United States Government Accountability Office

Report to Congressional Requesters

March 2021

ELECTRICITY GRID RESILIENCE

Climate Change Is Expected to Have Far-reaching Effects and DOE and FERC Should Take Actions

Accessible Version

A Century of Non-Partisan Fact-Based Work

GAO-21-346

GAO Highlights

Highlights of GAO-21-346, a report to congressional requesters

Why GAO Did This Study

According to the U.S. Global Change Research Program, changes in the earth's climate are under way and expected to increase, posing risks to the electricity grid that may affect the nation's economic and national security. Annual costs of weather-related power outages total billions of dollars and may increase with climate change, although resilience investments could help address potential effects, according to the research program. Private companies own most of the electricity grid, but the federal government plays a significant role in promoting grid resilience—the ability to adapt to changing conditions; withstand potentially disruptive events; and, if disrupted, to rapidly recover. DOE, the lead agency for grid resilience efforts, conducts research and provides information and technical assistance to industry. FERC reviews mandatory grid reliability standards.

GAO was asked to examine U.S. energy infrastructure resilience. This report describes: (1) potential climate change effects on the electricity grid; and (2) actions DOE and FERC have taken since 2014 to enhance electricity grid resilience to climate change effects, and additional actions these agencies could take. GAO reviewed reports and interviewed agency officials and 55 relevant stakeholders.

What GAO Recommends

GAO is making two recommendations: (1) DOE should develop a department-wide strategy to enhance grid resilience to climate change, and (2) FERC should identify and assess climate change risks to the grid and plan a response. DOE and FERC neither agreed nor disagreed with GAO's recommendations.

View GAO-21-346. For more information, contact Frank Rusco at (202) 512-3841 or RuscoF@gao.gov.

March 2021

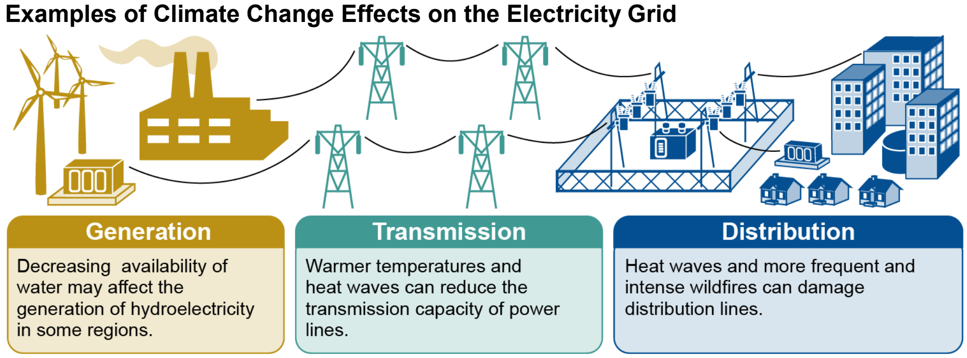
Electricity GRID Resilience

Climate Change Is Expected to Have Far-reaching Effects and DOE and FERC Should Take Actions

What GAO Found

Climate change is expected to have far-reaching effects on the electricity grid that could cost billions and could affect every aspect of the grid from generation, transmission, and distribution to demand for electricity, according to several reports GAO reviewed. The type and extent of these effects on the grid will vary by geographic location and other factors. For example, reports GAO reviewed stated that more frequent droughts and changing rainfall patterns may adversely affect hydroelectricity generation in Alaska and the Northwest and Southwest regions of the United States. Further, transmission capacity may be reduced or distribution lines damaged during increasing wildfire activity in some regions due to warmer temperatures and drier conditions. Moreover, climate change effects on the grid could cost utilities and customers billions, including the costs of power outages and infrastructure damage.

Examples of Climate Change Effects on the Electricity Grid



Source: GAO analysis of reports. | GAO-21-346

Text of Examples of Climate Change Effects on the Electricity Grid

- Decreasing availability of water may affect the generation of hydroelectricity in some regions.
- Warmer temperatures and heat waves can reduce the transmission capacity of power lines.
- Heat waves and more frequent and intense wildfires can damage distribution lines.

Source: GAO analysis of reports. | GAO-21-346.

Since 2014, the Department of Energy (DOE) and the Federal Energy Regulatory Commission (FERC) have taken actions to enhance the resilience of the grid. For example, in 2015, DOE established a partnership with 18 utilities to plan for climate change. In 2018, FERC collected information from grid operators on grid resilience and their risks to hazards such as extreme weather. Nevertheless, opportunities exist for DOE and FERC to take additional actions to enhance grid resilience to climate change. For example, DOE identified climate change as a risk to energy infrastructure, including the grid, but it does not have an overall strategy to guide its efforts. GAO's Disaster Resilience Framework states that federal efforts can focus on risk reduction by creating resilience goals and linking those goals to an overarching strategy. Developing and implementing a department-wide strategy that defines goals and measures progress could help prioritize DOE's climate resilience efforts to ensure that resources are targeted effectively. Regarding FERC, it has not taken steps to identify or assess climate change risks to the grid and, therefore, is not well positioned to determine the actions needed to enhance resilience. Risk management involves identifying and assessing risks to understand the likelihood of impacts and their associated consequences. By doing so, FERC could then plan and implement appropriate actions to respond to the risks and achieve its objective of promoting resilience.

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Abbreviations List

DOE	U.S. Department of Energy
EGCC	Energy Sector Government Coordinating Council
ESCC	Electricity Subsector Coordinating Council
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
GMLC	Grid Modernization Laboratory Consortium
ICE calculator	Interruption Cost Estimate calculator
ISO	independent system operator
LBNL	Lawrence Berkeley National Laboratory (of the U.S. Department of Energy)
NASA	National Aeronautics and Space Administration
National Academies	National Academies of Sciences, Engineering, and Medicine
NERC	North American Electric Reliability Corporation
NOAA	National Oceanic and Atmospheric Administration
QER	Quadrennial Energy Review
RTO	regional transmission organization
USGCRP	U.S. Global Change Research Program

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
A Century of Non-Partisan Fact-Based Work
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March 5, 2021

The Honorable Tom Carper
Chairman
Committee on Environment and Public Works
United States Senate

The Honorable Joe Manchin
Chairman
Committee on Energy and Natural Resources
United States Senate

Climate change poses risks to the electricity grid—the power generation, transmission, and distribution system—that can potentially affect the nation's economic and national security. In 2013, we identified the federal government's management of climate change risks as a high-risk area due to the fiscal exposure it represents.[1] According to the U.S. Global Change Research Program (USGCRP), changes in the earth's climate are underway, and many extreme weather and climate-related events are expected to become more frequent and intense.[2] Extreme weather events have been the principal contributors to an increase in the frequency and duration of power outages in the United States.[3] As we reported in 2014,

[1]The rising number of natural disasters and increasing reliance on the federal government for assistance is a key source of federal fiscal exposure. The costliness of disasters is projected to increase as extreme weather events become more frequent and intense due to climate change. See GAO, *High-Risk Series: An Update,* GAO-13-283 (Washington, D.C.: Feb. 14, 2013).

[2]Greenhouse gases already in the atmosphere are expected to continue to alter the climate in the future, regardless of efforts to control emissions, according to USGCRP and the National Academies of Sciences, Engineering, and Medicine (National Academies). Nevertheless, according to the Fourth National Climate Assessment, more immediate and substantial global greenhouse gas emission reductions, as well as regional adaptation efforts are needed to avoid the most severe consequences of climate change in the long-term. USGCRP, *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment*, vol. II (Washington, D.C.: 2018).

[3]According to the Quadrennial Energy Review and the USGCRP's Fourth National Climate Assessment, the leading cause of power outages in the United States is extreme weather. Quadrennial Energy Review (QER) Task Force, *Transforming the Nation's Electricity System: The Second Installment of the QER* (January 2017). Extreme weather includes high winds, thunderstorms, hurricanes, heat waves, intense cold periods, intense snow events and ice storms, and extreme rainfall. Such events can interrupt energy generation, damage energy resources and infrastructure, and interfere with fuel production and distribution systems, causing fuel and electricity shortages or price spikes.

most of our nation's energy infrastructure was engineered and built for our past or current climate and may not be resilient to continued changes.[4] Recent weather events—such as extreme heat and associated wildfires in California, extreme cold in Texas, and Hurricane Isaias on the East Coast—have adversely affected millions of electric utility customers. While it is not possible to say that climate change caused an individual weather event, these events are illustrative of the potential climate-related vulnerabilities facing the United States. Moreover, power disruptions during extreme weather events illustrate the need to plan for climate change risks and invest in climate resilience.[5]

Private companies own most of the electricity grid in the United States, but the federal government plays a significant role in promoting grid resilience—the ability to adapt to changing conditions; withstand potentially disruptive events, such as the loss of power lines; and if disrupted, to rapidly recover.[6] According to the National Academies of Sciences, Engineering, and Medicine (National Academies), no single entity is responsible for, or has the authority to implement, a comprehensive approach to grid resilience.[7] However, the U.S. Department of Energy (DOE) and the Federal Energy Regulatory Commission (FERC) play an important role in shaping electric industry decisions to adopt grid resilience measures. DOE is the lead agency for federal grid resilience efforts, conducts research and development on relevant technologies, and provides industry and other stakeholders with information and technical assistance. FERC regulates wholesale electricity markets and the transmission of electric energy in interstate commerce, reviews and approves mandatory grid reliability standards, and issues licenses for the construction of new hydropower projects, among other things.

[4]GAO, *Climate Change: Energy Infrastructure Risks and Adaptation Efforts,* GAO-14-74 (Washington, D.C.: Jan. 31, 2014).

[5]GAO, *Extreme Weather Events: Limiting Federal Fiscal Exposure and Increasing the Nation's Resilience,* GAO-14-364T (Washington, D.C.: Feb. 12, 2014).

[6]For purposes of this report, we use the definition of "resilience" in Presidential Policy Directive 21, which establishes national policy for critical infrastructure security and resilience. Specifically, Presidential Policy Directive 21 defines resilience as the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions, including naturally occurring threats or incidents.

[7]National Academies of Sciences, Engineering, and Medicine, *Enhancing the Resilience of the Nation's Electricity System* (July 2017).

You asked us to examine efforts to enhance U.S. energy infrastructure resilience. This report describes: (1) the potential effects of climate change on the electricity grid; and (2) actions DOE and FERC have taken since 2014 to enhance the resilience of the electricity grid to climate change effects, and additional actions the agencies could take to further enhance resilience.

To address both objectives, we reviewed relevant laws as well as agency guidance and documents, including the DOE Quadrennial Energy Review (QER) Task Force's Second Installment of the QER, the DOE and U.S. Department of Homeland Security's *Energy Sector-Specific Plan, 2015,* and FERC's *Strategic Plan, Fiscal Years 2018-2022*.[8] We interviewed DOE and FERC staff and representatives from the North American Electric Reliability Corporation (NERC)—the federally designated U.S. electric reliability organization.[9] We also conducted semi-structured interviews with 55 stakeholders who are knowledgeable about grid operations, climate change, and resilience measures.[10] We generally asked the same questions during each interview, including asking for recommendations for other stakeholders and organizations we should interview. These stakeholders include groups or individuals from academia; state government (e.g., an association representing state energy offices and another representing public utility commissions); industry (e.g., investor-owned utilities, public utilities, and electric cooperatives; regional and independent transmission organizations; and industry groups and associations); research organizations; environmental

[8]Quadrennial Energy Review Task Force, *Transforming the Nation's Electricity System.* U.S. DOE and U.S. Department of Homeland Security, *Energy Sector-Specific Plan, 2015* (Washington, D.C.: 2015), and Federal Energy Regulatory Commission. Strategic Plan, Fiscal Years 2018-2022 (Washington, D.C.: September 2018).

[9]We interviewed officials from several DOE offices, including the Office of Electricity, the Office of International Affairs, and the Office of Policy. We also received written responses from the Advanced Research Projects Agency-Energy, the Office of Cybersecurity, Energy Security, and Emergency Response and the Office of Energy Efficiency and Renewable Energy. FERC offices include: the Office of Electric Reliability, the Office of Energy Infrastructure Security, the Office of Energy Market Regulation, the Office of Energy Policy and Innovation, and the Office of the Executive Director.

[10]We did not interview but received written responses from a stakeholder group representing public utilities.

organizations; and staff from six DOE National Laboratories.[11] We also interviewed an energy consultant and a former FERC commissioner.

We identified these stakeholders through a review of prior GAO work and relevant reports (e.g., stakeholder involvement in related federal efforts such as the Fourth National Climate Assessment), and through recommendations from stakeholders and DOE and FERC staff. We selected stakeholders who were knowledgeable about electricity, climate change, and resilience. Specifically, for stakeholders from academia, we selected individuals who had authored a study on electricity grid resilience, climate change, or related topic; testified before the U.S. Congress on relevant topics; served on a relevant panel or advisory group (i.e., member of a relevant federal advisory committee, such as DOE's Electricity Advisory Committee, or the National Academies); or were recommended by one or more stakeholders we interviewed. We also selected research groups with knowledge of electricity and climate change data and models. We selected stakeholders from state government and industry (e.g., utilities and grid operators) from different regions of the United States, including Alaska and Hawaii, since climate change effects vary by region. Findings from our selected stakeholders cannot be generalized to those we did not speak with or include in our review; rather, our interviews provide insights into how selected stakeholders viewed the various topics.

To describe what is known about the potential effects of climate change on the electricity grid, we reviewed 30 reports, such as the USGCRP's Fourth National Climate Assessment and reports issued through DOE's Partnership for Energy Sector Climate Resilience.[12] To identify these reports, we reviewed prior GAO work and asked for recommendations from stakeholders we interviewed. To understand the potential costs of climate change on the electricity grid, we conducted a literature search for

[11]The number of stakeholders by category is as follows: six from academia; nine from state government including associations representing state energy offices, state public service commissioners, and state utility consumer advocates; 24 from industry (including three federal utilities: the Tennessee Valley Authority, the Bonneville Power Administration and the Western Area Power Administration); five research organizations including the research arm of one credit agency that has published work on climate change effects on utilities' credit ratings; three environmental organizations and staff from six DOE National Laboratories: Argonne National Laboratory; Pacific Northwest National Laboratory; Lawrence Berkeley National Laboratory; Sandia National Laboratory; National Renewable Energy Laboratory; and Oak Ridge National Laboratory.

[12]We use the term "report" to refer to federal agency program reports; journal articles; and publications by associations, nonprofit organizations, consultants, and think tanks.

reports published since 2012. We searched sources such as Scopus. We reviewed 19 reports and identified one that quantified the climate change impacts on transmission and distribution infrastructure. To understand the potential costs of power outages, we conducted a literature search for reports published since 2012. We searched sources including Scopus and ProQuest, among others, and asked for report recommendations from stakeholders we interviewed. We focused on reports that addressed three issues: (1) estimates of annual average costs of weather-related outages in the United States; (2) estimates of the costs of outages due to specific severe weather events; and (3) the types of costs—direct and indirect—that are included or excluded in these estimates. We identified three reports that estimated the annual costs of power outages in the United States specifically related to weather. We reviewed the methodologies of these reports and determined that the estimates were sufficiently reliable for our purposes of describing estimates of the annual average cost of weather-related outages.

To identify actions DOE and FERC have taken to enhance the resilience of the electricity grid to climate change since 2014, we reviewed federal agency reports, such as DOE's 2016 Climate Change Adaptation Plan[13] and budget documents; reports from federal entities such as the Congressional Research Service and DOE National Laboratories; and other documents including FERC proposed and final rules, and meeting transcripts. To identify further actions the agencies could take to enhance grid resilience, we reviewed 24 reports from DOE National Laboratories, academia, industry, consultants, research institutions, and environmental groups. This includes reviewing recommendations on grid resilience included in reports by the National Academies, the Electricity Advisory Committee, the House Select Committee on the Climate Crisis, and the

[13]U.S. Department of Energy, Sustainable Performance Office, *Climate Change Adaptation Plan, 2016 Interim Update* (Washington, D.C: December 2016).

National Commission on Grid Resilience.[14] To identify these reports, we searched industry news sources, reviewed prior GAO work, and asked for report recommendations from stakeholders we interviewed. We reviewed reports based on their relevance to how DOE and FERC could enhance the resilience of the electricity grid to climate change effects.[15] We also reviewed our prior work on risk management, climate change, and climate resilience; and assessed agency actions using agency planning documents and GAO's Disaster Resilience Framework and enterprise risk management framework.[16]

We also reviewed documents such as comments to FERC regarding grid resilience from regional and independent transmission organizations,[17] utilities, and organizations, such as the Center for Climate and Energy

[14]National Academies of Sciences, Engineering, and Medicine, *Enhancing the Resilience of the Nation's Electricity System;* and The Electricity Advisory Committee, *Policy and Research Opportunities for Grid Resilience: Recommendations for the U.S. Department of Energy* (March 2019). The Electricity Advisory Committee is a federal advisory committee composed of 35 members from state governments, regional planning entities, utility companies, cybersecurity and national security firms, the natural gas sector, equipment manufacturers, construction and architectural companies, nongovernmental organizations, and other electricity-related organizations. See also The House Select Committee on the Climate Crisis, Majority Staff Report*: Solving the Climate Crisis: The Congressional Action Plan for a Clean Energy Economy and a Healthy, Resilient, and Just America* (Washington, D.C.: June 2020). National Commission on Grid Resilience, *Grid Resilience: Priorities for the Next Administration* (August 2020). The National Commission on Grid Resilience is a bipartisan group chartered and supported by Woodstar Labs, a nonprofit technology and analysis firm owned by Associated Universities Inc.

[15]We reviewed information on grid resilience to climate change and not on mitigation or lowering emissions. We discuss mitigation to the extent that documents we reviewed and stakeholders identified mitigation as a strategy for enhancing the resilience of the grid.

[16]GAO, *Disaster Resilience Framework: Principles for Analyzing Federal Efforts to Facilitate and Promote Resilience to Natural Disasters,* GAO-20-100SP (Washington, D.C.: Oct. 23, 2019); and GAO, *Enterprise Risk Management: Selected Agencies' Experiences Illustrate Good Practices in Managing Risk,* GAO-17-63 (Washington, D.C.: Dec. 1, 2016).

[17]Different regions of the country use different approaches to ensure adequate electricity supplies. In some regions, entities called regional transmission organizations (RTOs) manage the system of electricity lines that comprise the grid and help ensure enough electricity is available to meet customers' electricity needs in the future. While major sections of the country operate under more traditional market structures, two-thirds of the nation's electricity is served in RTO regions. Independent operators of the transmission system can be referred to as RTOs or independent system operators (ISO). For the purposes of this report, we use the term "RTOs" to refer to both RTOs and ISOs. FERC does not regulate wholesale sales of electricity in the ISO market in Texas (which is known as the Electric Reliability Council of Texas) which is separate from the rest of the U.S. grid.

Solutions and Columbia University's Sabin Center for Climate Change Law.[18] We analyzed the information and identified themes from both interviews and reports. Throughout the report, we use the following categories to quantify statements identified by reports or stakeholders: "some," which we define as two to five reports or stakeholders collectively; "several," which we define as six to 10 reports or stakeholders collectively; and "many," which we define as more than 10 reports or stakeholders collectively. Given our methodology, we may not have identified every action DOE and FERC could take to enhance the resilience of the grid to climate change effects, but we provide key examples of actions these agencies could take.

We conducted this performance audit from November 2019 to March 2021, 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

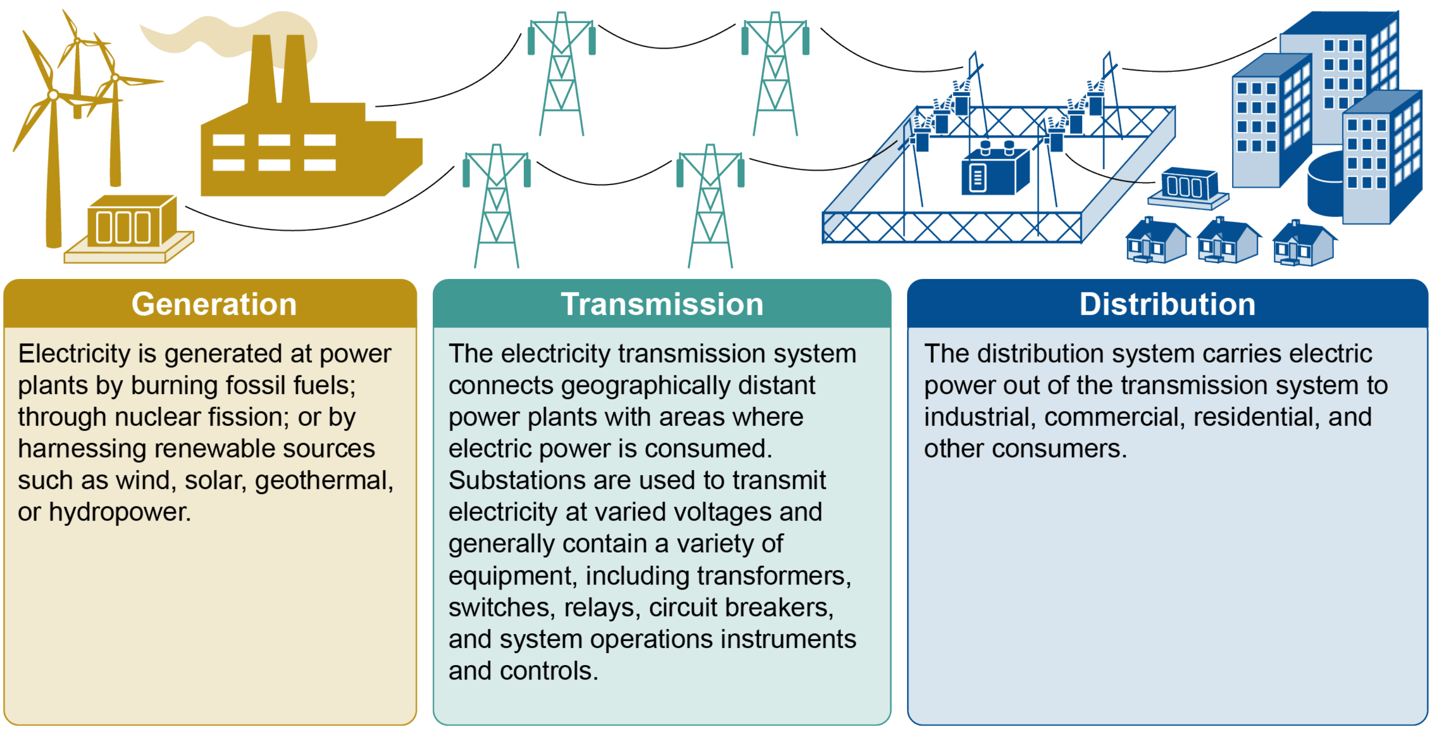
This section describes (1) the electricity grid, (2) oversight of the electricity industry, (3) the federal government's role in ensuring grid resilience to climate change, and (4) risk management and GAO's Disaster Resilience Framework.

The Electricity Grid

The electricity grid involves three main functions: generation, transmission, and distribution (see fig. 1).

[18]FERC Docket AD18-7-000, *Grid Resilience in Regional Transmission Organizations and Independent System Operators* (Jan. 8, 2018).

Figure 1: The Electricity Grid



Source: GAO analysis of reports. | GAO-21-346

Text of Figure 1: The Electricity Grid

Generation

- Electricity is generated at power plants by burning fossil fuels; through nuclear fission; or by harnessing renewable sources such as wind, solar, geothermal, or hydropower.

Transmission

- The electricity transmission system connects geographically distant power plants with areas where electric power is consumed. Substations are used to transmit electricity at varied voltages and generally contain a variety of equipment, including transformers, switches, relays, circuit breakers, and system operations instruments and controls.

Distribution

- The distribution system carries electric power out of the transmission system to industrial, commercial, residential, and other consumers.

Source: GAO analysis of reports. | GAO-21-346.

Throughout the process of generating and delivering electricity to customers, grid operators, such as local utilities, must constantly seek a balance between the generation and consumption of electricity. To do so, grid operators monitor electricity consumption from a centralized location, using information systems, and send minute-by-minute signals to power plants to adjust their output to match changes in the demand for electricity.

The United States has over 10,000 power plants, more than 642,000 miles of high-voltage transmission lines, and 6.3 million more miles of distribution lines. Grid operators in the United States are investing in an aging grid with a growing segment of the infrastructure that needs replacement or modernization. For example, about 70 percent of the electricity grid's transmission lines and power transformers are at least 25 years old, and the average age of power plants is at least 30 years old. According to the American Society of Civil Engineers, most of our nation's electricity transmission system was built in the 1950s and 1960s and was expected to last 50 years.[19] The electricity sector is experiencing complex transformations and challenges, including aging infrastructure; a changing mix of power generation; growing penetration of variable generation, such as wind and solar; climate change; increased physical and cybersecurity risks; and, in some regions, widespread adoption of distributed energy resources.[20] Moreover, the traditional model of large centralized generators is evolving as retiring generators are replaced with variable wind and solar generators;[21] smaller and more flexible natural gas

[19]American Society of Civil Engineers, *Failure to Act: Electric Infrastructure Investment Gaps in a Rapidly Changing Environment* (Reston, VA: 2020).

[20]A distributed energy resource is any resource located on the distribution system, any subsystem thereof, or behind a customer meter. These resources may include, but are not limited to, electric storage resources, distributed generation, demand response, energy efficiency, thermal storage, and electric vehicles and their supply equipment.

[21]Due to their variable output, these new technologies are different from traditional generation resources. Wind and solar units are only available to generate electricity when the wind is blowing or the sun is shining and, for this reason, they are often referred to as "variable generation" resources and do not fit the traditional paradigm of building capacity to meet baseload, intermediate, or peaking needs.

generators; and nontraditional resources, such as demand-response and distributed generation.[22]

New technologies provide utilities with additional options for meeting demand and providing reliable service. These options include variable energy resources, smart grid technologies, and energy storage.[23] Many of these options are relatively inexpensive and fast to deploy, especially compared with constructing large, conventional power plants. New technologies will also alter the traditional, real-time requirements for grid operations and the nature of production, transmission, and distribution. In addition, new technologies within the system are increasingly available for use by customers and can enable more flexible operations.

Grid operators conduct planning to assess the ability of the existing grid infrastructure to meet the demand for electricity and evaluate the cost and effectiveness of potential solutions to meet demand. Utilities have various options to meet the demand for electricity, including constructing new plants, upgrading existing plants, purchasing power from other utilities, building new transmission and distribution lines, and providing incentives to customers to reduce their demand for electricity. Utilities deal with uncertainties, such as future supply and user demand for electricity, partly by producing a range of forecasts and using models to help determine the least-costly way to meet demand. If their forecasts and models are incorrect, a utility could end up with more or less generating capacity than it needs to meet user demand for electricity, or with a resource portfolio that is not cost effective. These outcomes can affect electricity rates that customers pay, as well as the utility's financial situation.

There are three types of electric utilities: investor-owned utilities are large public companies that issue stock owned by shareholders; publicly owned utilities are operated by federal, state, or municipal governments; and electric cooperatives are member-owned not-for-profits. Investor-owned

[22]Demand response activities encourage consumers to reduce demand when the cost to generate electricity is high, which can reduce the costs of producing electricity, improve market functions, and enhance reliability.

[23]Smart grid technologies include information and communications systems to automate actions with the aim of improving the electric grid's reliability and efficiency, as well as facilitating the use of alternative energy sources. Smart grid technologies include new devices, such as smart meters and appliances that allow for the use of rate structures, and other mechanisms to more cost effectively balance the demand and supply of electricity.

utilities are required to disclose, through annual and other periodic filings with the Securities and Exchange Commission, information about known trends, events, and uncertainties that are reasonably likely to have a material effect on the company's financial condition or operating performance.[24] These disclosures may include information on climate-related risks.

Oversight of the Electricity Industry

Responsibility for regulating the electricity industry is divided between the states and the federal government. Most electricity customers are served by electric utilities that are regulated by the states, generally through state public utility commissions or equivalent organizations. As the primary regulator of electricity, state public utility commissions have a variety of responsibilities, such as approving utility investments in generation and distribution assets, the rates customers pay, and how those rates are set.[25] Before electricity is sold to end-use customers, it may be traded in wholesale electricity markets that the federal government oversees through FERC.[26] FERC regulates the interstate transmission of electricity and is responsible for overseeing regional transmission organizations' (RTO) development and operation of markets to ensure that wholesale electric rates are "just and reasonable" and not "unduly discriminatory or

[24]GAO, *Climate Related Risks: SEC Has Taken Steps to Clarify Disclosure Requirements,* GAO-18-188 (Washington, D.C.: Feb. 20, 2018). Almost three-quarters of utility customers get their electricity from investor-owned utilities.

[25]State regulators approve utility investments either in advance of construction or afterwards, when the utility seeks to recover costs in the rates it charges customers. Some states have integrated resource planning processes to determine what facilities should be built. The purpose of integrated resource planning is to meet future power demand by identifying the need for generating capacity and determining the best mix of resources to meet the need on a least-cost, system-wide basis. The integrated approach considers a broad range of feasible supply-side and demand-side options and assesses them with respect to financial, economic, and environmental impacts.

[26]FERC is to be composed of five commissioners, who are appointed by the President of the United States with the advice and consent of the Senate. FERC needs a quorum of three commissioners to conduct business. Commissioners serve 5-year terms and have an equal vote on regulatory matters.

preferential."[27] To do so, FERC reviews and approves RTO market rules and monitors the competitiveness of RTO markets. RTOs serve as grid operators by managing regional networks of electric transmission lines and also operate wholesale electricity markets to buy and sell services to maintain a reliable grid. In regions of the country without RTOs, electric utilities generally serve in the role of grid operator. Utilities in these regions may build and operate power plants to provide electricity to serve their customers. These utilities may also buy electricity from other power plant owners.

The Federal Government's Role in Ensuring Grid Resilience to Climate Change

National policies and federal preparedness efforts have highlighted the importance of enhancing the resilience of the nation's critical infrastructure, including the electricity grid. Presidential Policy Directive 21, issued in February 2013, established national policy on critical infrastructure security and resilience. The directive expanded the nation's focus from protecting critical infrastructure against terrorism to protecting critical infrastructure and increasing its resilience against all hazards, including natural disasters, terrorism, and cyber incidents.[28] In addition, the directive recognizes that proactive and coordinated efforts are necessary to strengthen and maintain critical infrastructure that is secure and resilient. It also identifies 16 critical infrastructure sectors, including the energy sector—which encompasses the electricity grid—and designates lead federal agencies to coordinate and prioritize security and resilience activities in each sector. *The Energy Sector-Specific Plan, 2015,* describes federal efforts to improve the security and resilience of the energy sector's critical infrastructure, including the electricity grid, and

[27]This authority is granted under sections 205 and 206 of the Federal Power Act, 16 U.S.C. §§ 824d-824e. According to FERC staff, FERC does not have an explicit statutory mandate under the Federal Power Act to initiate rates with respect to climate change considerations. However, under the Federal Power Act, if a public utility seeks to recover in its jurisdictional rates costs incurred related to climate change issues, FERC would review the proposed rates to determine whether they are just and reasonable given the inclusion of such costs, according to these officials.

[28]*Presidential Policy Directive-21*, Critical Infrastructure Security and Resilience (Feb. 12, 2013).

identifies federal priorities for enhancing the security and resilience of the grid and addressing potential risks, such as climate change.[29]

- **DOE:** Designated as the lead sector-specific agency for the energy sector, DOE is responsible for coordinating with other relevant federal agencies, such as the Department of Homeland Security, and for collaborating with critical infrastructure owners and operators to prioritize and coordinate federal resilience efforts. In 2015, DOE led the update to *Energy Sector-Specific Plan, 2015*. DOE also funds research and provides information and technical assistance to utilities and states and partners with other federal agencies on these efforts. DOE is a member of the USGCRP —which coordinates and integrates the activities of 13 federal agencies that research changes in the global environment and their implications for society and prepares the National Climate Assessment.
- **FERC.** In addition to overseeing RTO operation of markets, FERC reviews and approves standards that NERC develops to provide for the reliable operation of the bulk power system. NERC is the federally designated U.S. electric reliability organization and is responsible for conducting reliability assessments and developing and enforcing mandatory standards to provide for the reliable operation of the bulk power system.[30] FERC conducts inquiries, audits, and investigations of major blackouts and other grid-related events to determine whether the standards were violated and whether adjustments to the standards are needed to help prevent future blackouts.

Risk Management and GAO's Disaster Resilience Framework

According to USGCRP's Fourth National Climate Assessment, enhancing climate resilience entails a continuing risk management process through which individuals and organizations become aware of and assess risks and vulnerabilities from climate and other drivers of change, take actions

[29]DOE and U.S. Department of Homeland Security, *Energy Sector-Specific Plan, 2015.*

[30]The bulk power system includes the facilities and control systems necessary for operating the interconnected electricity transmission network and the electric energy from certain generation facilities needed for reliability. NERC has developed reliability standards for the bulk power system, including standards on cybersecurity and physical security. FERC can approve or disapprove NERC-proposed reliability standards, and can remand them back to NERC for further consideration, but it cannot author or unilaterally modify reliability standards.

to reduce those risks, and learn over time. In December 2016, we found that enterprise risk management can assist federal leaders in anticipating and managing risks. Enterprise risk management includes first identifying and assessing risks to understand the likelihood of impacts and their consequences, and then planning risk responses and making decisions.[31]

In October 2019, we issued the Disaster Resilience Framework to serve as a guide for analysis of federal action to facilitate and promote resilience to natural disasters.[32] The principles in this framework can help identify opportunities to enhance federal efforts to promote disaster resilience, including building resilience to climate change. As shown in figure 2, the framework is organized around three broad, overlapping principles to enhance federal efforts to promote disaster resilience.

[31] GAO-17-63.

[32] GAO-20-100SP.

Figure 2: GAO's Disaster Resilience Framework

Principle:

Information

Accessing information that is authoritative and understandable can help decision makers to identify current and future risk and the impact of risk-reduction strategies.

Provide reliable and authoritative information about current and future risk

To what extent could federal efforts:
- Enhance the validity and reliability of the disaster risk information produced?
- Generate and share additional information that would help decision makers understand their disaster risk?
- Reduce the complexity of and translate risk information for non-technical audiences?
- Help leverage and synthesize disaster risk information from other partners across agencies, governments, and sectors?
- Promote consensus around the reliability of the sources and methods that produce disaster risk information?

Improve the ability to assess alternatives to address risk

To what extent could federal efforts:
- Help decision makers identify and select among disaster risk-reduction alternatives?
- Provide technical assistance to help build capacity of nonfederal partners?
- Contribute to an understanding of approaches for estimating returns on investment?
- Help decision makers identify and combine available funding sources and innovative methods for meeting disaster risk-reduction needs?

Strengthen the ability to assess status and report progress

To what extent could federal efforts:
- Advance methodologies or processes to measure the current state of nationwide resilience?
- Promote monitoring of progress toward resilience on a programmatic basis?

Integration

Integrated analysis and planning can help decision makers take coherent and coordinated resilience actions.

Build an overarching strategic vision and goals

To what extent could federal efforts:
- Help to establish overarching strategies that guide national resilience efforts?
- Ensure that resilience goals are incorporated into relevant national strategies?
- Prioritize resilience goals that reflect the most pressing resilience challenges?

Promote coordination across missions and sectors

To what extent could federal efforts:
- Ensure consistent and complementary policies, procedures, and timing across relevant federal funding mechanisms?
- Convene stakeholders with different perspectives and interests to create whole systems solutions?
- Encourage governance mechanisms that foster coordination and integrated decision making within and across levels of government?
- Engage non-government partners in disaster risk reduction?

Recognize relationships among infrastructure and ecosystems

To what extent could federal efforts:
- Promote better understanding and awareness of the interactions among infrastructure components and ecosystems in disaster resilience actions?
- Assist decision makers in determining what combination of ecosystem and built infrastructure solutions will best suit their needs within their constraints?
- Assist in ensuring that projects undertaken under different programs and by different actors do not conflict?
- Facilitate planning across jurisdictions and sectors to avoid or respond to cascading failure?

Incentives

Incentives can help to make long-term, forward-looking risk-reduction investments more viable and attractive among competing priorities.

Provide financial and nonfinancial incentives

To what extent could federal efforts:
- Make risk-reduction measures more viable and attractive?
- Incorporate disaster risk-reduction measures in infrastructure and ecosystem management financial assistance?
- Require disaster risk-reduction measures for government-owned or -operated infrastructure and for federally funded projects?

Reduce disincentives

To what extent could federal efforts:
- Alleviate unnecessary administrative burden?
- Streamline review processes?
- Improve program design to motivate risk-reduction actions?

Source: GAO, Disaster Resilience Framework: Principles for Analyzing Federal Efforts to Facilitate and Promote Resilience to Natural Disasters, GAO-20-100SP (Washington, D.C.: Oct. 23, 2019). | GAO-21-346

Text of Figure 2: GAO’s Disaster Resilience Framework

Information

Accessing information that is authoritative and understandable can help decision makers to identify current and future risk and the impact of risk-reduction strategies.

Provide reliable and authoritative information about current and future risk

To what extent could federal efforts:

- Enhance the validity and reliability of the disaster risk information produced?
- Generate and share additional information that would help decision makers understand their disaster risk?
- Reduce the complexity of and translate risk information for non-technical audiences?
- Help leverage and synthesize disaster risk information from other partners across agencies, governments, and sectors?
- Promote consensus around the reliability of the sources and methods that produce disaster risk information?
- Improve the ability to assess alternatives to address risk

To what extent could federal efforts:

- Help decision makers identify and select among disaster risk-reduction alternatives?
- Provide technical assistance to help build capacity of nonfederal partners?
- Contribute to an understanding of approaches for estimating returns on investment?
- Help decision makers identify and combine available funding sources and innovative methods for meeting disaster risk-reduction needs?
- Strengthen the ability to assess status and report progress

To what extent could federal efforts:

- Advance methodologies or processes to measure the current state of nationwide resilience?
- Promote monitoring of progress toward resilience on a programmatic basis?

Integration

Integrated analysis and planning can help decision makers take coherent and coordinated resilience actions.

Build an overarching strategic vision and goals

To what extent could federal efforts:

- Help to establish overarching strategies that guide national resilience efforts?
- Ensure that resilience goals are incorporated into relevant national strategies?
- Prioritize resilience goals that reflect the most pressing resilience challenges?

Promote coordination across missions and sectors

To what extent could federal efforts:

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Climate Change Is Expected to Have Far-reaching Effects on the Electricity Grid That Could Cost Billions

Climate change is expected to have far-reaching effects on the electricity grid that could cost billions and affect every aspect of the electricity grid, from generation, transmission, and distribution to end-user demand, according to several reports we reviewed. The types and extent of the effects that climate change will have on the grid will vary by geographic location and other factors, according to reports we reviewed.

Climate Change Is Expected to Affect Every Aspect of the Electricity Grid

Climate change is expected to affect all aspects of the electricity grid, from generation, transmission, and distribution to end-user demand, according to several reports we reviewed.[33] The type and extent of the effects of climate change on the grid will vary by geographic location, energy source, condition of grid infrastructure, and other factors, according to several stakeholders we interviewed and reports we reviewed. According to the Fourth National Climate Assessment, many regions will experience more than one climate-related effect. For example, a region may see more extreme rainfall combined with coastal flooding, or extreme heat coupled with drought. However, warmer temperatures and more heat waves could affect all regions in the United States and could decrease the efficiency of electricity generation, transmission, and distribution systems, according to reports we reviewed.

- *Generation:* The effects of climate change could impact the efficiency of power plant operations and the ability to generate power. For example, storms can disrupt operations; extreme heat can affect the efficiency of power plant operations; and changes in the availability of resources needed to generate electricity, such as water, can affect the ability to generate power. Climate change is expected to increase the frequency and intensity of hurricanes. Paired with greater rainfall,

[33]DOE National Laboratories (Argonne National Laboratory, Brookhaven National Laboratory, Los Alamos National Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, and Sandia National Laboratory), *Resilience of the U.S. Electricity System: a Multi-Hazard Perspective* (August 2016).

rising sea levels, and larger storm surges, future hurricanes may increase the risk of coastal flooding. Power plants along the Atlantic and Gulf Coasts are especially vulnerable to flooding. In addition, wind turbines in close proximity to the Gulf of Mexico may be vulnerable to wind damage from more intense hurricanes.[34] According to the Fourth National Climate Assessment, hundreds of electricity facilities along the Gulf and Atlantic Coasts are threatened by Category 5 hurricanes, which have the potential to cause catastrophic damage. Electricity generation in these regions serves other parts of the country, and regional disruptions can have national implications.

In addition, more frequent droughts and changing rainfall patterns in some regions may affect the ability to generate electricity, such as water shortages affecting nuclear plants or hydroelectricity. For example, earlier snowmelt or more frequent droughts in regions that use hydroelectricity as a source of electricity generation—such as Alaska, the Northwest, and the Southwest—could face changes in hydroelectricity generation patterns. According to a 2015 DOE report, in Alaska—where hydroelectricity generates about 25 percent of the state's electricity—declining snowpack and earlier snowmelt, among other factors, may shift peak streamflow timing, reduce water availability, and limit hydroelectricity generation in the summer. Moreover, utilities in the western United States have also reported that earlier snowmelt and runoff due to higher temperatures have reduced the amount of water in reservoirs that are available for the warmer months of the year. Droughts can also reduce the amount of water available for the cooling of electricity-generating units, causing these units to go offline. In addition, high temperatures can trigger environmental requirements that force a power plant to shut down. For example, in 2007, 2010, and 2011, the Tennessee Valley Authority had to reduce power output from its Browns Ferry Nuclear Plant in Alabama because the temperature of the river was too high to receive discharge water without raising ecological risks.[35]

- *Transmission:* Climate change could also affect the ability of grid operators to transmit electricity. For example, warmer temperatures in the Southwest are estimated to decrease transmission line capacity by between 1.5 and 2.5 percent, according to a DOE report. Moreover, higher temperatures cause the expansion of transmission

[34]DOE, *Climate Change and the U.S. Energy Sector: Regional Vulnerabilities and Resilience Solutions* (Washington, D.C.: October 2015).

[35]To prevent hot water from harming fish and other wildlife, power plants typically are not allowed to discharge cooling water above a certain temperature. When power plants reach those limits, they can be forced to reduce power production or shut down.

line materials, and sagging lines can cause permanent damage to the lines, increasing the likelihood of power outages when the lines make contact with other lines, trees, or the ground. Additionally, warmer temperatures and drier conditions associated with climate change are projected to increase wildfire activity in the Northern Great Plains, Northwest, and Southwest regions of the United States. Increasing wildfires threaten critical transmission infrastructure, including transmission towers, and some utility operators conduct public safety power shutoffs because of wildfire risks.

- *Distribution.* Climate change could affect the ability of utilities to distribute electricity to customers. For example, higher temperatures could increase the likelihood of damage to power transformers on hot days, when electricity demand is at its highest.[36] According to a 2015 DOE report, prolonged exposure to higher temperatures can damage power transformers, and operators may be forced to reduce the supply of electricity to operate air conditioning systems to cool buildings and homes. In addition, areas in the Northeast United States are likely to experience more extreme weather, including more frequent and intense hurricanes that can threaten grid infrastructure and distribution capacity.[37]

Additionally, according to the Fourth National Climate Assessment, climate change is expected to affect the demand for electricity. For example, warmer temperatures and more heat waves could increase demand for electricity. According to the Fourth National Climate Assessment, in 2015 and 2016, Honolulu experienced 24 days of record-setting heat. As a result, the local utility issued emergency public service announcements asking residents to reduce their use of air conditioning because the increased demand for electricity threatened the grid. Figure 3 highlights examples of climate change effects on the electricity grid in different regions of the United States.

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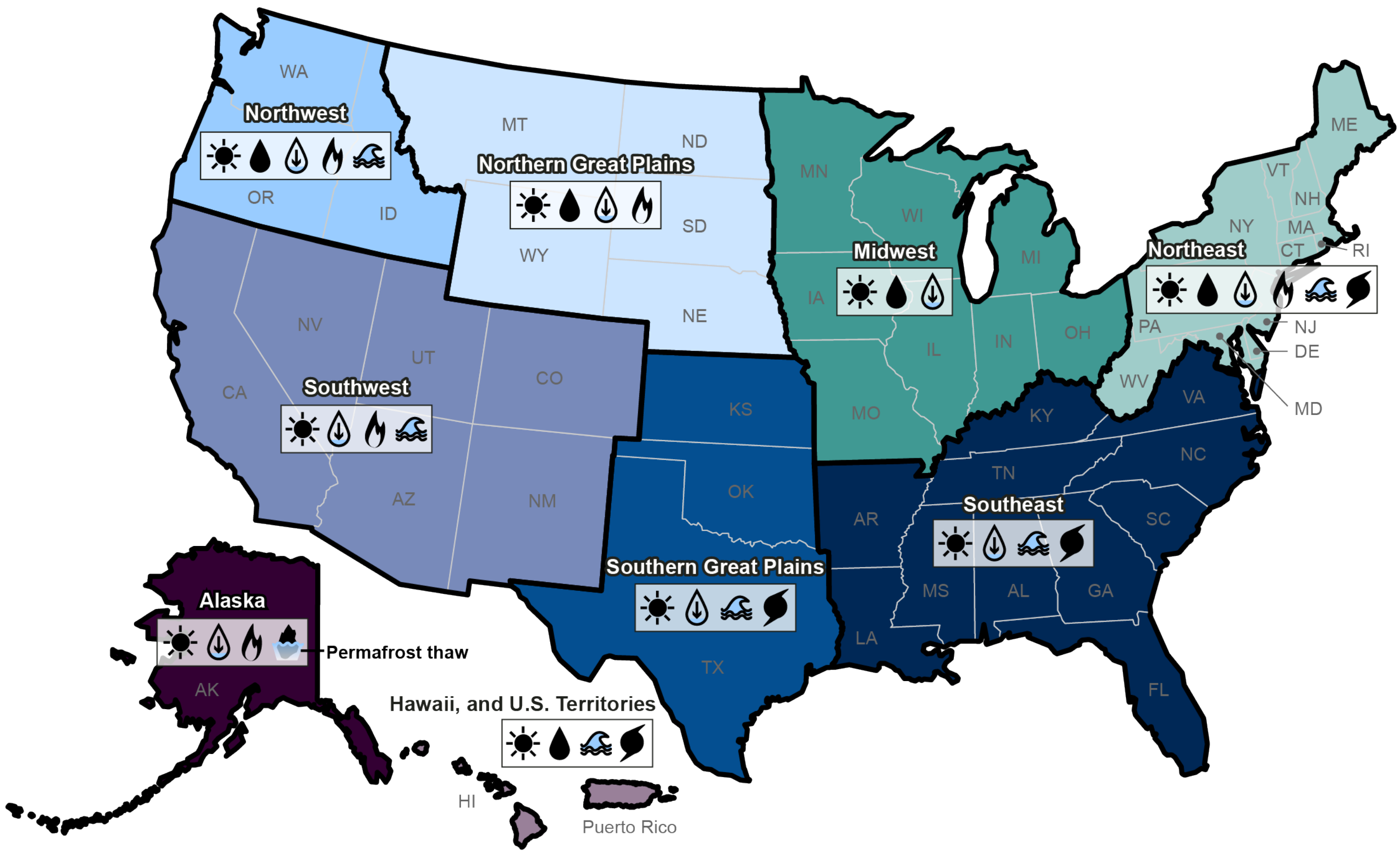
[36]A transformer changes the voltage of electricity in a conductor or power line. Transformers increase (step up) or reduce (step down) voltages as electricity moves from power plants to homes and businesses.

[37]According to the U.S. Energy Information Administration (EIA), in 2018, in the five states with the longest total annual power interruptions per customer, major weather events such as winter storms and hurricanes caused significant disruptions to service. North Carolina was hit by both Hurricane Florence and Hurricane Michael in 2018, resulting in lengthy outages. Maine, Vermont, Massachusetts, and West Virginia are heavily forested states where power interruptions resulting from falling tree branches are common, especially as a result of winter ice and snowstorms that weigh down tree limbs and power lines. EIA is a statistical administration within the U.S. Department of Energy that collects, analyzes, and disseminates independent information on energy issues.

Figure 3: Potential Climate Change Effects by Region and Examples of Climate-Related Events on the Electricity Grid



Key potential climate change effects examples:

Warmer temperatures and more heat waves:	Increasing precipitation or heavy downpours:	Decreasing water availability:	Increasing wildfires:	Increasing sea-level rise and storm surge:	Increasing frequency and intensity of hurricanes:
Warmer temperatures and more heat waves can reduce the transmission capacity of power lines. This reduced capacity, combined with an increased demand for electricity for cooling, can contribute to power outages. For example, a 2019 heat wave affected the Northeast, resulting in 100,000 customers in New York City losing power.	Increasing frequency and severity of heavy precipitation will increase heavy runoff and the risk of flooding. Floods can threaten low-lying grid structures. For example, in 2011, Missouri River floodwaters surrounded Nebraska's Fort Calhoun nuclear power plant, causing the reactor to remain closed during the summer because of flood waters.	Decreasing water availability may reduce downstream hydropower production. For example, in the summer of 2015, below-average precipitation, combined with above-average temperatures in the Northwest, resulted in lower-than-average runoff in the Columbia River Basin, which affected hydropower generation.	Increasing wildfires may damage critical transmission infrastructure and disrupt power supply. Warmer and drier conditions are projected to increase the risk of wildfires and lengthen the fire season. Based on increasing wildfire risk, a utility in California conducted public safety power shutoffs that affected more than 1 million customers in 2019.	Increasing sea-level rise and storm surge threatens low-lying coastal power plants in California. Rising sea-levels accelerate erosion and can increase flood risk during high tides and storm surges.	Increasing frequency and intensity of Category 4 and 5 hurricanes may increase the risk of physical damage to grid transmission and distribution infrastructure near the coasts. For example, in August 2020, Category 4 Hurricane Laura damaged low-lying grid infrastructure and caused outages for 616,000 customers in Arkansas, Louisiana, Mississippi, and Texas.

Sources: GAO review of Department of Energy reports, Fourth National Climate Assessment and other documents; Map Resources (map). | GAO-21-346

Text of Figure 3: Potential Climate Change Effects by Region and Examples of Climate-Related Events on the Electricity Grid

	Warmer Temperatures and More Heat waves	Increasing Precipitation or Heavy Downpours	Decreasing Water Availability	Increasing Wildfires	Increasing Sea-Level Rise and Storm Surge	Increasing Frequency and Intensity of Hurricanes
Description	Warmer temperatures and more heat waves can reduce the transmission capacity of power lines. This reduced capacity, combined with an increased demand for electricity for cooling, can contribute to power outages. For example, a 2019 heat wave affected the Northeast, resulting in 100,000 customers in New York City losing power.	Increasing frequency and severity of heavy precipitation will increase heavy runoff and the risk of flooding. Floods can threaten low-lying grid structures. For example, in 2011, Missouri River floodwaters surrounded Nebraska's Fort Calhoun nuclear power plant, causing the reactor to remain closed during the summer because of flood waters.	Decreasing water availability may reduce downstream hydropower production. For example, in the summer of 2015, below-average precipitation, combined with above-average temperatures in the Northwest, resulted in lower-than- average runoff in the Columbia River Basin, which affected hydropower generation.	Increasing wildfires may damage critical transmission infrastructure and disrupt power supply. Warmer and drier conditions are projected to increase the risk of wildfires and lengthen the fire season. Based on increasing wildfire risk, a utility in California conducted public safety power shutoffs that affected more than 1 million customers in 2019.	Increasing sea-level rise and storm surge threatens low-lying coastal power plants in California. Rising sea levels accelerate erosion and can increase flood risk during high tides and storm surges.	Increasing frequency and intensity of Category 4 and 5 hurricanes may increase the risk of physical damage to grid transmission and distribution infrastructure near the coasts. For example, in August 2020, Category 4 Hurricane Laura damaged low-lying grid infrastructure and caused outages for 616,000 customers in Arkansas, Louisiana, Mississippi, and Texas.
Regions affected	ALL	• Northeast • Midwest • Northern Great Plains • Northwest • Hawaii and US Territories	• Northeast • Midwest • Northern Great Plains • Northwest • Southwest • Southern Great Plains • Southeast • Alaska	• Northeast • Northern Great Plains • Northwest • Southwest • Alaska	• Northeast • Northwest • Soutwest • Southern Great Plains • Southeast • Hawaii and US Territories	• Northeast • Southern Great Plains • Southeast • Hawaii and US territories

Note: Alaska also suffers from potential permafrost thaw
Sources: GAO review of Department of Energy reports, Fourth National Climate Assessment and other documents; Map Resources (map). | GAO-21-346

The Effects of Climate Change on the Grid Could Cost Billions

The effects of climate change could cost billions, including the costs of power outages to utility customers and costs from storm damage, among others.[38] Specifically, three reports we reviewed estimated that the average annual costs of severe weather-related outages to utility customers in the United States totaled billions each year.[39] In the absence of measures to enhance resilience, more frequent and severe weather associated with climate change is likely to increase the cost of outages, according to these reports. According to one report, the total annual cost of outages to utility customers is estimated to increase from roughly $55 billion over the 2006-2019 period to over roughly $480 billion during the 2080-2099 period in 2019 dollar values, absent aggressive grid resilience

[38]As we reported in 2017, information on the economic effects of climate change is developing and imprecise, but it can convey insights into the nation's regions and sectors that could be most affected. 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, according to a 2010 National Academies report, literature reviewed, and experts GAO interviewed for that report. GAO, *Climate Change: Information on Potential Economic Effects Could Help Guide Federal Efforts to Reduce Fiscal Exposure,* GAO-17-720 (Washington, D.C.: Sept. 28, 2017).

[39]Three reports we reviewed included estimates of the average annual cost of weather-related outages in the United States, which range from about $2 billion to about $77 billion (2019 dollar values). Congressional Research Service, *Weather-Related Power Outages and Electric System Resiliency* (Aug. 28, 2012); Executive Office of the President, *Economic Benefits of Increasing Electric Grid Resilience to Weather Outages* (August 2013); and Peter H. Larsen et al., *Projecting Future Costs to U.S. Electric Utility Customers from Power Interruptions* (2017). These estimates cover periods ranging from the mid-1980s through 2012. The three reports differed with respect to the types of costs that they estimated and the data and methods underlying the report. The estimates are based on surveys of customers' willingness to pay to avoid outages or the estimated losses they would incur as a result of an outage, but the estimates do not account for all costs, including indirect costs on individuals, businesses, and local or regional economies. The large range—from $2 billion to $77 billion—reflects differences in what is counted and in methodologies. For example, the $2 billion estimate accounts for outages that are due to severe weather, while the $77 billion estimate includes outages that lasted over 5 minutes that were attributed to weather.

mitigation measures.[40] Power outages affect residential, commercial, industrial, and other customers' ability to use electricity for lighting, heating, cooling, and refrigeration; and for operating appliances, computers, electronics, machinery, and public transportation systems. Moreover, power outages can disproportionately affect vulnerable populations that rely on continued electricity service to address certain health conditions.[41] In addition, low-income groups are more vulnerable to events such as heat waves, given their limited ability to meet higher energy costs and invest in measures to minimize the impact of outages, such as backup generators. Power outages can also have significant cascading effects on critical sectors such as health, transportation, and telecommunications.[42] See table 1 for examples of the effects and costs of power outages.

Table 1: Examples of the Costs and Effects of Power Outages

Type of cost or effect	Examples
Residential customer losses	• spoilage of items dependent on refrigeration • inability to use elevators, appliances, fans, and lighting • inability to heat and cool homes (HVAC and boilers) and associated health impacts • inability to use ATM machines • inability to refuel at gas stations • public safety (street and traffic lights)
Commercial and industrial sector losses	• diminished or halted production of goods and services • spoilage of inventory dependent on refrigeration

[40]Larsen et al., *Projecting Future Costs to U.S. Electric Utility Customers.* This report projected the future customer costs of power outages through 2099, using climate change scenarios as one of the cost drivers in its model, and estimated changes in future severe weather metrics under 10 scenarios—including two climate change scenarios. The report did not include Hawaii or Alaska nor did it include any indirect (i.e., spillover) effects to the broader economy from power outages.

[41]For example, after Hurricanes Maria and Irma caused widespread power outages in Puerto Rico and the U.S. Virgin Islands, we reported that the chronically ill often did not have access to electricity to power their medical devices, such as ventilators. GAO, *Disaster Response: HHS Should Address Deficiencies Highlighted by Recent Hurricanes in the U.S. Virgin Islands and Puerto Rico*, GAO-19-592 (Washington, D.C.: Sept. 20, 2019). According to the Fourth National Climate Assessment, poor or marginalized populations often face a higher risk from climate change because they live in areas with higher exposure, are more sensitive to climate impacts, or lack the capacity to respond to climate hazards.

[42]Critical sectors rely on electricity, but the reliable operation of the grid also depends on the performance of multiple supporting infrastructures. Power outages can be caused by disruptions to other sectors, such as telecommunications, natural gas, and transportation, among other critical infrastructures.

Type of cost or effect	Examples
Critical infrastructure disruptions[a]	• drinking water and wastewater • telecommunications • transportation (failure of road and rail traffic signals) • hospitals/health care (loss of power to medical machinery and instrumentation, such as ventilators and dialysis machines) • emergency services • energy sector[b]
Supply chain disruption	• Impact on businesses that did not lose power, but were negatively affected because they rely on businesses that lost power

Source: GAO analysis of reports and documents that describe the range of effects of power outages. I GAO-21-346

[a]Critical infrastructure generally has backup power generation but these work only for limited periods, and in some cases, fuel disruptions because of refinery and transport disruptions result in fuel shortages that affect backup power.

[b]According to the U.S. Department of Energy (DOE), electric service disruptions also significantly affect the reliability of other parts of the energy sector. These losses are of special concern because outages caused by climate effects can be widespread and affect large geographic areas at once, according to DOE. Failure of electrical equipment (e.g., electrical lines, pumps) can shut down steam boilers, cooling towers, pumps, and electrically operated safety control mechanisms in oil and gas refineries, pumping stations, terminals, and other facilities. Besides the lost revenue and other costs associated with equipment damage in these sectors, disruptions can lead to disruption in fuel deliveries, worsening the effects of power outages for consumers. For example, following Hurricane Sandy in 2012, power outages caused widespread gasoline shortages in New Jersey and New York, limiting the ability of consumers to run generators.

In recent years, power outages resulting from extreme weather events have affected millions of customers. For example,

- In February 2021, extreme cold weather from the Canadian border as far south as Texas resulted in record winter power demand and left about 4.5 million customers in Texas without power, along with about 376,000 customers in Louisiana and Oklahoma.
- In 2019, dry and windy conditions in California that increased the risk of wildfires resulted in public safety power shutoff events that affected more than 1 million customers with an estimated economic cost of $2 billion.[43]
- In July 2019, a heat wave in the Northeast contributed to two power outages and resulted in over 100,000 customers in New York City losing power. The outages disrupted commercial activities, transportation systems, and traffic control operations.

[43]Rocky Mountain Institute, *Reimagining Grid Resilience* (2020). Three utilities in California are authorized to perform public safety power shutoffs in fire-prone areas to prevent wildfires caused by energized transmission and distribution lines. In October 2019, one California utility announced that it would issue $86 million in credits to its customers for one of these public safety power shutoffs.

- In September 2017, Hurricanes Irma and Maria damaged Puerto Rico’s electricity grid, causing the longest blackout in U.S. history.
- In August 2017, Hurricane Harvey left over 300,000 customers in Texas without power after the storm damaged electricity generation and transmission lines. The power outages affected critical infrastructure, such as hospitals, water and wastewater treatment plants, and refineries, and contributed to an increase in gasoline prices, regionally and nationally.
- In October 2012, Hurricane Sandy disrupted power service to over 8 million customers in the Northeast as the result of damage to generation, transmission, and distribution equipment. The most severely affected areas saw record winds and storm surge, including a 14-foot storm surge in Manhattan.

In addition to the costs of power outages to utility customers, extreme weather associated with climate change can increase the financial risk to utilities by contributing to sharp increases or declines in demand for electricity, according to one report.[44] Specifically, extreme weather conditions require more backup generation, which increases costs and can heighten the risk of system stress and service interruptions, according to this report. This may raise electricity prices as utilities add capacity to meet demand, thereby increasing costs to customers. For example, according to the Fourth National Climate Assessment, if greenhouse gas emissions continue unabated, the effects of climate change could require new generation capacity costing utility customers an estimated $30 billion per year by midcentury.

In addition, utilities and other entities, such as the federal government, also incur costs from storm damage resulting from severe weather. These costs could increase as the frequency and intensity of weather events increase in the future. According to one report, total annual expenditures for transmission and distribution infrastructure in the contiguous United States were found to increase with climate change by as much as 25

[44]Moody’s Analytics, *Regulated Electric Utilities in the United States: Intensifying Climate Hazards to Heighten Focus on Infrastructure Investments* (January 2020). Sharp volatility in demand could affect liquidity because utilities will need to buy or sell power or natural gas as demand fluctuates.

percent (or about $25 billion) in 2090 as compared with annual expenditures in 2015.[45]

To minimize the occurrence of power outages and enhance the resilience of grid infrastructure to the effects of climate change, utilities and government entities are investing in resilience measures.[46] For example:

- Following Hurricane Sandy, Con Edison, the utility that serves New York City, planned to invest $1 billion to make the grid more resilient to the potential effects of climate change. Con Edison reported damage to five transmission substations and the loss of about 1,000 utility poles, and more than 900 transformers. Power restoration following the storm required crews from over 100 companies in 34 states to help conduct repairs to the grid. According to utility documents, Con Edison has spent $847 million on resilience measures, including floodwalls, submersible transformers, and flood proofing at substations and generating stations.
- To protect its nuclear power plants from damage, the Tennessee Valley Authority has spent $153 million on modifications and improvements related to extreme flooding preparedness, and expects to spend an additional $27 million to complete the modifications, according to Tennessee Valley Authority financial filings.

[45]Charles Fant et al., *Climate Change Impacts and Costs to U.S. Electricity Transmission and Distribution Infrastructure* (January 2020). According to the report, total annual increase in expenditures on transmission and distribution infrastructure due to climate change could range from $6 billion to about $25 billion with climate change by 2090 as compared with annual expenditures in 2015, but expected costs are estimated to decrease by half if resilience measures are adopted. The report estimates these costs using two emission scenarios and three response cases—(1) no adaptation, (2) reactive adaptation, and (3) proactive adaptation. The $6 billion increase estimate is associated with a proactive adaptation strategy under a climate scenario where greenhouse gas emissions have been “significantly” reduced, while the $25 billion increase estimate is associated with a substantial warming scenario due to high emissions and with no adaptation strategy. It considers temperature, precipitation, lightning, wildfires, and vegetation growth but does not consider floods, high winds (including hurricanes), or ice storms. All figures reported here have been converted to 2019 dollar values.

[46]Some stakeholders we interviewed told us that there is a need to lower emissions and invest in resilience. Lowering emissions could enhance resilience because doing so would lessen the effects of climate change on grid infrastructure, according to one stakeholder. According to the Fourth National Climate Assessment, neither global efforts to mitigate climate change causes nor regional resilience efforts currently approach the scale needed to avoid substantial damage to the U.S. economy, environment, and human health over the coming decades.

- Following Hurricanes Irma and Maria, federal agencies provided about $3.9 billion to help restore electricity service in Puerto Rico, including temporary or partial repairs, such as attaching electricity lines to damaged poles.[47] More recently, the Federal Emergency Management Agency (FEMA) has committed $10 billion to fund longer-term grid improvements in Puerto Rico.[48]

Figure 4 provides examples of measures that could enhance grid resilience to potential climate change effects.

[47]GAO, *Puerto Rico Electricity: FEMA and HUD Have Not Approved Long-Term Projects and Need to Implement Recommendations to Address Uncertainties and Enhance Resilience,* GAO-21-54 (Washington, D.C.: Nov. 17, 2020).

[48]GAO-21-54.

Figure 4: Examples of Resilience Measures

Flood protection

- Elevate substations, control rooms, and pump stations
- Build or strengthen berms, levees, and floodwalls
- Install flood monitors

Substation floodwall during Hurricane Harvey.

Wind protection

- Inspect and upgrade transmission and utility poles
- Bury power lines underground
- Improve vegetation management

Example of a utility pole inspection and upgrade.

Drought protection

- Expand low water-use power generation, such as solar
- Adopt water-efficient approaches to cooling thermoelectric plants
- Utilize nonfreshwater sources

Example of solar panel use in drier conditions.

Sources: GAO analysis of reports and documents, CenterPoint Energy; Jamie Hooper, and Wirestock/stock.adobe.com. | GAO-21-346

Text of Figure 4: Examples of Resilience Measures

Flood Protection	• Elevate substations, control rooms, and pump stations • Build or strengthen berms, levees, and floodwalls • Install flood monitors

Wind Protection	• Inspect and upgrade transmission and utility poles • Bury power lines underground • Improve vegetation management
Drought Protection	• Expand low water-use power generation, such as solar • Adopt water efficient approaches to cooling thermoelectric plants • Utilize nonfreshwater sources

Sources: GAO analysis of reports and documents, CenterPoint Energy; Jamie Hooper, and Wirestock/stock.adobe.com. | GAO-21-346

Note: For additional information on measures adopted by utilities to improve grid resilience and minimize damage from flooding, storm surges, and high winds, see GAO, *Electricity Grid: Opportunities Exist for DOE to Better Support Utilities in Improving Resilience to Hurricanes*, GAO-21-274 (Washington, D.C.: Mar. 5, 2021). In addition to the flood protection examples in the figure, utilities have also installed network protectors that contain flood monitoring sensors that detect when there is an abnormal water level near an electrical facility, such as a substation. Network protectors also insulate electrical facility equipment from flooding, thereby enabling the equipment to function when submerged in water. Utilities have also adopted technologies that enhance operational capacity and can help provide quick restoration of service. For example, some automated technologies provide enhanced communication capabilities; monitor electrical systems to detect, locate, and repair sources of service disruptions; and continue service through part of the grid when the central grid experiences a service disruption.

Investments in measures to enhance resilience can be expensive and it can be difficult for utilities to calculate the return on such investments because the benefit typically is realized only when a major event threatens the reliability of service. As a result, these investments can be difficult to justify, and utilities must balance the need to enhance resilience with the associated costs, which could result in increases to the rates charged to customers.[49] Further, increases in rates could disproportionately affect low-income populations that spend a greater portion of their income on energy expenses. It is important for utilities and other stakeholders to take vulnerable and disadvantaged populations into account when planning for and investing in resilience because many customers cannot afford rate increases to pay for resilience investments, according to several stakeholders and reports we reviewed.

[49]In our March 2021 report, we found that most utilities recover the cost of resilience measures through rates paid by the utilities' customers. Utilities face challenges justifying investments and obtaining regulatory approval, and some utilities have limited resources to pursue resilience enhancements, such as researching grid resilience technologies. GAO, *Electricity Grid: Opportunities Exist for DOE to Better Support Utilities in Improving Resilience to Hurricanes*, GAO-21-274 (Washington, D.C.: Mar. 5, 2021).

DOE and FERC Have Taken Actions to Enhance Grid Resilience and Have Opportunities to Further Address Climate Change

DOE and FERC have taken some actions since 2014 to enhance the resilience of the electricity grid. According to stakeholders we interviewed and reports we reviewed, opportunities exist for DOE and FERC to take additional actions to further enhance the resilience of the grid to climate change.

DOE Has Taken Actions to Enhance Grid Resilience to Potential Climate Change Effects since 2014

Since 2014, DOE has provided information and technical assistance, supported research through its Grid Modernization Initiative and other efforts, and developed resilience tools.[50] While not all of these actions directly address climate change risks, they could yield climate resilience benefits.

- **DOE provided information and technical assistance.** DOE has provided information and technical assistance to utilities and states, and has partnered with other federal agencies on these efforts.[51] For example, in 2015, DOE established the Partnership for Energy Sector Climate Resilience with utility owners and operators to help them plan

[50]According to DOE documents, the Grid Modernization Initiative works across DOE to help create a modern grid of the future. According to DOE officials, DOE's Grid Modernization Initiative has invested over $30 million in developing Resilient Distribution Systems through a solicitation with the Grid Modernization Laboratory Consortium (GMLC). The GMLC is a strategic partnership between DOE's headquarters and 13 DOE National Laboratories. According to DOE, the GMLC brings together leading experts and resources to collaborate on national grid modernization goals.

[51]This is consistent with the Disaster Resilience Framework, which states that federal efforts should improve the availability of authoritative, understandable, and comprehensive information on disaster risks and risk reduction strategies in order to help entities effectively assess their climate risks, determine what viable alternatives are available to increase resilience to those risks, and better understand and measure the impact of resilience strategies. Furthermore, bringing together the disparate missions and resources that support disaster risk reduction can help build national resilience to natural hazards. See GAO-20-100SP.

for climate change. Through the partnership, DOE collaborated with 18 utilities, published several reports and guidance documents, facilitated webinars to help members develop climate change vulnerability assessments, and provided other technical assistance to utilities.[52] DOE also facilitated the sharing of climate science information by other federal agencies, such as the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA), to support the development of the vulnerability assessments.[53] DOE officials we interviewed told us that the agency, in collaboration with members of the partnership, developed several draft reports addressing methods for conducting a cost-benefit analysis of energy resilience investments, attributes of resilience, and a compendium of federal programs that provide funding assistance for resilience investments.[54] Some members we interviewed said that DOE's partnership provided a forum to share best practices with member utilities and found the partnership valuable. DOE was assessing whether to continue actions related to the partnership as of January 2021.[55] DOE also facilitates

[52]Utilities that joined the partnership committed to identifying vulnerabilities to energy infrastructure assets and operations from extreme weather and climate change effects. DOE, Office of Energy Policy and Systems Analysis, *A Review of Climate Change Vulnerability Assessments: Current Practices and Lessons Learned from DOE's Partnership for Energy Sector Climate Resilience* (Washington, D.C.: May 2016); DOE, *Climate Change and the Electricity Sector: Guide for Climate Change Resilience Planning* (Washington, D.C.: September 2016); and DOE, *Climate Change and The Electricity Sector: Guide for Assessing Vulnerabilities and Developing Resilience Solutions to Sea Level Rise* (Washington, D.C.: July 2016).

[53]According to DOE officials we interviewed, climate change information is generated by other federal agencies, such as NOAA and NASA. These agencies work to identify and provide tools, methods, and down-scaled extreme weather information (e.g., temperature, precipitation, drought, wildfire, sea level rise, etc.) for utility resilience planning, according to these officials.

[54]Craig Zamuda et al., *Resilience Management Practices for Utilities and Extreme Weather* (November 2019); Craig Zamuda et al., *Monetization Methods for Evaluating Investments in Electricity System Resilience to Extreme Weather and Climate Change* (November 2019); Craig Zamuda and Anne Ressler, *Federal Adaptation and Mitigation Programs Supporting Community Investment in Electricity Resilience to Extreme Weather* (October 2020).

[55]According to DOE officials, as part of this assessment, DOE worked with members to identify priority gaps and needs in the summer of 2020. For example, members identified a need to increase awareness of available climate information and technical assistance from DOE, NOAA, and NASA; and federal resilience funding opportunities. Members also identified a need for guidance on how to assess the benefits and effectiveness of resilience measures, information on how to work with vulnerable or disadvantaged communities, and how to develop an enhanced understanding of various natural hazards.

communication between the government and the private sector, including holding meetings with the Electricity Subsector Coordinating Council (ESCC).[56] These efforts are not focused on climate change, but the ESCC recently partnered with government leaders to address wildfire risks.

DOE also provided information and technical assistance to states. For example, according to a DOE report and agency officials we interviewed, in 2016, DOE collaborated with state and regional organizations through the State Energy Risk Assessment Initiative to raise state officials' awareness of the risks to their energy infrastructure. DOE worked with states to help them make decisions on resilience solutions, energy system and infrastructure investments, energy assurance planning, and asset management.[57] While this effort has not continued, DOE's Office of Cybersecurity, Energy Security, and Emergency Response is currently updating the Energy Risk Profiles that examine the relative magnitude of risks at a state and regional level, according to DOE officials.[58] In addition, according to DOE documents, DOE works with state and local governments through the State Energy Assurance Plan Assistance program to develop information and tools and to conduct forums, training sessions, and tabletop exercises for energy officials, emergency managers, policy makers, and industry asset owners and operators. Furthermore, DOE officials told us that they developed a Distribution Resilience Decision Framework—a multiyear project on this topic—in

[56]The ESCC includes chief executive officers and executives from electric companies, public power utilities, and rural electric cooperatives, as well as their trade association leaders. According to its charter, the purpose of the ESCC includes coordinating activities and initiatives designed to improve the reliability and resilience of the electricity subsector, including the electricity grid, and serving as the principal liaison between the council's membership and the Energy Sector Government Coordinating Council (EGCC). DOE co-chairs the EGCC—the government counterpart to the ESCC—in coordination with the U.S. Department of Homeland Security. According to its charter, the EGCC serves as a single point of contact to facilitate communication between the government and the private sector when preparing for and responding to issues and threats resulting from physical, cybersecurity, or weather-related disasters of national significance impacting the energy sector. The EGCC includes representatives from various levels of government (federal, state, local, territorial, and tribal).

[57]DOE, *Climate Change and the Electricity Sector: Guide for Climate Change Resilience Planning*.

[58]DOE's State and Regional Energy Risk Profiles can be found here: https://www.energy.gov/ceser/state-and-regional-energy-risk-profiles [last visited Jan. 27, 2021].

consultation with states and utilities to help them and utility regulators make better decisions about utilities' resilience investments.[59]

DOE also partnered with other federal agencies to provide climate information and technical assistance, according to DOE officials we interviewed. For example, DOE participates in the Climate Data Initiative and contributes to the Climate Resilience Toolkit to provide information, data, and tools that the public and private sectors can use to increase climate change preparedness and resilience.[60] In addition, according to a 2016 DOE report, DOE collaborates with other federal agencies to advance climate change understanding in the following areas: wildfire management (U.S. Forest Service); storm water modeling (U.S. Geological Survey); and climate science (U.S. Department of Homeland Security, U.S. Environmental Protection Agency, and NASA).[61]

[59]According to DOE officials we interviewed, DOE's Office of Electricity developed a strategy and implementation planning guidebook for state regulators and communities. The reference document includes considerations for distribution resilience planning and decision making resulting from research of the multiyear project. See DOE *Modern Distribution Grid (DSPx) Strategy and Implementation Planning Guidebook, vol. iv* (Washington, D.C.: June 2020).

[60]The Climate Data Initiative is a web portal that provides access to federal climate-related statistics and information to help companies, communities, and citizens understand and prepare for the impacts of climate change, such as coastal flooding and sea-level rise. The Climate Resilience Toolkit is a website designed to help people find and use tools, information, and subject matter expertise to build climate resilience. This interagency initiative operates under the auspices of the U.S. Global Change Research Program. The site is managed by the National Oceanic and Atmospheric Administration's Climate Program Office and is hosted by the agency's National Centers for Environmental Information. U.S. federal government, "U.S. Climate Resilience Toolkit," last accessed on Feb. 2, 2021, https://toolkit.climate.gov/. DOE officials told us that the resulting information generated through its Partnership for Energy Sector Climate Resilience can be accessed through the Climate Resilience Toolkit. See: https://toolkit.climate.gov/topics/energy-supply-and-use.

[61]DOE was a member of the Interagency Climate Change Adaptation Task Force—established in 2009 and co-chaired by the Council on Environmental Quality, the Office of Science and Technology Policy, and the National Oceanic and Atmospheric Administration. It included representatives from more than 20 federal agencies, including DOE. In addition, DOE was a member of the Council on Climate Preparedness and Resilience, established by Executive Order 13653 to, among other things (1) coordinate interagency efforts on priority federal government actions related to climate preparedness and resilience and (2) facilitate the integration of climate science in policies and planning of government agencies and the private sector. Executive Order 13653, *Preparing the United States for the Impacts of Climate Change* (Washington, D.C.: Nov. 1, 2013; revoked in March 2017 by Executive Order 13783).

- **DOE conducted research.** DOE conducts fundamental energy science and energy technology research and development, and climate change is an ongoing part of this research.[62] DOE program offices support a range of research and development activities related to climate change. For example, DOE's Office of Science supports several climate change projects at the National Laboratories. According to DOE officials, one project—the Integrated Multi Scale Sector Modeling Project—evaluates the impact of climate change on the grid, looking at direct and indirect impacts on other sectors or activities.[63] Another project—the Integrated Coastal Modeling project—provides deeper understanding of coastal processes, hazards to critical infrastructure, and integrated responses in the context of climate change, hurricanes, and urbanization in coastal areas, according to officials. In addition, DOE's Office of Energy Efficiency and Renewable Energy funds a range of research, development, and deployment activities related to renewable power, sustainable transportation, energy efficiency, and combined heat and power, which have the potential to improve resilience and mitigate the impacts of extreme weather events.[64]

DOE has also funded laboratory research through its Grid Modernization Initiative and Grid Modernization Lab Consortium (GMLC). Under the GMLC, DOE funded the Midwest Interconnection Seams Study to

[62]This is consistent with the Disaster Resilience Framework, which states that the federal government should provide reliable and authoritative information about current and future risk, and promote consensus around the reliability of the sources and methods that produce disaster risk information. See GAO-20-100SP.

[63]The long-term goals of this project are to develop flexible modeling capabilities that capture the dynamic multiscale interactions among climate, energy, water, land, socioeconomics, critical infrastructure, and other sectors and to use these capabilities to study the vulnerability and resilience of coupled human and natural systems from local to continental scales under scenarios that include short-term shocks, long-term stresses, and feedbacks associated with human decision-making.

[64]DOE was directed by a 2009 law to submit a report to committees of Congress on each effect of, and risk resulting from, global climate change with respect to: (1) water supplies used for hydroelectric power generation and (2) power supplies marketed by each Federal Power Marketing Administration. Omnibus Public Land Management Act of 2009, Pub. L. No. 111-1, § 9505(c), 123 Stat. 991, 1337.

analyze scenarios facilitating regional transfers of electricity.[65] Several stakeholders we interviewed told us that an interconnected grid that facilitates transfers of electricity across the three main interconnections could have several benefits, including enhancing the resilience of the grid to climate change.[66] For example, one stakeholder said that if there is more interconnection, regions can exchange energy and, if local infrastructure goes down, these regions can rely on other regions for power. An interconnected grid could also accelerate the growth of renewable energy, such as wind energy, and help lower emissions, according to another stakeholder. However, DOE officials we interviewed told us that after reviewing early results from the study, the agency decided not to pursue the project further because of other priorities. DOE officials told us that an interconnected grid is unquestionably feasible in engineering terms but that it has yet to be demonstrated whether an interconnected grid would provide substantial economic and other benefits. These questions could be answered conclusively only through a large-scale, multi-million-dollar project requiring collaboration and

[65]At the highest level, the U.S. power system is made up of three main interconnections, which operate largely independently from each other with limited transfers of electricity between them. These three main interconnections are the Eastern Interconnection, which encompasses the area east of the Rocky Mountains and a portion of the Texas panhandle; the Western Interconnection, which encompasses the area from the Rockies to the west; and the Electric Reliability Council of Texas, which covers most of Texas. These interconnections extend into parts of Canada and Mexico. The network structure of the interconnections helps maintain the reliability of the grid by providing multiple routes for power to flow and allowing generators to supply electricity to many load centers. This redundancy helps prevent transmission line or power plant failures from causing interruptions in service to customers.

[66]In June 2020, the House Select Committee on the Climate Crisis recommended that the federal government designate National Interest Electric Transmission Corridors, building on the Interconnection Seam Study conducted by the National Renewable Energy Laboratory. The report stated that a better-connected national grid would enable the country to maximize the use of the lowest-cost sources of renewable energy, which may be located far from population centers. According to the report, federal financial support through loan guarantees or access to the tax credits could facilitate project development. House Select Committee on the Climate Crisis, Majority Staff Report*: Solving the Climate Crisis*. In June 2020, FERC issued a report on barriers and opportunities for high voltage transmission that discussed the benefits of high voltage transmission, including the ability for utilities to share generating resources, enhance the stability of the existing transmission system and help with restoration and recovery after an event. The report also discussed barriers and limitations such as permitting and planning challenges. See Federal Energy Regulatory Commission, *Report on Barriers and Opportunities for High Voltage Transmission*: *A Report to the Committees on Appropriations of Both Houses of Congress Pursuant to the 2020 Further Consolidated Appropriations Act* (Washington, D.C.: June 2020).

coordination among many government agencies and private companies, according to DOE officials.

- **DOE supported development of resilience metrics and tools.** DOE has funded efforts to develop metrics for grid resilience.[67] DOE officials we interviewed told us that there is a need for resilience metrics and that DOE and the National Laboratories are working with states, utilities, and other stakeholders to develop such metrics. DOE officials said that progress has been made but that work remains to develop resilience metrics. In our March 2021 report, we stated that officials from several utilities and some National Laboratories said that the lack of resilience metrics, as well as difficulties quantifying the benefits of resilience, has made it challenging for utilities to justify the costs of adopting resilience measures to their regulators.[68] Specifically, in that report, we stated that without a way to demonstrate the value of such investments, these utilities face challenges justifying investments and obtaining regulatory approvals to increase rates.

In addition, in 2018, DOE's Lawrence Berkeley National Laboratory (LBNL) and an industry partner updated a tool—the Interruption Cost Estimate (ICE) calculator—that LBNL originally released to the public in 2011. The tool aims to help utilities and others estimate short-duration outage costs to customers. The analysis and models used in the ICE calculator are designed to estimate the cost to customers of short-duration outages that do not exceed 1 day. However, utilities can use the tool to estimate some of the benefits of resilience improvements to justify

[67]Examples of metrics for grid operations and resilience include time and cost to recover from an outage, or critical services (e.g., healthcare, public safety) without power. The objective of the resilience metrics project is to define, develop, and validate a set of metrics that can be used to measure progress toward grid modernization. The metrics DOE is developing are not climate change specific metrics but could yield climate resilience benefits. DOE officials we interviewed told us that DOE is working with the Department of Defense on a joint project to characterize energy-related threats at selected military facilities and develop metrics that would reveal which threats would significantly impair a facility's ability to perform its essential functions. These same metrics could then be used to gauge the effectiveness of alternative investments in terms of reducing the facility's vulnerability to specified threats, according to these officials.

[68]GAO-21-274.

investments.[69] DOE officials told us that, in addition to supporting the development and continued availability of the ICE calculator, the agency has also collected information from industry on cost-effective ways to enhance grid resilience to severe weather events to help identify best practices. According to DOE officials we interviewed, DOE plans to publish a summary of this information but there is no timeline for doing so.

In addition, DOE National Laboratories have developed various tools that can help utilities prepare for and respond to weather-related events. For example, Argonne National Laboratory developed the Hurricane Electric Assessment Damage Outage tool, designed to estimate the likely effects of hurricanes on the electricity sector, including restoration needs and number of customers affected. DOE officials also told us that they supported the development of another tool—the Transmission Resilience Maturity Model—developed jointly by the North American Transmission Forum, the Pacific Northwest National Laboratory, and the Electric Power Research Institute. The tool is designed to help utilities prioritize actions and investments to improve the resilience of their systems.[70] DOE officials said that the tool has been validated and refined through pilot tests with several utilities and is now available for general use. The tool was designed to address all hazards, but utilities can apply the tool to evaluate their preparedness for any combination of risks that could threaten the

[69]According to a DOE report, some utilities have used the ICE calculator to demonstrate how it can help estimate the benefits of resilience measures. For example, EBP [formerly known as the Electric Power Board of Chattanooga] used funding from DOE's Smart Grid Investment Grant to deploy 1,200 automatic circuit switchers and sensors to improve reliability. The ICE calculator estimated the benefits of these improvements to consumers at about $26.8 million annually, in the form of avoided customer interruption costs. See DOE*, Climate Change and the Electricity Sector: Guide for Climate Change Resilience Planning.* In March 2019, the Electricity Advisory Committee recommended that DOE consider creating and publicizing broad training webinars on resilience-related tools such as the ICE calculator, and inviting state utility commission staff to these webinars. See Electricity Advisory Committee, *Policy and Research Opportunities for Grid Resilience.*

[70]In August 2020, the National Commission on Grid Resilience recommended that the President issue a Presidential Decision Directive initiating climate impact modeling of a range of future scenarios to identify where it will be safe to site new and upgraded bulk electric transmission. According to the commission report, these planning scenarios should take into account sites critical to national infrastructure, areas threatened by environmental impacts (including sea-level rise, extreme heat, and climate-driven population migration), impacts to the national economy, and enhancements that could be made by public-private partnerships. National Commission on Grid Resilience, *Grid Resilience: Priorities for the Next Administration* (August 2020).

resilience of their transmission system, and help prioritize needed investments, according to DOE officials.

DOE is also working with several National Laboratories to develop an all-hazards risk management tool—the North American Energy Resilience Model—that aims to identify interdependencies with other sectors such as natural gas, and vulnerabilities to the electricity grid. The tool also aims to address the impacts of both natural (e.g., hurricanes, flooding) and man-made threats (e.g., cyber-attacks, electromagnetic pulses).[71] Some stakeholders, including DOE National Laboratory staff we interviewed, told us that as DOE continues to develop the North American Energy Resilience Model, the agency could consider incorporating climate change scenarios and sharing the tool with potential users—such as utilities and grid operators—to help them identify and manage climate change risks. According to DOE, the agency has completed the basic North American Energy Resilience Model modeling and analytics tool including the data sets with interdependency cases on natural gas.

Opportunities Exist for DOE to Take Additional Actions to Enhance Grid Resilience to Climate Change

According to many stakeholders we interviewed and reports we reviewed, opportunities exist for DOE to take additional actions to further enhance grid resilience to climate change, including sharing tools and information to evaluate resilience measures and plan for climate change, and providing incentives, such as grants, to invest in resilience measures.

- **Share tools and information to help evaluate resilience measures and plan for climate change.** DOE could provide information to help entities evaluate investments in resilience by identifying a set of metrics and providing information on the cost of long-term power

[71]For example, the North American Energy Resilience Model aims to integrate other models such as the Hurricane Electric Assessment Damage Outage model developed eight National Laboratories. According to DOE, the North American Energy Resilience Model can and does provide the modeling to show the best use of taxpayer dollars for infrastructure investment (where to install renewable energy and energy storage). In addition, the real-time situational awareness layers are to assess the impact of immediate threats from physical equipment and/or weather, according to DOE.

outages.[72] According to a 2017 National Academies report, establishing a set of resilience metrics and building consensus around these metrics is an important prerequisite for comparing resilience measures and for assessing their costs and benefits. According to another report we reviewed, energy providers face challenges evaluating investments in resilience because of an absence of climate resilience metrics and analytical frameworks.[73] Many stakeholders and DOE officials we interviewed told us that there is a need for a vetted set of resilience metrics that utilities and others can use. DOE is supporting efforts to develop resilience metrics through the GMLC but has not identified a set of agreed-upon metrics that utilities and others can use.[74] In addition, in our March 2021 report, we stated that DOE has funded some case studies to explore these metrics.[75]

DOE could also help entities evaluate investments in measures to enhance resilience by providing information on the cost of long-term power outages. According to many stakeholders we interviewed and reports we reviewed, information on the cost of long-term power outages is needed to help utilities understand the benefits of measures that could enhance resilience and justify investments.[76] Specifically, according to the reports we reviewed and stakeholders we interviewed, the ICE calculator is limited because it only estimates the cost to customers from outages lasting less than a day, and there

[72]According GAO's Disaster Resilience Framework, the federal government could help improve the ability to assess alternatives to address risk. For example, the federal government could contribute to an understanding of approaches for estimating returns on investment, according to the framework. See GAO-20-100SP. In our March 2021 report, we recommended that the Secretary of Energy take steps to better leverage the National Laboratories' emerging grid resilience efforts and technologies by developing a formal mechanism to share this information with utilities. GAO-21-274.

[73]Pacific Gas and Electric Company, *Climate Change Vulnerability Assessment and Resilience Strategies* (November 2016).

[74]According to DOE officials, the Grid Modernization Initiative has done some work developing resilience metrics. In April 2020, the Grid Modernization Lab Consortium issued a report on resilience metrics. According to the report, research results will help regional decision makers prioritize resilience investments. Grid Modernization Lab Consortium, *Grid Modernization: Metrics Analysis (GMLC1.1)—Resilience,* PNNL-28567 (April 2020).

[75]GAO-21-274.

[76]Legislation introduced in the 116th Congress would have directed DOE to develop a report that provides recommendations on how to minimize the need for, effects of, and duration of planned electric power outages that are due to extreme weather conditions. Utility Resilience and Reliability Act, H.R. 7186, 116th Cong. § 4 (2020).

is a need for a tool to calculate the cost of longer-term power outages. Moreover, in March 2019, the Electricity Advisory Committee recommended that DOE direct LBNL to modify the ICE calculator to evaluate costs of power outages beyond 24 hours and support efforts to evaluate investments in resilience measures. However, in DOE's response to the recommendation, the agency stated that expanding the calculator would cost more than $10 million and require extensive support and collaboration from state regulators, utilities, and other relevant groups. DOE officials told us that the agency recognizes the importance of understanding the potential costs of long-term outages, but said that it is difficult to analyze because of the many uncertainties that could affect these costs. According to DOE officials we interviewed, the agency is taking other actions to help utilities understand and measure the impact of resilience strategies, such as supporting the continued public availability of the ICE calculator.

In our March 2021 report, we stated that developing tools that support planning for grid resilience would help utilities evaluate investments in grid resilience.[77] DOE has efforts underway to develop tools for resilience planning but DOE did not have a plan to fully develop these tools.[78] In our report, we recommended that DOE establish a plan to guide the agency's efforts to develop tools for resilience planning, such as performance measures for resilience, a framework for resilience planning, and additional information on the cost of long-term outages.

- **Provide incentives.** According to several stakeholders we interviewed, the federal government has an opportunity to promote resilience by providing financial and other incentives as well as addressing disincentives.[79] DOE can provide financial assistance to further its mission and goals in the form of formula and competitive

[77]GAO-21-274.

[78]GAO-21-274.

[79]This is consistent with GAO's Disaster Resilience Framework, which states that incentives can lower the costs or increase the benefits of risk-reduction measures, which can help stimulate investment by state, local, and tribal governments, individuals, and the private sector. Because much of the nation's infrastructure is not owned and operated by the federal government, many resilience-related decisions ultimately are made by nonfederal actors, and those decision makers face competing priorities, according to the framework. Disincentives, such as confusing or overly complex practices and administrative burden, can discourage participation in resilience programs. See GAO-20-100SP.

grants, cooperative agreements, and prizes (i.e., competitions).[80] DOE officials told us that they plan to release a funding opportunity announcement in fiscal year 2021 to support energy resilience initiatives. According to these officials, the funding is intended to enhance resilience of critical energy infrastructure to mitigate against malicious and natural threats, including extreme weather events resulting from climate change. Officials also told us that DOE is working with the Department of Housing and Urban Development and FEMA to identify resources available to mitigate possible threats to the electricity grid. Several reports we reviewed and stakeholders we interviewed said that a grant program to enhance the resilience of the grid to climate change effects should be targeted to regions in most need and to utilities with fewer resources.[81] As mentioned previously, when planning for and investing in resilience measures, it is important to take vulnerable and disadvantaged populations into account, as several stakeholders told us. For example, one stakeholder said that creating a program to help pay for resilience investments through a cost-sharing mechanism, such as a federal grant, would help mitigate the need to raise electricity rates to fund resilience investments, or make it easier for regulators to approve investments if partially funded through other mechanisms.[82]

In considering the specific actions cited that stakeholders cited, DOE would benefit from having an overall strategy to enhance grid resilience to climate change. According to GAO's Disaster Resilience Framework, such a strategy and the associated planning can help decision makers

[80]Legislation that was introduced in the 116th Congress would have directed DOE to award grants for research and development on technologies and capabilities to help withstand current and projected impacts of a changing climate on electricity grid infrastructure, including extreme weather events and other natural disasters. Grid Modernization Research and Development Act of 2020, H.R.5428, 116th Cong. §4. Another bill from the 116th Congress would have required the Secretary of Energy to establish a grant program to provide grants to states, local governments, and Indian tribe economic development entities to improve preparedness and restoration time to mitigate power disturbances resulting from severe weather and climate change, among other threats. Leading Infrastructure for Tomorrow's America Act, H.R.2741, 116th Cong. § 31101(b)(2) (2019).

[81]According to the Quadrennial Energy Review, the combination of large service territories, minimal staffing, limited budgets, lack of access to tax incentives, and low customer density presents challenges to small utilities addressing new and evolving threats. See *Quadrennial Energy Review (QER) Task Force, Transforming the Nation's Electricity System.*

[82]This is consistent with GAO's Disaster Resilience Framework, which states that the federal government can also provide matching funding to help stimulate partner investment. See GAO-20-100SP.

take coherent and coordinated resilience actions.[83] The framework states that federal efforts can focus on disaster risk reduction by creating resilience goals in all relevant national strategies and by linking those goals to an overarching strategy.

DOE has taken some actions consistent with principles described in our Disaster Resilience Framework. For example, it identified climate change as a risk to energy infrastructure, including the electricity grid, in its *Energy Sector-Specific Plan, 2015,* and in the Second Installment of the Quadrennial Energy Review.

However, DOE does not have a strategy to guide its efforts to enhance the resilience of the grid to climate change. In addition, it has not established goals, objectives, or performance measures for its climate change resilience efforts. DOE officials told us that it has not developed a strategy because the agency currently regards other threats, such as cyber intrusions and electromagnetic pulse, as greater risks to the grid that are of higher priority than weather-related risks.[84] However, the severity of the risks identified by numerous climate change forecasts demonstrates that weather-related events and effects could also be deemed a high priority.

A department-wide strategy could improve DOE's ability to address risks to the grid and enhance grid resilience. Developing and implementing a grid strategy for climate change that defines specific goals and measures progress could help guide DOE's agency-wide grid climate resilience efforts and help the agency prioritize actions to ensure that resources are targeted effectively. For example, such a strategy could describe and prioritize DOE efforts to coordinate with industry and other federal

[83]GAO-20-100SP.

[84]DOE has similar strategies for potential cyber incidents and electromagnetic pulse events. DOE officials told us that they recently began working on establishing a coordinated DOE Defense Critical Electric Infrastructure capability strategy against all-hazards including natural and weather related disasters but this effort does not explicitly consider climate change effects as they pertain to extreme weather events. Subsection 215A(a)(4) of the Federal Power Act defines Defense Critical Electric Infrastructure as "any electric infrastructure located in any of the 48 contiguous States or the District of Columbia that serves a facility designated by the Secretary [of Energy] pursuant to subsection [215A(c) of the Federal Power Act], but is not owned or operated by the owner or operator of such facility."

agencies; conduct research and development through the National Laboratories; and identify incentives, such as existing grant programs.

FERC Has Taken Some Actions to Enhance Grid Resilience

Since 2014, FERC has taken several actions to enhance the resilience of the grid. Specifically:

- **FERC collected and shared information.** In 2018, FERC requested information from grid operators and other interested entities on resilience.[85] In 2019, FERC held a technical conference on the reliability of the grid where stakeholders discussed how NERC should address risks including climate change.[86] In addition, on February 22, 2021, FERC announced that it would open a new proceeding to examine the threat that climate change and extreme weather events pose to electric reliability.[87] NERC also holds webinars and meetings with grid operators to discuss a variety of topics, some of which address climate-related risks.
- **FERC assessed grid vulnerabilities.** FERC, working with NERC, also has assessed grid vulnerabilities through ad hoc efforts that include some potential climate change effects. For example, NERC conducts seasonal assessments of grid reliability and assessments following extreme weather events. In November 2019, NERC's Reliability Issues Steering Committee published a report on reliability risk priorities and identified extreme natural events, such as storms

[85]FERC Docket AD18-7-000. On February 18, 2021 FERC terminated the proceeding and stated that FERC did not believe that any generic action was appropriate. Instead, FERC stated that resilience concerns would be best addressed on a case-by-case and region-by-region basis.

[86]Climate change was not the focus of the technical conference but stakeholders discussed extreme weather and what NERC could do to help prepare for events such as wildfires in the West, hurricanes in the Southeast and extreme cold and blizzards in the Northeast. See: FERC Docket AD19-13-000: 2019 *Reliability Technical Conference Regarding the Bulk-Power System* (June 27, 2019).

[87]FERC announced that the new proceeding will examine how grid operators prepare for and respond to extreme weather events, including, but not limited to droughts, extreme cold, wildfires, hurricanes, and prolonged heat waves.

and wildfires, as risks.[88] The committee recommended that NERC and the six regional entities conduct special assessments of extreme natural event impacts including infrastructure interdependencies and analytical data and insights regarding resilience under severe weather conditions. In addition, in 2019, FERC and NERC issued a report on an extreme cold weather event that caused power outages in the South Central United States.[89] The report included several recommendations to enhance grid resilience, including developing a mandatory reliability standard on cold weather preparedness for generators. In February 2021, FERC and NERC announced a joint inquiry into the operations of the bulk-power system during extreme winter weather conditions in the Midwest and South Central states that contributed to power outages affecting millions of electricity customers throughout the region.

- **FERC approved reliability standards.** NERC officials we interviewed told us that existing standards could help address effects from severe weather.[90] Furthermore, according to several stakeholders we interviewed, existing reliability standards could help address potential climate change effects. For example, these stakeholders told us that an existing transmission planning standard—TPL-001-4 Transmission System Planning Performance Requirements—calls for grid operators to plan for extreme weather events, such as those associated with climate change.[91] Specifically, the standard requires grid operators to conduct studies to assess the impact of extreme events including severe weather. However, the standards are based on historical data, and several stakeholders told us that historical weather patterns may not reflect future conditions

[88]North American Electric Reliability Corporation, Reliability Issues Steering Committee, *2019 ERO Reliability Risk Priorities Report* (Atlanta, GA: November 2019). According to the report, extreme natural events and their potential effects on the reliability of the bulk power system should be monitored and addressed to maintain reliability and improve resiliency.

[89]In January 2018, regional operators in the Midwest and South Central United States called for voluntary reductions in electricity use due to abnormally cold temperatures and higher-than-forecast demand. See 2019 NERC and FERC Staff Report: *The South Central United States Cold Weather Bulk Electric System Event of January 17, 2018* (July 2019).

[90]These NERC officials also noted that NERC's emergency preparedness and operations standards support mitigation of operating emergencies, provide for system restoration, and require event reporting.

[91]TPL-001-4 Transmission System Planning Performance Requirements.

given climate change. Therefore, they may not directly address all future climate change effects.

- **FERC issued market rules.** FERC has issued market rules that could affect grid resilience. For example, in March 2020, it proposed revising its transmission incentives policy to encourage development of transmission facilities.[92] The proposed revisions include encouraging grid operators to participate in regional transmission planning organizations and to consider transmission projects that provide resilience and reliability benefits—including hardening transmission assets against adverse weather events.[93] According to FERC staff we interviewed, the proposed revisions include offering public utilities incentives for transmission projects that provide significant and demonstrable reliability benefits. Generally, increased investment in transmission facilities should lead to a more robust grid that promotes resilience by being better able to respond to disruptive events, according to FERC staff. [94] This matter is pending before the Commission.

  Some stakeholders we interviewed said that incentivizing distributed energy resources and energy storage could enhance the resilience of

[92]According to FERC documents, since the last formal review of FERC's transmission incentives policy, the landscape for planning, developing, operating, and maintaining transmission infrastructure has changed considerably. These changes include an evolution in the resource mix, an increase in the number of new resources seeking transmission service, and FERC's implementation of Order No. 1000, which, according to FERC staff, directed the development of regional transmission planning processes to consider transmission needs driven by reliability, economic, and public policy considerations. In 2011, FERC issued Order No. 1000, which requires that public utility transmission providers participate in a regional transmission planning process and develop a regional transmission plan. See Transmission Planning and Cost Allocation by Transmission Owning and Operating Public Utilities, 76 Fed. Reg. 49,842 (Aug. 11, 2011) (codified at 18 C.F.R. pt. 35). Order No. 1000 also requires public utility transmission providers to consider alternatives to transmission—such as energy efficiency, demand response, energy storage, distributed generation, and combined heat and power systems sited close to load—in the regional transmission planning process. As a result, the order could also promote energy efficiency and demand response, two strategies that some stakeholders we interviewed told us could help enhance the resilience of the grid.

[93]Electric Transmission Incentives Policy Under Section 219 of the Federal Power Act, 85 Fed. Reg. 18,784 (Apr. 2, 2020).

[94]In reference to the electric transmission incentives rule, one stakeholder told us that prudent investments should be recoverable in rates without incentives and that there is little reason to think that transmission providers and developers would need incentives to undertake these projects.

the grid.[95] According to FERC staff we interviewed, FERC has taken steps to ensure access of evolving technologies to markets through recent rulemaking orders, such as orders on storage and distributed energy sources. For example, in February 2018, FERC issued Order No. 841, which aims to address barriers to integrating storage into organized wholesale markets.[96] In September 2020, FERC issued Order No. 2222, which aims to address barriers to participation of distributed energy resources in wholesale markets.[97] According to FERC staff we interviewed, both Order No. 841 and Order No. 2222 may increase the amount of storage and other resources located closer to load—an end-use device or customer that receives power from the electric system. To the extent that more storage and distributed energy resources interconnect with the grid, the grid would be better able to react to disruptive events, according to FERC staff.

[95]As we reported in 2018, storage can provide services that support resilience by helping the grid adapt to changing conditions and potentially disruptive events and, if a disruptive event occurs, to rapidly recover. Specifically, in the event of an outage during which power sources or power lines become unavailable, storage can respond quickly to provide backup power or black start services—the provision of the power necessary to restore a generation plant when power from the grid is unavailable during a major outage. In addition, storage can also support microgrids—systems that can connect and disconnect from the grid depending on operating conditions—that could maintain power for a small area independent of the grid. See GAO, *Energy Storage: Information on Challenges to Deployment for Electricity Grid Operations and Efforts to Address Them,* GAO-18-402 (Washington, D.C.: May 24, 2018). FERC staff we interviewed told us that, if designed correctly, charging batteries prior to power outages or the pairing of local resources, such as solar rooftops with behind-the-meter storage, can allow customers to continue to use electricity during power outages. Storage can also be operated or dispatched to charge during periods of over-generation and then discharged later to reduce reliance on other types of generation according to these officials.

[96]The rule requires that RTOs establish participation models consisting of market rules that recognize the physical and operational characteristics of electric storage resources to facilitate their participation in the RTO markets. Electric Storage Participation in Markets Operated by Regional Transmission Organizations and Independent System Operators, 83 Fed. Reg. 9,580 (Mar. 6, 2018) (codified at 18 C.F.R. pt. 35). In prior years, FERC issued several orders—such as FERC Order Nos. 755 and 792—that also aimed to address barriers to storage participation in organized wholesale electric markets.

[97]Participation of Distributed Energy Resource Aggregations in Markets Operated by Regional Transmission Organizations and Independent System Operators, 85, Fed. Reg. 67,094 (Oct. 21, 2020) (codified at 18 C.F.R. pt. 35). According to FERC, this rule enables distributed energy resources to participate alongside traditional resources in the regional organized wholesale markets through aggregations, opening U.S.-organized wholesale markets to new sources of energy and grid services and could yield several benefits, such as lower costs for consumers through enhanced competition, more grid flexibility and resilience, and more innovation within the electric power industry. According to FERC staff, as of March 2, 2021, a rehearing for Order No. 2222 was pending.

This is because locating resources closer to load may allow customers, communities, distribution utilities, and others to operate independently of the grid, if there is a loss of power, according to FERC staff.

Opportunities Exist for FERC to Take Actions Focused on Climate Change

Opportunities exist for FERC to take specific actions to further enhance grid resilience to climate change, according to several stakeholders we interviewed and documents we reviewed. The actions stakeholders identified include developing climate resilience standards and guidance; identifying statutory changes needed to address climate change risks; and examining whether and how the Commission should consider climate change risks when reviewing and approving projects, such as hydropower facilities. Some stakeholders we interviewed suggested that convening a technical conference would facilitate the sharing of information that could assist FERC in making decisions about specific actions FERC could take to enhance the resilience of the grid to climate change.[98]

- **Climate resilience standards.** Some stakeholders told us that FERC could require NERC to update reliability standards to specifically address climate change.[99] In addition, in 2017, the Quadrennial Energy Review recommended that the federal government take formal steps to update reliability standards and planning requirements to increase resilience to emerging and rapidly evolving hazards, such

[98]Some stakeholders we interviewed told us that FERC has an opportunity to convene stakeholders from different sectors and entities who do not typically work together at a technical conference on climate change risks. Another stakeholder suggested that FERC establish a state energy policy advisory function at FERC, where state entities would routinely provide input and advice to FERC staff and commissioners. According to this stakeholder, involving the states is essential to address the risks presented by climate and other threats. According to our Disaster Resilience Framework, the federal government has an opportunity to act as a trusted clearinghouse and integrator of federal and nonfederal information in a way that enhances its reach and value. Furthermore, federal efforts can leverage the expertise and resources of other partners across agencies, governments, and industry sectors, bringing together the disparate missions and resources that support disaster risk reduction to help build national resilience to natural hazards. See GAO-20-100SP.

[99]In addition, legislation introduced in the 116th Congress would have directed NERC to develop a resilience standard. Utility Resilience and Reliability Act, H.R. 7186, 116th Cong. § 2 (2020).

as climate change.[100] One stakeholder said that FERC, in collaboration with grid operators, should require relevant stakeholders to periodically "take the pulse" of the grid with a focus on climate change. This stakeholder said that this would provide the federal government with the basis to develop standards and regulations that could significantly affect the grid's ability to respond to future climate change effects. However, some stakeholders told us that national standards may not make sense, given that climate change effects will vary by region.[101] One stakeholder said that national resilience standards could be beneficial, but they should not be too specific; rather, they should be broad enough to allow grid operators to determine how to best enhance the resilience of the grid.

- **Statutory changes.** FERC could also take steps to determine whether statutory changes are needed to adequately address climate change risks to the grid. Section 215 of the Federal Power Act provides for FERC's oversight of grid reliability, but there is no specific requirement that FERC consider climate change in doing so. According to some stakeholders and a report we reviewed, FERC has not addressed climate change risks due to lack of specific direction in the Federal Power Act. One stakeholder we interviewed stated that Congress could specifically require that FERC, NERC, or grid operators study how climate change will affect the grid and develop a plan for managing any adverse effects. This stakeholder said that this could be done by amending the Federal Power Act or new legislation. FERC staff we interviewed told us that legislative action to modify the Federal Power Act to expressly define FERC's role in incentivizing grid resilience may be helpful to clarify actions that FERC could take in this regard.
- **Project review and authorization.** FERC could examine whether and how FERC should consider climate change risks when reviewing and authorizing projects, such as hydropower facilities. According to some stakeholders we interviewed, FERC could require that operators of these facilities account for climate change effects when designing

[100]Quadrennial Energy Review (QER) Task Force, *Transforming the Nation's Electricity System.*

[101]In June 2020, the House Select Committee on the Climate Crisis also recommended developing resilience standards for components of the bulk electric system for hazards such as wildfires; floods; extreme heat; and extreme weather events, such as hurricanes. According to the committee, these standards could be tailored to local conditions but provide consistency across the nation and help drive down costs in developing resilient power systems. House Select Committee on the Climate Crisis, Majority Staff Report, *Solving the Climate Crisis*.

or relicensing facilities. Specifically, these stakeholders told us that FERC could develop or update criteria such as engineering guidelines for electricity generation facilities to ensure that facilities are designed to withstand climate change effects. FERC staff told us that FERC considers climate change impacts to specific projects in its environmental reviews. In its review of hydropower proposals, FERC considers historical and recent hydrological data and stream flow information, which would include any alterations due to climate change, and often includes monitoring and provisions that allow FERC to alter license requirements, should environmental conditions change in the future, according to FERC staff. For natural gas projects, FERC analyzes physical design considerations that allow facilities, especially coastal liquefied natural gas terminals, to have accounted for potential hurricanes and storm surges, according to FERC staff we interviewed. However, in both cases, FERC has not found any scientifically accepted methods for determining project area specific forecasts of climate change effects, according to staff. According to FERC staff, the Commission recently reopened a review to explore methods to consider climate change impacts in its natural gas pipeline work, which may be useful in assessing climate change impacts to the electricity grid and hydroelectric projects.[102]

In considering these suggestions from stakeholders—developing climate resilience standards and guidance, identifying statutory changes that could help address climate change risks, and examining whether and how the Commission should consider climate change risks when reviewing and approving projects—FERC could take a risk-based approach in determining appropriate actions to take in addressing climate change and resilience. As we have previously reported, risk management should involve identifying and assessing risks to understand the likelihood of impacts and their associated consequences. This assessment enables the organization to plan and implement actions responsive to the highest-priority risks.

FERC has not identified and assessed risks posed to the grid by climate change or planned a response. As previously mentioned, in 2018, FERC requested and collected information on grid resilience.[103] The information

[102]In February 2021, FERC asked for new information and additional perspectives that would assist the Commission with a review of the 1999 Policy Statement on the Certification of New Interstate Natural Gas Facilities. See Certification of New Interstate Natural Gas Facilities, 86 Fed. Reg. 11,268 (Feb. 24, 2021).

[103]FERC Docket AD18-7-000.

FERC collected about grid resilience included information on the potential effects of climate change on the electricity grid and indicated a need to plan for climate change risks.[104] However, while FERC staff told us that they reviewed the record for this proceeding, the Commission has not taken further action on this collection effort or on identifying and assessing specific risks.[105] As mentioned previously, FERC announced that it would open a proceeding to examine the threat that climate change and extreme weather events pose on electric reliability, but FERC has not issued a formal notice for this proceeding. According to FERC's strategic plan, one of FERC's core functions includes protecting and improving the reliable and secure operation of the bulk-power system by identifying reliability and security risks; overseeing the development, implementation, and enforcement of mandatory reliability standards; and promoting the resilience, reliability, and security of the bulk-power system.[106] However, according to FERC staff, FERC has not taken steps to identify or assess climate change risks to the grid or planned a response because the Commission has not directed staff to do so. By taking steps to identify and assess climate-related risks and plan a response, including identifying the actions needed to enhance the resilience of the grid to climate change, FERC could better manage such risks and achieve its objective of promoting resilience.

[104]Several utilities and entities from academia and nonprofits responded to FERC's request and indicated a need to plan for climate change. According to FERC staff, in terminating the proceeding in Docket No. AD18-7-000, the Commission stated that it will continue to work closely with RTOs, ISOs and other public utilities to address grid resilience and take all the appropriate actions to ensure that the electricity grid remains stable.

[105]FERC staff told us that FERC generally does not require reporting on climate-related risks to the electricity grid. However, according to FERC staff, FERC has authority under sections 304 and 307 of the Federal Power Act to require reporting of information necessary for FERC's oversight of the rates and operations of jurisdictional electric utilities, including financial risk disclosures, if FERC finds it necessary. FERC staff noted that this issue is currently being considered by the Securities and Exchange Commission, and if the Securities and Exchange Commission requires additional disclosure requirements, those disclosures would be available for any future use deemed appropriate by FERC.

[106]FERC's strategic plan states that multiple internal and external factors–including threats from extreme weather and natural disasters–are creating challenges and opportunities to maintain and improve reliability, security, and resilience. Federal Energy Regulatory Commission, *Strategic Plan, Fiscal Years 2018-2022.*

Conclusions

Key stakeholders cite changes in the earth's climate that are expected to result in more frequent and intense extreme weather and climate-related events. These changes pose risks to the electricity grid—the power generation, transmission, and distribution system—that can potentially affect the nation's economic and national security. DOE and FERC have taken actions to enhance the resilience of the electricity grid, and they have opportunities to further enhance grid resilience to climate change. DOE has not prioritized climate change resilience and does not have a department-wide strategy to coordinate its efforts to enhance the resilience of the grid to climate change. Developing and implementing a department-wide strategy for climate change, consistent with GAO's Disaster Resilience Framework, that defines goals and measures progress, could help guide and prioritize DOE's efforts and ensure that resources are targeted effectively.

Opportunities also exist for FERC to take actions focused on climate change. While the new proceeding might pose opportunities to do so, FERC has not taken steps to identify and assess climate change risks to the grid and, therefore, is not well positioned to determine the actions needed to enhance resilience. Risk management involves identifying and assessing risks to understand the likelihood of impacts and their associated consequences. By taking steps to identify and assess climate-related risks and plan a response, FERC could better manage such risks to achieve its objective of promoting resilience.

Recommendations for Executive Action

We are making two recommendations, one to DOE and one to FERC.

The Secretary of Energy should develop and implement a department-wide strategy to coordinate its efforts that defines goals and measures progress to enhance the resilience of the electricity grid to the risks of climate change. **(Recommendation 1)**

The Chairman of FERC should direct staff to take steps to identify and assess climate related risks to the electricity grid, and plan a response, including identifying actions to address the risks and enhance the resilience of the grid to climate change. **(Recommendation 2)**

Agency Comments

We provided a draft of this report to the U.S. Department of Energy and the Federal Energy Regulatory Commission for review and comment. We received comments from DOE, which have been reproduced in appendix I. We received comments from FERC staff via email. In addition, DOE and FERC provided technical comments which we incorporated as appropriate.

In its comments, DOE neither agreed nor disagreed with our recommendation. The comment letter states that DOE remains committed to working with FERC and other partners, as appropriate, to strengthen resilience. We continue to believe that developing and implementing a department-wide strategy to coordinate DOE's efforts that defines goals and measures progress to enhance the resilience of the grid to the risks of climate change could improve DOE's ability to address risks to the grid and enhance grid resilience.

In its email, FERC staff stated that they did not have significant concerns with the specific recommendation in the draft report. FERC staff note, and our report acknowledges, that the FERC Chairman has recently announced a new proceeding to examine the threat that climate change and extreme weather events pose to reliability. We believe that the new proceeding that FERC announced might pose opportunities to identify and assess risks posed to the grid by climate change. We continue to believe that taking steps to identify and assess climate related risks to the electricity grid, and plan a response, could better position FERC to determine the actions needed to enhance the resilience of the electricity grid and manage such risks.

As agreed with your offices, unless you publicly announce the contents of this report earlier, we plan no further distribution until 5 days from the report date. At that time, we will send copies of this report to the appropriate congressional committees, the Secretary of the U.S. Department of Energy and the Executive Director of the Federal Energy Regulatory Commission, and other interested parties. 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 me at (202) 512-3841 or ruscof@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.

Frank Rusco
Director, Natural Resources and Environment

Appendix I: Comments from the U.S. Department of Energy

Department of Energy
Washington, DC 20585

March 2, 2021

Mr. Frank Rusco
Director
Natural Resources and Environment
U.S. Government Accountability Office
441 G Street, NW
Washington, DC 20548

Dear Mr. Rusco:

The U.S. Department of Energy (DOE or Department) appreciates the analysis provided by the Government Accountability Office (GAO) in the draft report titled, *ELECTRICITY GRID RESILIENCE: Climate Change Is Expected to Have Far-reaching Effects and DOE and FERC Should Take Actions (GAO-21-346)*.

DOE remains committed to working with FERC and other partners, as appropriate, to strengthen grid resilience. Given the short period of time provided for responding to this report, DOE will perform a full assessment of GAO's report and provide a complete response to GAO's recommendation when it provides its management decision letter to Congressional committees, as required by 31 U.S.C. § 720. Technical comments on GAO's report are provided in an attachment to this letter.

GAO should direct any questions to Charles Kosak, Deputy Assistant Secretary for Energy Resilience, at Charles.kosak@hq.doe.gov.

Sincerely,

Patricia A. Hoffman
Digitally signed by Patricia A. Hoffman
Date: 2021.03.02 10:59:27 -05'00'

Patricia A. Hoffman
Acting Assistant Secretary
Office of Electricity

Text of Appendix I: Comments from the U.S. Department of Energy

March 2, 2021

Mr. Frank Rusco Director

Natural Resources and Environment

U.S. Government Accountability Office 4

41 G Street, NW

Washington, DC 20548

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Technical comments on GAO's report are provided in an attachment to this letter.

GAO should direct any questions to Charles Kosak, Deputy Assistant Secretary for Energy Resilience, at Charles.kosak@hq.doe.gov.

Sincerely,

Patricia A. Hoffman Acting Assistant Secretary Office of Electricity

Appendix II: GAO Contact and Staff Acknowledgments

GAO Contact

Frank Rusco at (202) 512-3841 or ruscof@gao.gov

Staff Acknowledgments

In addition to the contact named above, the following individuals made key contributions to this report: Janice Ceperich (Assistant Director), Celia Rosario Mendive (Analyst-in-Charge), Austin Barvin, and Kelsey Sagawa. Also contributing to this report were Antoinette Capaccio, Tara Congdon, John Delicath, Jaci Evans, Philip Farah, Cindy Gilbert, Paige Gilbreath, Kathryn Godfrey, Leslie Gordon, Susan Irving, Madhav Panwar, Sara Sullivan, J.D. Thompson, and Meg Tulloch.

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