society, requiring assumptions about how society will respond to future changes in the climate. For example, some sector-specific models assume that historical observed relationships between weather events and economic output variables—such as between temperature and crop production—will represent the effects of long-term climate change. However, over the long time periods under which climate change is expected to occur, individuals, businesses, and government institutions may develop new approaches or technologies to adapt to climate change, lessening its economic effect. For example, one expert said that farmers may respond by making different crop choices. On the other hand, future climate change may have effects that are not revealed in historical events. According to one study, the likelihood that the climate will produce unprecedented effects—

[31]The Intergovernmental Panel on Climate Change (IPCC) defines climate sensitivity as the change in global mean surface temperature at equilibrium that is caused by a doubling of the atmospheric $CO_2$ concentration. In its 2013 Fifth Assessment Report, the IPCC estimated that the likely range for climate sensitivity is from 1.5 to 4.5 degrees Celsius. The report also indicated that a "best" estimate could not be determined.

[32]The *American Climate Prospectus* study incorporated the IPCC range in its analysis. According to EPA officials, the *Climate Change Impacts and Risks Analysis* study used climate sensitivity values from the IPCC's Fourth Assessment Report because the emissions scenarios were developed before the IPCC's Fifth Assessment Report. Specifically, the officials said that they assumed a climate sensitivity value of 3 degrees Celsius in its main analysis and a value of 6 degrees Celsius in a sensitivity analysis for selected economic sectors. Also, some of the underlying studies included estimates for different values of climate sensitivity.

for example, heat so extreme that it can induce heat stroke in healthy individuals—will increase as temperatures rise outside the realm of past human experience.

Similarly, data showing how populations will adapt to climate change are limited, so the methods use different assumptions about the extent to which society will adapt to climate change in different sectors. For instance, the *Climate Change Impacts and Risk Analysis* study assumed that for some sectors, such as agriculture, cost-effective adaptation actions will be taken, such as adjusting the type of crops grown in a region. For the coastal sector, the study considered four adaptation strategies: beach nourishment (adding sand), property elevation, shoreline armoring (using physical structures to protect from erosion), and property abandonment. However, for other sectors, such as the labor sector, the study did not take into account potential adaptation measures—such as using potential technological advances to reduce exposure—that could reduce future economic effects. The *American Climate Prospectus* study generally assumed that no adaptation would occur in response to climate change.[33] Also, the methods might not incorporate potential market inefficiencies. For example, in the *Climate Change Impacts and Risk Analysis*, the coastal sector analysis does not consider how subsidized insurance might affect adaptation actions. If insurance prices do not reflect actual risks—such as in the presence of insurance subsidies—insurance availability might disincentivize adaptation actions.

### Incomplete Coverage of Sectors, Interactions, and Impacts

The methods have not included all sectors because the U.S. economy is complex and the information available for different sectors and climate impacts varies. Typically, studies using the methods include sectors for which the most information about climate impacts and economic effects is available. For example, both the *American Climate Prospectus* and *Climate Change Impacts and Risk Analysis* studies selected sectors based on whether sufficient information and modeling methods were available for the sector and the potential for impacts in the sector to affect the country as a whole, among other things. In addition, the methods do not fully cover some of the sectors that are included. For example, the

[33]According to EPA officials, for several sectors, the study relied on the historical, observed relationship between weather variables and economic output. Implicitly, any historical adaptation response in the observations would be reflected in the analysis.

*American Climate Prospectus* study's analysis of the agricultural sector included the impacts of temperature and precipitation changes on the largest commodity crops—maize, wheat, soy, and cotton—but not on fruits, vegetables, nuts, or livestock, which dominate the agricultural sectors in some states.

Furthermore, the methods do not always capture interactions between sectors that may influence economic effects. Such interactions include the ability of capital and labor to move between sectors in the economy, potentially lessening the economic effects of climate change; the impact of changes in water supply on the cost of electric power generation; or the effects of an extreme event cascading throughout a region over time by redistributing the workforce or raising the cost of capital.[34]

Finally, the methods do not include potential impacts that fall outside of the market economy—such as the loss of species from ecosystem disruptions and threats to endangered historical or cultural monuments from rising sea levels or more intense storms—because many of these impacts are difficult to quantify in monetary terms.

## Challenges of Modeling over Long Time Frames

Modeling the effects of climate change is challenging because, among other things, it often involves projections over long periods into the future, and these projections become more uncertain over time. For example, the *American Climate Prospectus and Climate Change Impacts* and *Risk Analysis* studies both included projections of economic effects though the end of this century, but how the economy will evolve and how society may respond to climate changes over such time frames is inherently uncertain. As a result of this high degree of uncertainty, the methods require that modelers make assumptions about these factors. For example, the *American Climate Prospectus* study assumed that the structure of the U.S. economy would remain as it is today—an assumption the study notes is almost guaranteed to be wrong—and therefore provided a projection of the effect of potential climate changes through the end of this century on today's economy, as opposed to projecting these effects on the economy of the future. The *Climate Change Impacts and Risk Analysis* study made assumptions about future economic growth and

[34]Analyses that include economy-wide modeling can capture some market interactions between sectors.

labor productivity growth but did not report the sensitivity results associated with this and other key economic assumptions.

Challenges also arise with discounting future benefits and costs, particularly when modeling over long time frames. According to OMB, benefits or costs that occur sooner are generally more valuable than those that occur later. However, according to the literature reviewed and some experts interviewed, the appropriate discount rate to apply when considering benefits and costs across generations, such as those associated with climate change, is subject to much debate.[35] According to one of its authors, this debate was one reason why the *American Climate Prospectus* study did not present its estimates in discounted terms. For several sectors, the *Climate Change Impacts and Risk Analysis* study presented some estimates in discounted present value terms consistent with OMB and EPA guidance but presented undiscounted estimates of economic effects for all sectors for 2050 and 2100.[36] Nevertheless, climate change could have both positive and negative potential economic effects at different points in time in the future. Discounting is a way to account for differences in the timing of these effects.

As a result of the challenges of modeling over long time frames, economic analyses may assess the uncertainty in assumptions and data

[35]A discount rate is the interest rate used to convert benefits and costs occurring in different time periods to a common present value. OMB Circular A-4 states that for regulatory analysis federal agencies should provide estimates of net benefits and costs using both a 3 and 7 percent discount rate and, if the rule will have important intergenerational benefits or costs, the agency should consider a lower discount rate in addition to using the discount rates of 3 and 7 percent. OMB Circular A-4 is designed to assist regulatory agencies in conducting regulatory analysis and standardizing the way benefits and costs of federal regulatory actions are measured and reported. Neither the *American Climate Prospectus* study nor the *Climate Change Impacts and Risk Analysis* study was a regulatory analysis and therefore they were not subject to this guidance. Office of Management and Budget, *Regulatory Analysis,* OMB Circular A-4 (Washington, D.C.: Sept. 17, 2003).

[36]OMB Circular A-4 and Environmental Protection Agency, National Center for Environmental Economics, *Guidelines for Preparing Economic Analyses* (Washington D.C.: May 2014). Where the *Climate Change Impacts and Risk Analysis* study used present values, it used a single discount rate of 3 percent but did not analyze the sensitivity of the results to this selection. OMB Circular A-4 is designed to assist regulatory agencies in conducting regulatory analysis and standardizing the way benefits and costs of federal regulatory actions are measured and reported. EPA's *Guidelines for Preparing Economic Analyses,* among other things, explains how EPA implements OMB Circular A-4. Neither the *American Climate Prospectus* study nor the *Climate Change Impacts and Risk Analysis* study was a regulatory analysis and therefore they were not subject to this guidance.

used in making long-term projections. For example, according to one author, the *American Climate Prospectus* study provided ranges of estimated economic effects for each sector to help account for uncertainty associated with the underlying climate and economic models, such as uncertainty in climate sensitivity. The *Climate Change Impacts and Risk Analysis* study primarily reported results as point estimates, not providing a range of estimated effects, and reported on only a limited assessment of uncertainty.[37] The authors of the study further acknowledged that exploration of the uncertainties and limitations throughout the study, including the development of ranges for all impact projections, would strengthen the *Climate Change Impacts and Risk Analysis* study's results.

## Methods Can Convey Useful Insight into Broad Themes about Potential Climate Damages in the United States

Several experts we interviewed noted that even though the methods produce imprecise results, they can convey useful insight into broad themes about potential climate damages across sectors in the United States. For example, according to several experts we interviewed, these methods can provide valuable research information about the potential magnitude of economic effects and potential areas of greatest concern, including where assets may be at greatest risk. Some other experts told us that using the methods can help identify areas where additional research would be most useful. Finally, another expert said that exploring differences among the results from various models and scenarios can help researchers explore and better understand some of the factors that drive the potential economic effects of climate change.

Recent and emerging research could produce additional insight and begin to address some of the limitations of the methods, including those related to incomplete coverage of sectors and climate impacts, according to

[37]According to EPA officials, the *Climate Change Impacts and Risk Analysis* study was designed to investigate the relative importance of four key sources of uncertainty regarding physical climate science: (1) future greenhouse gas emissions growth, (2) climate sensitivity, (3) natural variability, and (4) climate model selection. Because process-based sectoral impact models can be computationally demanding to run, the *Climate Change Impacts and Risk Analysis* study first assessed the degree to which each of these four sources of uncertainty could influence future climate outcomes in the United States. The results of this screening analysis were then used to inform the selection of scenarios and uncertainty sources simulated in the impact models and described in the 2015 summary study. According to EPA officials, the journal papers underlying the study reported a broader evaluation of uncertainty for most sectors.

some experts we interviewed. For example, a new study published in June 2017 by almost all of the same authors of the *American Climate Prospectus* study and others expands on the research of the A*merican Climate Prospectus* study and provides additional insight into the potential economic effects of climate change in particular sectors and regions of the United States by examining county-level effects.[38] In addition, since the 2015 *Climate Change Impacts and Risk Analysis* summary study was published, EPA has expanded the research project to enhance the analysis of sectors covered in the 2015 report; expand analyses of adaptation for some of these sectors; and include additional sectors such as winter recreation, Alaskan infrastructure, and rail. According to EPA officials involved in the study, they plan to publish a study summarizing these new modeling analyses, estimating impacts across 24 sectors in conjunction with the Fourth National Climate Assessment.

# National-Scale Studies and Experts Suggested That Potential Economic Effects of Climate Change in the United States Could Be Significant and Unevenly Distributed

The two national-scale studies—the A*merican Climate Prospectus* and the *Climate Change Impacts and Risk Analysis*—and many of the experts we interviewed suggested that although the methods are developing and produce imprecise results, the potential economic effects of climate change could be significant in many sectors across the U.S. economy and unevenly distributed across U.S. sectors and regions.

## National-Scale Studies and Experts Suggested That Potential Economic Effects of Climate Change in the United States Could Be Significant

The national-scale studies and many experts we interviewed suggested that climate change could result in significant economic effects in the United States, and the studies indicated that these effects will likely

[38]Hsiang et al., "Estimating Economic Damage from Climate Change in the United States." According to EPA officials, this study represents a major advance in the field by, for example, constructing spatially explicit, probabilistic, and empirically derived estimates of economic damages in the United States resulting from climate change.

increase over time for most of the sectors analyzed. As shown in table 1, the *American Climate Prospectus* study estimated net costs in the near term for most of the five sectors analyzed and net costs by the end of the century for almost all of the six sectors analyzed. For example, the study projected potential economic costs from climate change impacts such as damage to coastal property from storms, decreases in labor supply from higher temperatures, and increases in energy expenditures for air conditioning. The study estimated that the likely combined direct economic effects of the six sectors could reach 0.7 to 2.4 percent of the U.S. gross domestic product per year by the end of this century.[39]

**Table 1: Economic Effects of Climate Change in the United States Reported by the *American Climate Prospectus* Study**

Dollars in billions

Annual projected economic effects of climate change with no additional emissions reductions within different time periods[a] (positive values indicate costs and negative values indicate benefits)

| Sector | Climate change impacts measured | 2020-2039 | 2040-2059 | 2080-2099 |
|---|---|---|---|---|
| Health | Changes in temperature-related mortality costs based on the value of statistical life | Not reported | -12 to 161 | 90 to 506 |
| | Lost lifetime labor supply from changes in temperature-related mortality | Not reported | 3.4 to 14 | 13 to 41 |
| Labor | Changes in labor productivity from lost work hours | 0.1 to 22 | 10 to 52 | 42 to 150 |
| Coastal communities | Storm losses from sea level rise, changes in the intensity and frequency of storms, and increase in inundation | Not reported | Not reported | 59 to 89 |
| | Storm losses from sea level rise and changes in the frequency and intensity of storms | 4 to 6 | 13 to 23 | 51 to 74 |
| | Storm losses from sea level rise | 2 to 3.7 | 6 to 12 | 18 to 27 |
| Energy | Increase in average annual energy expenditures from increased energy demand | 0.5 to 11 | 8.3 to 29 | 32 to 87 |
| Agriculture | Change in crop yields from changes in temperature, precipitation, and carbon dioxide fertilization | -8.5 to 9.2 | -8.2 to 19 | -12 to 53 |

[39]The *American Climate Prospectus* study included a macroeconomic analysis described by the authors as "a conceptual exercise" using a CGE model to explore how direct impacts in individual sectors or regions may affect other regions. For example, a decrease in agricultural output in Iowa can affect food prices nationwide. When considering some of these macroeconomic effects, the study reports combined economic effects from climate change from 1.0 to 3.0 percent of gross domestic product.

| Sector | Climate change impacts measured | 2020-2039 | 2040-2059 | 2080-2099 |
|---|---|---|---|---|
| Crime | Change in direct property and violent annual crime costs associated with increased temperature[b] | 0 to 2.9 | 1.5 to 5.7 | 5.0 to 12 |

Source: GAO presentation of Rhodium Group results. | GAO-17-720

Note: The *American Climate Prospectus* study was produced by the Rhodium Group in 2014 to assess the economic effects of potential climate changes on different sectors of the U.S. economy and regions of the country. According to the study, these estimates are intended to provide information on the probability, timing, and scope of climate impacts, rather than provide a definitive estimate of climate change costs in the United States. Rhodium Group, LLC., *American Climate Prospectus: Economic Risks in the United States* (New York: October 2014).

[a]These results were based on comparison of a scenario in which no policies are enacted to reduce global greenhouse gas and assumed that these emissions will continue to rise along current trajectories, with a scenario in which future climate conditions are unchanged relative to those in 2012. The estimates are presented in real 2011 dollars. Office of Management and Budget guidance for conducting benefit-cost analyses of federal programs states that benefits and costs expected to occur in the future should be discounted to account for the time value of money—the concept that benefits and costs that occur sooner are more valuable. According to an *American Climate Prospectus* study author, the authors of the study did not discount the results, in part, because the selection of a rate is subject to debate. The author also noted that in discounting the results, one would have to account for projected economic growth, which could increase the numbers.

[b]According to the *American Climate Prospectus* study, other studies have found that individuals are more likely to exhibit aggressive or violent behavior toward others if temperatures are higher.

In all sectors analyzed, estimated net economic costs increased over time, becoming greater by late in the century. Specifically, for all sectors that have net economic costs at the lower and upper bounds of the likely ranges of economic effects, the study indicated a projected increase from about two to four times from mid-century to late century. For example, the study estimated that coastal property losses from sea level rise and increases in the frequency and intensity of storms could range from $4 billion to $6 billion per year in the near term (i.e., 2020 through 2039), increasing to a range of $51 billion to $74 billion per year by late century. According to several experts we interviewed, the estimates presented in the study are not precise and may be underestimated because the study did not quantify all known climate impacts.[40]

While the results of the *Climate Change Impacts and Risk Analysis* study cannot be directly compared with those of the *American Climate Prospectus* study, the *Climate Change Impacts and Risks Analysis* study also suggested that climate change could have significant economic effects on several of the economic sectors analyzed, and that those

[40]For example, the study does not include: (1) all potential effects within the included market impacts; (2) interactions between impacts; (3) some nonmarket impacts, such as ocean acidification; and (4) effects on international trade and security.

effects would increase by the end of the century.[41] The results of this study, shown in table 2, were primarily presented in terms of the benefits associated with significant global action to reduce greenhouse gas emissions.[42]

**Table 2: Economic Effects of Significant Global Emissions Reductions in the United States Reported by the *Climate Change Impacts and Risk Analysis* Study**

Dollars in billions

Annual economic effects from emissions reductions[a]
(positive values indicate benefits and negative values indicate costs)

| Sector | Climate change impacts measured | 2050 | 2100 |
|---|---|---|---|
| Health | Value of avoided deaths from poor air quality | 160 | 930 |
| | Value of avoided deaths from extreme heat and cold in 49 major U.S. cities | 21 | 200 |
| | Value of avoided loss of labor hours | 18 | 110 |
| | Avoided damages from poor water quality | 0.507 to 0.700 | 2.6 to 3.0 |
| Infrastructure | Value of fewer bridges made structurally vulnerable | 0.12 to 1.5 | 1.1 to 1.6 |
| | Avoided adaptation costs for roads | 0.56 to 2.3 | 4.2 to 7.4 |
| | Avoided adaptation costs for urban drainage in 50 cities | 0.056 to 2.9 | 0.050 to 6.4 |
| | Avoided damages and adaptation costs for coastal property from sea level rise and storm surge | 0.14 | 3.1[b] |
| Electricity | Savings in power system costs from changes in energy demand | 10 to 34 | Not estimated |
| Water resources | Avoided damages from changes in inland flooding | -0.260 to 0.230 | -0.032 to 2.5 |
| | Avoided damages to the agriculture sector from drought | 1.2 to 1.4 | 2.6 to 3.1 |
| | Avoided damages because of water shortages | 3.9 to 54 | 11 to 180[c] |
| Agriculture and forestry | Avoided agriculture damages | 1.5 to 3.8 | 6.6 to 11 |
| | Avoided forestry damages | -9.6 to -9.5 | 0.520 to 1.5 |

[41]The *American Climate Prospectus* and the *Climate Change Impacts and Risk Analysis* studies are not directly comparable because their analyses are based on different greenhouse gas emissions scenarios, compared to different baselines. Specifically, the primary results reported in the *American Climate Prospectus* study are calculated using different trajectories of greenhouse gas emissions, compared to a baseline of the climate in 2012. The primary results of the *Climate Change Impacts and Risk Analysis* study are calculated using a greenhouse gas emissions scenario that would require significant global emissions reductions, compared to a baseline current trajectories of greenhouse gas emissions.

[42]The study did not estimate the potential costs of significant global action to reduce greenhouse gas emissions, noting that such costs were well-examined elsewhere in the literature.

| Sector | Climate change impacts measured | 2050 | 2100 |
|---|---|---|---|
| Ecosystems | Avoided losses of coral reefs in Hawaii, Florida, and Puerto Rico | 1.4 | 1.2 |
| | Benefits to consumers from avoided loss of shellfish supply | 0.085 | 0.380 |
| | Avoided damages from changes in recreational freshwater fishing | -0.0038 to 0.013 | 0.095 to 0.280 |
| | Avoided wildfire response costs | 0.160 to 0.390 | 0.940 to 1.4 |

Source: GAO presentation of Environmental Protection Agency (EPA) results. | GAO-17-720

Note: The Climate Change Impacts and Risk Analysis, an ongoing EPA project, published a 2015 summary study entitled *Climate Change in the United States: Benefits of Global Action*, to assess the extent to which reducing global greenhouse gas emissions may help avoid or reduce climate change impacts and adverse economic effects to multiple U.S. sectors. According to the study, these results are intended to provide insight into the potential direction and magnitude of climate change impacts to the United States, rather than provide definitive predictions of future impacts at a particular place or time.

[a]These estimates represent the projected benefits of a global greenhouse gas emissions reduction policy representing "significant global action," relative to current policies in which greenhouse gas emissions will increase along current trajectories. None of the estimates consider the costs of global greenhouse gas emissions reductions. In addition, the estimates are presented in 2014 dollars; the annual estimates presented here are not discounted. Also, for some of the sectors analyzed—such as coastal infrastructure and roads and bridges—the study assumed that some measures to adapt to climate change would be taken. The analyses for other sectors assumed no adaptation. Finally, the study reported point estimates for several of the sectors analyzed because EPA did not conduct a robust sensitivity analysis of the effect of underlying assumptions and data on the estimates. For additional details on the analysis, see https://www.epa.gov/cira.

[b]Using a scenario without emissions reductions, the study projected $5.0 trillion in damages to coastal property through 2100 (discounted at 3 percent).

[c]Using a scenario without emissions reductions, the study projected $7.7 billion to $190 billion in damages associated with the supply and demand of water across the United States.

According to EPA officials involved in the study, the results highlighted sectors with potentially higher economic effects of climate change. For some sectors, the study estimated the costs of climate changes without any emissions reductions. For example, the study reported $5.0 trillion in economic costs to coastal property from climate change through 2100 (discounted at 3 percent).[43] However, the study did not explain how these estimated costs were obtained, and these estimated costs did not match

[43]The authors of the study reported that this estimate is based on the assumption that no adaptation measures are taken to protect coastal infrastructure from the effects of climate change. In addition, the results of the coastal infrastructure analysis were only presented for a time frame that might not capture the benefits of emissions reductions on sea level rise, the methodology did not allow for feedback between adaptation actions and property values (e.g., the model for the coastal sector did not allow for any potential effects that the adaptation actions themselves might have on property values), and the distributional analysis did not account for storm surge. In addition, only a limited number of adaptation strategies were considered.

those reported in the underlying journal papers.[44] EPA officials told us that the scenario that led to this estimate was added as a result of reviewer comments.

## National-Scale Studies and Experts Interviewed Suggested That the Potential Economic Effects of Climate Change Could Be Unevenly Distributed across Sectors and Regions

According to the two national-scale studies and several experts we interviewed, potential economic effects could be unevenly distributed across sectors and regions. First, the studies and some experts suggested that climate change will affect certain sectors more than others. The results of the *American Climate Prospectus* study suggested that nationwide economic effects on sectors, including human health, labor, coastal infrastructure, and energy, could exceed the economic effects on the agriculture and crime sectors. The factors driving the economic effects on the health, labor, coastal infrastructure, and energy sectors included costs associated with, respectively, (1) an increase in premature mortality from higher temperatures, (2) reduced number of hours worked because of high temperatures, (3) infrastructure damage from increased flooding and storm surge, and (4) increased energy demand. In the near term, the annual sector-specific economic effects reported in this study for 2020 through 2039 varied from a range of $8.5 billion in benefits to $9.2 billion in costs for the agriculture sector up to a range of $0.1 billion to $22 billion in costs from changes in labor productivity. In the long term, for 2080 through 2099, the annual sector-specific economic effects reported in this study varied from a range of $12 billion in benefits to $53 billion in costs for the agriculture sector up to a range of $90 billion to $506 billion in mortality costs for the health sector.

[44]EPA officials stated that the differences in results between the 2015 summary study and underlying method papers were primarily based on the use of different base years, dollar years, and discounting. EPA officials also stated that (1) minor modeling modifications (e.g., changes to the extrapolation of storm surge hydraulic relationships between sample sites and updated construction cost data) were made to the national coastal property model in response to comments from peer reviewers of the 2015 summary study, (2) updates were made after the underlying papers were submitted to the respective journals but prior to finalizing the 2015 summary study, and (3) all results were verified during quality control checks and subject to external and independent peer reviews.

The *Climate Change Impacts and Risk Analysis* study suggested that the benefits from emissions reductions would affect some sectors more than others. For example, among the sectors analyzed, the study reported that emissions reductions would generate relatively larger effects in 2050 for sectors relating to human health, water resources, and electric power.[45] The factors driving the estimated economic effects in this study included lost labor hours and premature mortality from poor air quality and extreme heat in the health sector, costs to water users—such as domestic and industrial water users—when sufficient water is not available, and costs to expand power system capacity in the energy sector.

Another difference in the economic effects across different sectors identified in the studies is that adaptation actions can reduce the negative economic effects of climate change in particular sectors, according to the national-scale studies and several experts we interviewed. For example, the *Climate Change Impacts and Risk Analysis* study reported that protective adaptation measures—such as beach nourishment, property elevation, shoreline armoring, and property abandonment—can reduce projected coastal property damage in the contiguous United States.[46] In addition, some experts we interviewed said that adaptation actions in coastal areas can be cost effective. However, according to the studies and some experts, information on the cost-effectiveness of adaptation actions in many other sectors remains limited.

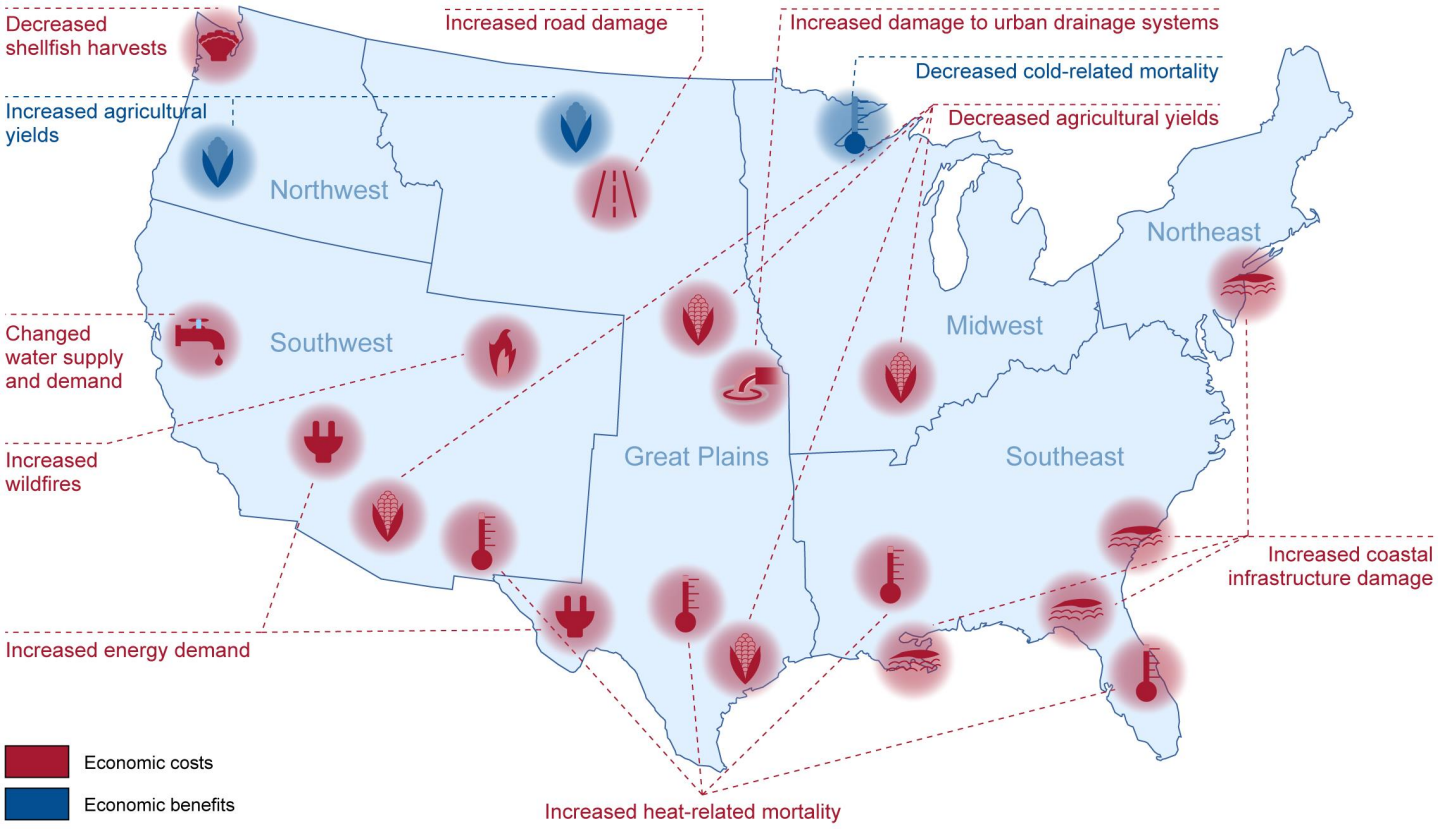
With regard to variation across regions, the studies suggested that the economic effects of climate change could be more significant in some geographic areas than others. For example, the *American Climate Prospectus* study reported that depending on the specific climate impacts evaluated, the combined direct net economic effects for each state could

[45]The study also reported the largest benefits in emissions reductions for the health and water resources sectors in 2100 but did not report a value for the electricity sector in 2100.

[46]The *Climate Change Impacts and Risk Analysis* study reported that certain protective adaptation measures could reduce projected coastal property damages in the contiguous United States from an estimated $5.0 trillion to $810 billion. As we previously mentioned, the study does not explain how the $5.0 trillion estimate was obtained. The study also does not explain how the $810 billion estimate was obtained. EPA officials told us that the difference with regard to the underlying journal papers cited as sources was due to using different base years to compute dollar estimates, among other factors. EPA officials also stated that underlying studies have always been intended to serve as the methodological basis for the modeling analyses, not a repository of results and that all results were verified during quality control checks and subject to external and independent peer reviews.

range from annual benefits of 0.8 to 4.5 percent of economic output in Vermont to annual costs of 10.1 to 24 percent of current economic output in Florida by the end of the century. In the Tampa Bay, Florida, area alone, the *Climate Change Impacts and Risk Analysis* study estimated that damage to coastal property from sea level rise and storm surge could reach $2.8 billion per year by 2100.[47] Figure 2 shows examples of potential economic effects in different U.S. geographic areas.

**Figure 2: Examples of Potential Economic Effects from Climate Change by 2100**




Sources: GAO analysis of Environmental Protection Agency, *Climate Change Impacts in the United States: Benefits of Global Action* (Washington, D.C.: 2015), and Solomon Hsiang et al., "Estimating Economic Damage from Climate Change in the United States," *Science*, vol. 356 (2017); Map Resources (map). | GAO-17-720

Note: Examples are shown in approximate locations and do not reflect the relative magnitudes of potential economic effects.

[47]This estimate is based on a scenario using current greenhouse gas emissions trajectories and assumes no adaptation measures will be implemented.

According to the *American Climate Prospectus* study, the Southeast, Midwest, and Great Plains regions will likely experience greater combined economic effects than other regions, largely because of coastal property damage in the Southeast and changes in crop yields in the Midwest and Great Plains.[48] The *Climate Change Impacts and Risk Analysis* study also reported economic effects in particular regions. For instance, according to the study, ocean acidification in the Pacific Northwest is already affecting shellfish harvests, which the study projected could decline by 32 to 48 percent by the end of the century in a scenario without emissions reductions. In addition, under the same scenario, the study estimated that wildfires could burn an additional 1.9 million acres annually in the Rocky Mountains by the end of the century, compared to today, which would significantly increase wildfire response costs. Some experts noted the importance of considering the economic effects of climate change in specific sectors and regions because nationwide estimates can average out some important differences. For example, in the agricultural sector, climate change could cause economic benefits in northern regions of the country from moderate warming, which could offset some agricultural economic losses from more extreme heat in southern regions.

## According to Leading Practices and Experts, Information on the Potential Economic Effects of Climate Change Could Help Decision Makers Better Manage Climate Risks

Information on the potential economic effects of climate change could help federal decision makers better manage climate risks, according to leading practices for climate risk management and economic analysis we reviewed and the views of several experts we interviewed. Several experts we interviewed said that existing information on the potential economic effects of climate change could help federal decision makers identify significant climate risks to the federal government. Further, additional economic information could help federal, state, local, and private sector decision makers manage climate risks that drive federal fiscal exposure.

[48]The study estimated that the economic effects on these regions from unmitigated emissions growth would range from less than 1 percent to about 6 percent of output, depending on the region and model used.

## Existing Information on Potential Economic Effects Could Help Identify Significant Climate Risks to the Federal Government

Even though existing information on the potential economic effects of climate change, such as that from the two national-scale studies, is imprecise, it is a first step toward effective climate risk management at the federal level. Several experts we interviewed said federal decision makers could use the insight this information provides about economic damages in various sectors or regions for different scenarios. Along with other available information about current and future climate risks, collectively this information could start informing federal decision makers about climate risks in different sectors and identifying areas of high fiscal exposure. For example, several experts we interviewed said that existing research indicates that infrastructure in coastal areas faces high financial risks relative to the risks posed to many other sectors or geographic regions. In addition, according to some experts we interviewed, projections about adverse economic effects in coastal areas, when considered with other information—for example, disaster costs already incurred such as the approximately $50 billion appropriated for recovery from Hurricane Sandy—could help decision makers better understand the potential magnitude of risks to coastal areas and identify vulnerable coastal infrastructure as a source of potentially high fiscal exposure.

Such a first step in risk assessment is consistent with leading practices for climate risk management and federal standards for internal control.[49] The National Academies' 2010 leading practices state that managing risk in the context of climate change involves using the best information, including economic information, to assess risks and determine priorities for managing them. Further, in its 2010 report, the National Academies concluded that an iterative process—in which decisions are based on an evolving understanding of the underlying natural and social science—can improve decisions related to climate change risk management because of the opportunities it offers for considering uncertainty. This is consistent with what we reported in December 2016—that the first steps in developing enterprise risk management involve identifying and assessing

[49]National Research Council of the National Academies, America's Climate Choices: Panel on Adapting to the Impacts of Climate Change, *Adapting to the Impacts of Climate Change* and GAO, *Standards for Internal Control in the Federal Government*, GAO-14-704G (Washington, D.C.: September 2014).

risks to understand the likelihood of impacts and their associated consequences.[50] As we found in that report, federal managers often handle complex and risky missions, such as preparing for and responding to natural disasters and building and managing safe transportation systems. While it is not possible to eliminate all uncertainties associated with these missions, risk management strategies exist to help federal managers anticipate and manage risks. In addition, under federal standards for internal control, management—in this case, the federal government—should identify, analyze, and respond to risks related to achieving the defined objectives. For example, management estimates the significance of a risk by considering the magnitude of impact, likelihood of occurrence, and nature of the risk—which provides a basis for responding to the risks—and management may need to conduct periodic risk assessments.[51]

Our past work and the work of others have reported that climate change impacts and their economic effects have already cost the federal government money and pose future risks that could lead to increased federal fiscal exposure.[52] As we concluded in our October 2009 report, given the potential magnitude of climate change and the lead time needed to adapt, preparing for these impacts now may reduce the need

[50]As we found in our December 2016 report, once risks are identified and analyzed, the next steps in the enterprise risk management process include planning risk responses and making decisions. GAO, *Enterprise Risk Management: Selected Agencies' Experiences Illustrate Good Practices in Managing Risks*, GAO-17-63 (Washington, D.C.: Dec. 1, 2016).

[51]GAO-14-704G. The federal standards for internal control apply across the federal government and provide agencies the overall framework for establishing and maintaining effective internal controls, a key factor in improving accountability in achieving an entity's mission.

[52]In particular, climate change impacts call attention to areas where government-wide action is needed to reduce fiscal exposure. Specifically, our High-Risk List framework for Limiting the Federal Government's Fiscal Exposure by Better Managing Climate Change Risks outlines five areas where action is needed: (1) strategic plan that coordinates federal efforts and informs state, local, and private sector action; (2) defense facilities and federal property; (3) federal flood and crop insurance programs; (4) data and technical assistance to federal, state, local, and private sector decision makers; and (5) disaster aid. Criteria for removing this issue from the High-Risk List include demonstrating leadership commitment that is sustained and enhanced to address all aspects of the federal fiscal exposure to climate change cohesively. See, for example, GAO-14-446; GAO, *Federal Emergency Management Agency: Opportunities Exist to Strengthen Oversight of Administrative Costs for Major Disasters,* GAO-15-65 (Washington, D.C.: Dec. 17, 2014); and Office of Management and Budget, *Climate Change: The Fiscal Risks Facing the Federal Government.*

for far more costly steps in the decades to come.[53] For example, we reported in our February 2013 High-Risk update that federal disaster aid functions as the insurance of last resort in certain circumstances, increasing the federal government's fiscal exposure to a changing climate.[54] We also reported in December 2014 that from fiscal years 2004 through 2013, the Federal Emergency Management Agency obligated about $95 billion in federal disaster assistance for 650 major disasters declared during this time frame.[55] Then, in July 2015, we reported that the federal government does not adequately plan for disaster resilience and that most federal funding for hazard mitigation is available after a disaster.[56]

Even with the magnitude of these disaster recovery costs, the federal government does not have government-wide strategic planning efforts in place to help set clear priorities for managing significant climate risks before they become federal fiscal exposures. The federal government has not undertaken strategic, government-wide planning to manage climate risks, using the best available information, including information on the potential economic effects of climate change, to identify and assess significant risks. In May 2011, we found that a government-wide strategic planning process could enhance how priorities for an overall federal response to climate change are set and recommended that the Executive Office of the President establish federal strategic climate change

[53]GAO, *Climate Change Adaptation: Strategic Federal Planning Could Help Government Officials Make More Informed Decisions,* GAO-10-113 (Washington, D.C.: Oct. 7, 2009).

[54]GAO-13-283.

[55]While not all of these disasters can be attributed to climate change, as discussed, USGCRP reported that the impacts and costliness of weather disasters will increase in significance as what are considered rare events become more common and intense because of climate change. See GAO-15-65 and Melillo, Richmond, and Yohe, *Climate Change Impacts in the United States: The Third National Climate Assessment.*

[56]For example, from fiscal years 2011 to 2014, the Federal Emergency Management Agency obligated more than $3.2 billion for the Hazard Mitigation Grant Program for post-disaster hazard mitigation while obligating approximately $222 million for the Pre-Disaster Mitigation Grant Program. GAO, *Hurricane Sandy: An Investment Strategy Could Help the Federal Government Enhance National Resilience for Future Disasters,* GAO-15-515 (Washington, D.C.: July 30, 2015).

priorities.[57] The Executive Office of the President has not implemented this recommendation. Later, in July 2015, we found that the federal government had no comprehensive, strategic approach to identifying, prioritizing and implementing investments for disaster resilience.[58] This report concluded that a strategy to guide federal investments in disaster resilience could result in more effective returns on these investments. Building disaster resilience can include taking actions to adapt to the effects of climate change, as we found in May 2016.[59]

In addition, in our February 2015 High-Risk update, we reported that federal officials do not have a shared understanding of strategic government-wide priorities related to climate change, which along with other issues, limits the federal government's ability to manage climate risks.[60] In February 2017, we found that federal agencies had undertaken various strategic planning efforts, but it was unclear how they related to each other or whether they amounted to a government-wide approach for reducing federal fiscal exposures.[61] Subsequently, a March 2017 Executive Order rescinded some of these planning efforts and created uncertainty about whether other planning efforts would continue or take their place.[62]

The National Academies' 2010 leading practices state that climate change risk management efforts need to be focused where immediate

[57]GAO, *Climate Change: Improvements Needed to Clarify National Priorities and Better Align Them with Federal Funding Decisions,* GAO-11-317 (Washington, D.C.: May 20, 2011). Entities within the Executive Office of the President—such as the Council on Environmental Quality, Office and Management and Budget, and Office of Science and Technology Policy—work together to ensure that federal climate change activities are guided by the latest climate science.

[58]GAO-15-515.

[59]GAO, *Climate Change: Selected Governments Have Approached Adaptation through Laws and Long-Term Plans*, GAO-16-454 (Washington, D.C.: May 12, 2016).

[60]GAO-15-290.

[61]GAO-17-317. Such strategic planning efforts include the June 2013 Climate Action Plan, the March 2015 Executive Order 13693 on Planning for Federal Sustainability in the Next Decade, and an October 2016 report by the interagency Council on Climate Preparedness and Resilience.

[62]Specifically, Executive Order 13783 rescinded the Climate Action Plan and revoked the executive order establishing the Council on Climate Preparedness and Resilience. Although Executive Order 13693 has not been revoked, it is uncertain whether the agency adaptation plans and other strategic planning efforts it calls for will continue.

attention is needed and that, by prioritizing federal climate risk management activities well, the federal government can help to minimize negative impacts and maximize opportunities associated with climate change.[63] In addition, most experts we interviewed told us that federal decision makers should prioritize risk management efforts on significant climate risks that create the greatest fiscal exposure. By using information on the potential economic effects of climate change to assess and identify significant climate risks and craft appropriate federal responses, the federal government could take an initial step in establishing government-wide priorities to manage significant climate risks, which we recommended in May 2011 to reduce federal fiscal exposure and continue to believe is important.[64] This initial step could include establishing a strategy to identify, prioritize, and guide federal investments to enhance resilience against future disasters, as we recommended in July 2015.[65]

To achieve the ultimate objective of establishing government-wide priorities, decision makers need information on policy alternatives that are representative of all available alternatives and their economic effects, such as benefits and costs. The authors of the *American Climate Prospectus* study highlighted, for instance, that national decision makers must weigh the potential economic and social impacts of climate change against the costs of policies to reduce emissions or make our economy more resilient. Further, EPA officials stated that using information from national-scale economics reports to make policy choices would involve a number of intermediate analytical steps, including (1) estimating the federal risk exposure from the national or regional estimates, (2) identifying policy options, and (3) analyzing the costs and benefits of those options. The relevant point for decision makers, according to these EPA officials, is that multisector, national estimates of climate damages can be made available for use, though additional analysis may be needed for specific policy actions.

[63]National Research Council of the National Academies, America's Climate Choices: Panel on Adapting to the Impacts of Climate Change, *Adapting to the Impacts of Climate Change*.

[64]GAO-11-317.

[65]GAO-15-515.

## Additional Information on Potential Economic Effects Could Help Decision Makers' Efforts to Manage Climate Risks

A strategy to identify, prioritize, and guide federal investments to enhance resilience against future disasters could include additional information on the economic effects of climate change. Such economic information could help inform future efforts by federal, state, local, and private sector decision makers to manage climate risks, according to a 2010 National Academies report, our prior work, literature we reviewed, and several experts we interviewed. The 2010 National Academies report, literature we reviewed, and several experts we interviewed noted that to make informed adaptation choices, decision makers need more comprehensive information on economic effects to better understand the potential costs of climate change to society and begin to develop an understanding of the benefits and costs of different adaptation options. In addition, economic guidance generally states that investment decisions—which would include decisions about adaptation investments—should be informed by a consideration of both benefits and costs of relevant alternatives. For example, OMB has issued guidance on using benefit-cost analyses to help federal agencies efficiently allocate resources through well-informed decision making. This guidance includes OMB Circular A-94, which directs agencies to follow certain economic guidelines for benefit-cost and cost-effectiveness analyses of federal programs or policies to promote efficient resource allocation through well-informed decision making in certain circumstances.[66]

The *American Climate Prospectus* study also recognized the importance of balancing benefits and costs, stating that national policy makers must weigh the potential economic and social impacts of climate change against the cost of the policies to manage climate risks. When it comes to managing climate risks through adaptation, the literature we reviewed and several experts we interviewed noted that a full understanding of the

[66]Office of Management and Budget, *Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs*, OMB Circular A-94 (Washington, D.C.: Oct. 29, 1992). These guidelines apply, with limited exception, to any analysis used to support government decisions to initiate, renew, or expand programs or projects that would result in a series of measurable benefits or costs extending for 3 or more years into the future. The circular applies specifically to: (1) benefit-cost or cost-effectiveness analysis of federal programs or policies, (2) regulatory impact analysis, (3) analysis of decisions on whether to lease or purchase; and (4) asset valuation and sale analysis.

adaptation alternatives would require information on the economic effects of climate change impacts, how adaptation may lessen some of these effects, and the costs of adaptation.

In our 2013 High-Risk update, we reported that the federal government has a role to play in providing information to decision makers so they can make better choices about adapting to climate change since their decisions can drive federal fiscal exposure.[67] Moreover, we found in our 2015 High-Risk update that state, local, and private sector decision makers drive federal climate-related fiscal exposures because they are responsible for planning, constructing, and maintaining certain types of vulnerable infrastructure paid for with federal funds, insured by federal programs, or eligible for federal disaster assistance.[68] Therefore, federal efforts to provide information to these decision makers could help them make more informed choices about how to manage climate risks, ultimately helping to reduce federal fiscal exposure. In our November 2016 report, we reported that these decision makers need climate information—including economic information—that represents the best available information and is updated over time.[69]

Some experts we interviewed noted that emerging research—which includes updates to the national-scale studies of the economic effects of climate change—will help fill information gaps. Recognizing that decision makers need more comprehensive economic information to manage climate risks, the National Academies recommended in 2016 that USGCRP integrate social, behavioral, and economic science into the National Climate Assessment to support decision-making processes.[70] EPA officials told us that, as a step toward this integration, the agency's updates to the *Climate Change Impacts and Risk Analysis* project advance the understanding of economic effects of climate change. The officials said that this information is documented in new analyses serving as input to the next National Climate Assessment. While several experts we interviewed noted that information on the economic effects of climate

[67]GAO-13-283.

[68]GAO-15-290.

[69]GAO, *Climate Information: A National System Could Help Federal, State, Local, and Private Sector Decision Makers Use Climate Information,* GAO-16-37 (Washington, D.C.: Nov. 23, 2015).

[70]National Academies, *Review of the U.S. Global Change Research Program's Update to the Strategic Plan Document*.

change is currently relatively sparse, they also said that new information is still emerging.

## Conclusions

Climate change impacts are already costing the federal government money, and these costs will likely increase over time as the climate continues to change. Even though existing information on the potential economic effects of climate change, such as that from the two national-scale studies, is imprecise, it could help identify significant potential damages for federal decision makers—an initial step in the process for managing climate risks. Under the National Academies' 2010 leading practices, climate change risk management efforts need to be focused on where immediate attention is needed, and by prioritizing federal climate risk management activities well, the federal government can help to minimize negative impacts and maximize opportunities associated with climate change. The 2010 National Academies report, literature we reviewed, and several experts we interviewed noted that to make informed adaptation choices, decision makers need more comprehensive information on economic effects to better understand the potential costs of climate change to society and begin to develop an understanding of the benefits and costs of different adaptation options. By using information on the potential economic effects of climate change to help identify significant climate risks and craft appropriate federal responses—such as establishing a strategy to guide federal investment to enhance resilience against future disasters—the federal government could take an initial step in establishing government-wide priorities to manage significant climate risks. To help prioritize and guide federal investments, such a strategy could include developing more comprehensive information on the potential benefits and costs of different adaptation options.

## Recommendation for Executive Action

We are making the following recommendation to the Executive Office of the President:

The appropriate entities within the Executive Office of the President, including the Council on Environmental Quality, Office and Management and Budget, and Office of Science and Technology Policy, should use information on the potential economic effects of climate change to help identify significant climate risks facing the federal government and craft

appropriate federal responses. Such responses could include establishing a strategy to identify, prioritize, and guide federal investments to enhance resilience against future disasters. (Recommendation 1)

## Agency Comments

We provided a draft of this report for review and comment to the Council on Environmental Quality, the Office of Science and Technology Policy, and EPA. The Council on Environmental Quality and the Office of Science and Technology Policy did not provide comments. EPA did not provide written comments on our findings and recommendation but instead provided technical comments, which we incorporated as appropriate.

As agreed with your offices, unless you publicly announce the contents of this report earlier, we plan no further distribution until 30 days from the report date. At that time, we will send copies to the Director of the Office of Science and Technology Policy, the Director of the Council on Environmental Quality, and the Administrator of the Environmental Protection Agency. In addition, the report will be available at no charge on the GAO website at http://www.gao.gov.

If you or your staff have any questions about this report, please contact J. Alfredo Gómez at (202) 512-3841 or gomezj@gao.gov or Oliver Richard at (202) 512-2700 or richardo@gao.gov. Contact points for our Offices of

Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix II.

J. Alfredo Gómez
Director, Natural Resources and Environment

Oliver Richard
Director, Applied Research and Methods

# Appendix I: Objectives, Scope, and Methodology

In this report, we examine (1) what is known about methods used to estimate the potential economic effects of climate change in the United States; (2) what is known about the potential economic effects of climate change in the United States; and (3) to what extent have leading practices and experts found that information about the potential economic effects of climate change could inform efforts to manage climate risks across the federal government.

To address our audit objectives, we conducted a literature search for studies that (1) described the methods used to develop estimates of the economic effects of climate change in the United States and (2) produced estimates of such effects at a national scale, across different sectors and regions. We targeted the literature search to studies that were published in 2005 or later to encompass the 10 years of research preceding the start of our work. We identified relevant studies though three efforts: (1) searching literature databases, including Scopus, Web of Science, EBSCO, ProQuest, PolicyFile, and OCLC databases; (2) referrals from experts we interviewed during semistructured interviews (a discussion of these interviews is included below); and (3) reviewing citations in literature we reviewed. In total, we identified 30 studies that were relevant to our objectives and scope. We reviewed these studies to identify common themes related to the types of methods used to estimate the economic effects of climate change in the United States, the limitations of these methods, and what is known about the economic effects of climate change in the United States.

Of the 30 studies identified that described methods to estimate economic effects, 2 included estimates of the potential economic effects of climate change in the United States on a national-scale, across different sectors and regions—the *American Climate Prospectus* study by the Rhodium Group and the *Climate Change Impacts and Risk Analysis* study by the Environmental Protection Agency.[1] Many experts we interviewed

[1]Rhodium Group, LLC., *American Climate Prospectus: Economic Risks in the United States* (New York: October 2014), and Environmental Protection Agency, Office of Atmospheric Programs, *Climate Change Impacts in the United States: Benefits of Global Action*, EPA 430-R-15-001 (Washington, D.C.: 2015).

confirmed that these two studies represented the best available estimates to date. To review the two national-scale studies, we used standard economic principles, similar to those embodied in federal and agency guidance, including a review of the statement of objective and scope, methodology, analysis of effects, sensitivity analysis, and documentation. Through this assessment, we identified several limitations that affect the precision of the studies' results and are common to the methods used to estimate the economic effects of climate change that were identified in literature we reviewed and by experts we interviewed. We discuss these limitations in the report. Finally, we interviewed the authors of these studies to discuss the studies' methodologies and limitations.

In addition, to address our audit objectives we conducted 26 semistructured interviews with economists and other experts we identified through snowball sampling based on expert referrals. Specifically, we interviewed experts who (1) were recommended by at least one other expert, (2) authored at least one study identified through our literature review, (3) were available and agreed to meet with us, and (4) had a range of views and expertise needed to address our objectives. For example, we interviewed experts who were knowledgeable enough about methods to estimate the economic effects of climate change impacts that they could discuss strengths and limitations of these methods. Repeated recommendations of the same experts indicated that we reached saturation of the field and were identifying the appropriate experts. We reviewed experts' curricula vitae—to the extent they were available—to ensure that their areas of expertise and research were relevant to the engagement's objectives and that we were gathering the range of expertise that we needed, including expertise on the strengths and limitations of the methods discussed in this report. During these interviews, we asked experts about (1) methods used to develop estimates of the economic effects of climate change impacts in the United States; (2) strengths and limitations these methods may have; (3) what is known about the economic effects of climate change in the United States; (4) potential federal fiscal exposures that could result from these effects; and (5) how, if at all, information about potential economic effects of climate change could inform climate risk management across the federal government. We interviewed 23 out of the 26 experts in person in select geographic areas: Berkeley, California; Stanford, California; Boulder, Colorado; Boston, Massachusetts; Cambridge, Massachusetts; and Washington, D.C. Because this is a nonprobability sample, our findings cannot be generalized to other experts we did not interview. Rather, these interviews provided us with illustrative examples of methods used to estimate economic effects of climate change, what is known about

economic effects of climate change in the United States, and ways information about the potential economic effects of climate change could inform efforts to manage climate risks across the federal government. In addition, the specific areas of expertise varied among the experts we interviewed, so not all of the experts commented on all of the interview questions we asked.

Finally, to address our third audit objective, we reviewed leading practices and principles of risk management to identify key elements. We reviewed these practices and principles to identify how, if at all, economic information could be considered in risk management frameworks. National Academies' leading practices on climate risk management characterize climate change adaptation as a risk management strategy, so we then identified how information about the economic costs and benefits of climate change could be considered to manage climate risks. We also reviewed our reports related to risk management and climate change to determine what federal actions could reduce fiscal exposure because of climate risks. We then determined how, if at all, what is known about economic effects of climate change could help implement or enhance these actions.

We conducted this performance audit from December 2015 to September 2017 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

# Appendix II: GAO Contacts and Staff Acknowledgments

## GAO Contacts

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In addition to the individual contacts named above, Joseph Dean Thompson (Assistant Director), Colleen Candrl, Lilia Chaidez, Ellen Fried, Cindy Gilbert, Tim Guinane, Anne Hobson, Jeanette Soares, Sara Sullivan, Kiki Theodoropoulos, and Michelle R. Wong made key contributions to this report.

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