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A Blueprint for Adaptation

Preparing the U.S. and German Energy Systems for the Risks that Climate Change Poses

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Executive Summary

Climate change poses an increasing threat to our electric system which we rely on to support a high standard of living and to keep our economies functioning. Extreme weather events, sea level rise and wildfires not only expose vulnerabilities in our electric system but can have catastrophic impacts when combined with failures in high-voltage electric facilities.

The existing literature on climate policy and climate impacts on the economy is robust. However, there is a limited amount of research to date on the climate vulnerability of critical infrastructure sectors – which are vital for sustaining national security, public safety and national economic security – and in particular of the energy sector.

This project identifies various risks that climate change impacts pose to the critical electric infrastructure in Germany and the United States, including the generation, transmission and distribution facilities, and suggests a political course that both countries can follow. The American States of California and Texas are used as case studies in this report.

Some of the key findings include:

- Extreme weather trends seen in recent decades, such as with growing wildfire and storm surge risk, are expected to accelerate as global temperatures and sea levels rise and the climate becomes more unstable.
- While climate adaptation and resilience policies have been in place for over a decade in both the U.S. and Germany, only more recently have some electricity companies begun to plan for longer-term climate impacts.
- Thermal generation, including natural gas- and coal-fired power plants, and hydroelectric facilities are among the most vulnerable generation sources to climate change.
- Overhead distribution infrastructure in many locations and utility infrastructure in coastal and river flood plains are the most vulnerable to climate change.

This report identifies 34 recommendations for the German, U.S. Federal Government and the state governments of California and Texas. At a high level, these recommendations include:

- Engage in comprehensive vulnerability assessments through at least 2070 and prioritize adaptation and resilience measures. This should be conducted by both governments (primarily federal and state levels) and by the electricity generation, transmission, and distribution companies themselves.
- Where information does not exist, such as an optimal mix of policies and incentives to meet various adaptation and resilience goals, governments should conduct studies and seek stakeholder input.
- Buildings and infrastructure that are rebuilt post-disaster should be built back based on resilience standards so that they will be able to withstand future events. Likewise, climate vulnerability assessments and resilience standards should apply to new facilities requiring permits.
- Market mechanisms and incentives to increase resource adequacy and offset customer electricity demand where possible should be explored.

While the findings and recommendations pertain to the energy sector, the approach of proactively assessing vulnerabilities and prioritizing resilience measures is applicable to all sectors worldwide and to a broad scope of physical and cybersecurity risks.

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Glossary

Adaptation	Adjustment in natural or human systems in anticipation of or response to a changing environment in a way that effectively uses beneficial opportunities or reduces negative effects. (Source: Obama White House Archives)
Adequacy	A measure of the ability of a bulk power system to supply the aggregate electric power and energy requirements of the customers within component ratings and voltage limits, taking into account scheduled and unscheduled outages of system components and the operating constraints imposed by operations. (Source: North American Electric Reliability Corporation (NERC))
Critical Infrastructure Sectors	Sectors whose assets, systems, and networks, whether physical or virtual, are considered so vital to countries that their incapacitation or destruction would have a debilitating effect on security, national economic security, national public health or safety, or any combination thereof. (Source: U.S. Cybersecurity and Infrastructure Security Agency)
General Rate Case (GRC)	A utility regulatory proceeding wherein each of the energy utilities files an application requesting the Public Utilities Commission to authorize and adopt a revenue requirement for its operations and services. (Source: CPUC Decision (D.)14-12-025)
Greenhouse Gas	Gasses that trap heat in the atmosphere. These include carbon dioxide (CO_2), methane (Ch_4), nitrous oxide (N_2O), and fluorinated gases. (Source: EPA)
N-1 Criterion	An elementary principle for the operation and planning of electric networks, and in particular the transmission grid. The power grid must be able to cope with the failure of an important line or other component at any time without causing large-scale power outages. The remaining lines must not be overloaded even if one line fails. (Source: Bundesnetzagentur)
Re-dispatch measures	(Also referred to as redispatching). Reducing and increasing electricity feed-in from power plants according to a contractual arrangement with a network operator or with a statutory obligation towards the network operator with reimbursement of costs. (Source: Bundesnetzagentur)
Reliability	A general term encompassing all the measures of the ability of the system to deliver electricity to all points of utilization within acceptable standards and in the amounts desired. (Source: NERC)
Resilience	The ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions. (Source: Obama White House Archives)
Security	The measure of how an electric power system can withstand sudden disturbances such as electric short circuits or unanticipated loss of system components. (Source: NERC)
System Average Interruption Duration Index (SAIDI)	A system reliability index that measures the average duration of supply interruptions for the low and medium voltage systems per connected end consumer in the respective year. (Source: Bundesnetzagentur)

Abbreviations

ACER	European Union’s Agency for the Cooperation of Energy Regulators
AEP	American Electric Power
APA	Adaptation Action Plan
ASCE	American Society of Civil Engineers
BBPlG	Federal Requirements Plan (Bundesbedarfsplan)
BNetzA	German Federal Network Agency (Bundesnetzagentur)
BMUV	German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety and Consumer Protection (Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbrauchershutz), (formerly the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, BMU)
BMWK	German Federal Ministry for Economic Affairs and Climate Action (Bundesministerium für Wirtschaft und Klimaschutz), (formerly the Federal Ministry for the Economy and Energy, BMWi)
CAISO	California Independent System Operator
CER	Resilience of Critical Entities
COVID-19	Coronavirus disease 2019
CPUC	California Public Utilities Commission
CRI	Climate Risk Index
DAS	German Adaptation Strategy (Deutsche Anpassungsstrategie)
DAX	A market index composed of the 30 major German blue-chip companies trading on the Frankfurt Stock Exchange (Deutscher Aktienindex)
DOE	U.S. Department of Energy
DSO	Distribution System Operator
DWD	German Weather Service (Deutscher Wetterdienst)
ECG	European Union’s Electricity Coordination Group
EC	European Commission
ECI	European Critical Infrastructure
EEA	European Environment Agency
EEG	Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz)
EIA	U.S. Energy Information Agency
EnLAG	Power Grid Expansion Act of 2009 (Energieleitungsausbaugesetz)

ENTSO-E	European Network of Transmission System Operators for Electricity
EnWG	Energy Industry Act of 2015 (Energiewirtschaftsgesetz)
E.O.	U.S. Executive Order
EPCIP	European Programme for Critical Infrastructure Protection
ERCOT	Electricity Reliability Council of Texas
EU	European Union
FEMA	U.S. Federal Emergency Management Agency
FERC	U.S. Federal Energy Regulatory Commission
GHG	Greenhouse gas
GRC	General Rate Case
HVDC	High-voltage direct current
ICARP	Integrated Climate Adaptation and Resiliency Program
IEEE	Institute of Electrical and Electronics Engineers
IMAA	Interministerial Working Group on Adaptation to Climate Change (Interministerielle Arbeitsgruppe Anpassung an den Klimawandel)
IOU	Investor-owned Utility
JRC	Joint Research Centre of the European Union
KLiVO	The German Climate Preparedness Portal (Deutsches Klimavorsorge-Portal)
KomPass	Competence Center for Climate Impacts and Adaptation (Kompetenzzentrum Klimafolgen und Anpassung)
KWRA	Climate Impact and Risk Analysis (Klimawirkungs- und Risikoanalyse)
KVBG	Act to reduce and end coal-fired power generation of 2020 (Gesetz zur Reduzierung und zur Beendigung der Kohleverstromung, Kohleverstromungsbeendigungsgesetz)
LÜKEX	Interstate and Interdepartmental Crisis Management Exercise (Länder- und Ressortübergreifende Krisenmanagementübung (EXercise))
NABEG	Grid Expansion Acceleration Act (Netzausbaubeschleunigungsgesetz Übertragungsnetz)
NAERM	North American Energy Resilience Model
NEP	Transmission Network Development Plan (Netzentwicklungsplan)
O&M	Operations and Maintenance
PG&E	Pacific Gas and Electric
PSPS	Public Safety Power Shutoff

PUCT	Public Utility Commission of Texas
RAMP	Risk Assessment Mitigation Phase
RRC	Texas Railroad Commission
SAIDI	System Average Interruption Duration Index
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
TNMPC	Texas New Mexico Power Company
TSO	Transmission System Operator
TYNDP	Ten-Year Network Development Plan
UBA	German Federal Environmental Agency (Umweltbundesamt)
UNFCCC	United Nations Framework Convention on Climate Change
UP KRITIS	Critical Infrastructure Protection Implementation Plan (Umsetzungsplan Kritischer Infrastrukturen)
WMP	Wildfire Mitigation Plan
WUI	Wildland Urban Interface

1 Introduction

In the morning of February 15, 2021, Texans woke up to an unusual scene: snow, ice and record-low temperatures in a state that is known for having mild winters. A polar vortex event, which is a large area of low pressure in the north pole that drives the jet stream and cold air southward, had caused temperatures to plummet overnight and brought rare, snowy conditions down to Texas. Freezing conditions throughout the state paralyzed Texas's natural gas industry and brought the electric grid within minutes of collapse amidst record high winter electricity demand.[i] Texas had little choice but to initiate rolling blackouts that left millions of Texans freezing in their homes without electricity, water and heat for up to a week.[ii] As many as 700 people died and the event cost $80 billion to $130 billion in economic damages.[iii,iv]

How could an advanced economy like U.S. state of Texas be so badly devastated due to a severe winter storm that might be commonplace in other parts of the U.S. or other advanced economies? Is climate change related to this event and could even more damaging extreme weather events occur more frequently in the future? How could an event like this be avoided or at least mitigated to prevent widespread outages and cascading societal impacts?

What has become clear from events such as the February 2021 Texas polar vortex event and the July 2021 floods in Germany is that climate change is no longer only a concern for future generations or people in the Global South. It is a concern for all of us today including those of us in the rich world.

This paper seeks to answer the questions above not only for the 2021 Texas Freeze and the 2021 German Floods, but for all extreme weather events that pose a risk to the electricity sector. This study tries to understand what that the U.S. could learn from the experience of Germany, Europe's largest economy, to improve its climate resilience policies for the future and better safeguard its electricity sector. Similarly, this report explores what Germany can likewise learn from the U.S.'s experience.

2 Methodology

Literature Review

In preparation for this report, I examined various government publications from several U.S., German and European Union (EU) governing agencies including those at the sub-national level (i.e., state governments). Additionally, this literature included publications from academic and research organizations, electric sector entities, industry associations, and independent media.[1]

[1] I reviewed German government publications from the Bundesnetzagentur (BNetzA), Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbrauchershutz (BMUV) and the Umweltbundesamt (UBA) concerning the Energiewende, transmission network expansion, the Deustche Anpassungsstrategie (DAS) and associated plans and monitoring reports, studies on climate vulnerability and adaptive measures. For instance, I reviewed the 2020 and 2021 BNetzA Monitoring Reports and Annual Reports, and the UBA studies such as the "In-depth economic analysis of individual policy instruments and measures to adapt to climate change." The documents I examined concerning EU-wide matters included policy and regulatory documents from EU bodies such as the European Commission (EC) and the EU Agency for the Cooperation of Energy Regulators (ACER) concerning the Risk Preparedness Regulation, European Critical Infrastructure (ECI) Directive and proposed Resilience of Critical Entities (CER) Directive, EU Climate Adaptation Strategy, and the
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Industry Interviews

In order to gain more direct insight into the adaptation policies and planning methods that are currently in use or envisioned, I interviewed state and regulatory authorities at the German states of Berlin, Bremen and Hesse, as well as the Federal Network Agency (Bundesnetzagentur, or BNetzA). I interviewed a corporate social responsibility manager at RWE, a large German-based multinational renewable and conventional energy generation company, to understand how generation companies are factoring climate risks into the development of new facilities and the company's experience with the July 2021 floods. Additionally, I interviewed the Head of Security Management for transmission at Amprion, who also serves a senior advisor for European Network of Transmission System Operators for Electricity (ENTSO-E) to learn about how transmission system operators (TSOs) are considering climate risk in their planned and existing transmission facilities. Furthermore, I interviewed the emergency crisis team leader at Westnetz, a West German distribution utility and subsidiary of the multinational energy company E.ON, which was heavily impacted by the July 2021 flooding. I also interviewed a senior regulatory analyst at the California Public Utilities Commission (CPUC), who informed me about California's efforts to enhance summer electricity reliability to avoid rotating outages during extreme peak demand events.

German Electric Industry Survey

Despite the potential risks that climate change poses to business's operations, supply chains and facilities, recent survey data suggests that German companies across various sectors may not be adequately assessing these risks.[2,v] To find out how and to what extent the energy sector is assessing and preparing for such risks, I circulated an online survey in July 2021 to registered members of the German Energy and Water Association (Bundesverbrand der Energie- und Wasserwirtschaft, or BDEW). The survey used in this study was composed primarily closed-ended questions that were used in by researchers in the former Chameleon Research Group in a 2011 study, "Why are Utilities Reluctant to Adapt to Climate Change," and original questions by the author. These questions were used to assess what level of progress the energy industry in Germany has made since 2010 – when the Chameleon Research Group conducted their survey – to prepare for the potential impacts of climate change, in terms of enhancing their knowledge and any planned or completed investments or retrofits. These questions were sent to a comprehensive list of BDEW members and their general contacts, which was filtered down to approximately 1,400 private energy companies and municipal utilities.[3] The survey was published online in Google Forms and had both English and German language versions containing 29 questions each.[4] The questions were broken down by the following topics:

EU's Joint Research Centre (JRC) on studies on climate vulnerability among the member states. In terms of U.S. government documents, I reviewed federal- and state-level vulnerability assessments, relevant legislation and executive orders, and state-level adaptation plans. Additionally, I assessed third-party industry and industry association documents from the German transmission system operators (TSOs), U.S. utilities, and the American Society of Civil Engineers (ASCE). I examined academic studies from groups such as the Lawrence Berkeley National Laboratory (LBNL), the Chameleon Research group. Furthermore, I reviewed articles and industry reports from independent media outlets.

[2] For instance, only about half of Germany's 30 largest companies (represented in the DAX 30 Index) – including seven large German utilities – publicly report on the risks posed by climate change. In addition, the DAX 30 companies see themselves more affected by risks and potential cost increases from climate protection and adaptation policies than by the physical risks from climate change itself. (See: https://www.umweltbundesamt.de/sites/default/files/medien/5750/publikationen/reporting-climate-related-risks-survey-summary-2021-02-01.pdf).

[3] Note that the final, filtered contact list included some municipal utilities that did not have an electricity focus and some subsidiaries of larger companies that the BDEW already listed as contacts.

[4] The survey used for this current report largely resembles the Chameleon Research Group's 2011 survey, however the question count on certain topics was reduced, the order was changed and the allowable responses were further limited and made more descriptive. These changes were intended to make the survey

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- Company background;
- Level of the companies' awareness of climate change effects and policy;
- Level of the companies' concern about climate change impacts;
- The companies' consideration of climate and weather data in planning; and
- Investment decisions on long-lasting infrastructure.

The full list of questions can be found in Appendix II of this report.

Electricity Sector Climate Adaptation Webinar Series

In addition to carrying out the other research methods for this report, I organized a two-part webinar series to discuss the challenges and opportunities for climate adaptation and resilience in the U.S. and German electricity sectors before a transatlantic audience of professionals in the energy sector, government and academia. The webinar series included presentations on climate change trends, adaptation and resilience policies, and discussions on best practices for advancing climate adaptation in the electricity sector. Speakers represented organizations such as the Ecologic Institute, Tulane University, Columbia Law School, the U.S. Department of Energy, the German Meteorological Service (Deustcher Wetterdienst, or DWD), ICF International, the Regulatory Assistance Project, Southern California Edison, the Electric Power Research Institute (EPRI), and the BNetzA.[5]

3 Germany

This section provides an overview on the key trends in the German energy sector, the relevant policymakers and regulatory bodies, the predicted climate impacts for Germany and the climate adaptation policies that are intended to address them. Additionally, this section describes the relevant European Union policies that have implications for climate adaptation in Germany's electricity sector.

3.1 Key German Energy Sector Trends

> *"The Energiewende is the German equivalent of the project to get the first man on the moon"*
>
> – Frank-Walter Steinmeier (Current President of Germany), 2015.

The German energy sector is undergoing an extensive transition to mitigate international climate change, which is known as the "Energiewende" in German. The objective of the Energiewende is to eliminate the energy sector's contribution to German greenhouse gas (GHG) emissions – currently more than 80% of the total GHG emissions in Germany – by 2045.[vi,vii] The Energiewende is part of a comprehensive effort to transform Germany into a carbon neutral

easier to complete and more focused on relevant topics. For instance, this study's survey had fewer questions concerning the company background (i.e., removed questions concerning the company's annual revenue, years in operation, and percent of public ownership). This study also modified the questions concerning level of knowledge concerning relevant adaptation and resilience policies to include recent EU regulations and directives and replaced many "yes" or "no" questions and open response questions with multiple choice questions and a supplemental question to allow respondents to elaborate further.

[5] The links to the webinar series recordings are as follows, Day 1: https://www.youtube.com/watch?v=JGdRYXwCz94, Day 2: https://youtu.be/0ao92TnBp68.

economy by 2045.[6] The Energiewende also supports Germany's international climate commitments under United Nations (UN) Paris Agreement, and the EU's European Green Deal and 2021 Climate Law framework to achieve economy-wide GHG neutrality by 2045.[7,viii,ix]

In order to achieve the climate targets in the energy sector, Germany will replace the current energy system reliant on fossil fuel and nuclear generation with a sustainable, and energy efficient system based primarily on renewable energy technologies (renewables). Germany plans to phase out nuclear and coal generation by 2022 and 2038 respectively and switch to 100% renewable energy by 2050. Furthermore, Germany aims to reduce its primary energy consumption by 50% and power consumption by 25% from 2008 levels by 2050.[8]

In this context, Germany is also constructing approximately 7,800 kilometers of new high-voltage electric transmission lines primarily to further connect the wind-rich North to the industrial West and South to relieve current transmission congestion and further support the Energiewende. In addition, Germany is upgrading its distribution system to better accommodate two-way electricity flows, thus allowing for better integration of small-scale renewable energy generation and storage.

Renewable electricity generation

As one of the key pillars to the Energiewende, renewables such as wind and solar energy are to serve as the primary electric generation resources to power the German economy. Germany has set a target of meeting 65% and later 100% of its gross electricity generation with renewables by 2030 and 2050 respectively.[x,xi] However, Germany may need to increase its renewable energy generation to approximately 70% and effectively end its coal consumption by 2030 in order to comply with the April 2021 ruling from the German Constitutional Court on the 2019 Climate Protection Act.[xii]

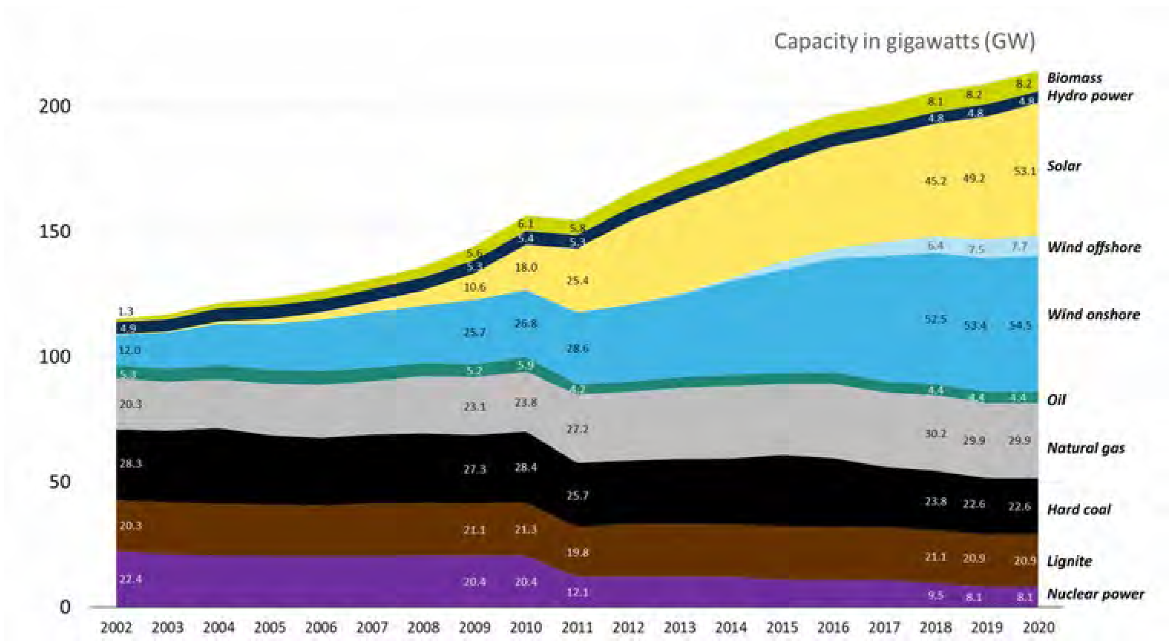
To meet its renewable targets, Germany has grown its renewable capacity by more than 600% over the past two decades from 18.54 gigawatts (GW) in 2002 to 132.59 GW in 2021.[xiii] This dramatic growth can be seen in Figure 1 below.

[6] The German Constitutional Court ruled in late April 2021 that Germany's 2019 Climate Protection Act, which set a timeline for achieving carbon neutrality in 2050, is partly unconstitutional as it placed too great of a responsibility on future generations to reduce emissions. The Court directed the Parliament to determine new plans for reducing emissions from 2030-2045 and develop plans to ensure that carbon neutrality across all sectors is now reached by 2045. (See https://www.dw.com/en/german-climate-law-is-partly-unconstitutional-top-court-rules/a-57369917).

[7] The UN Paris Agreement is the legally binding international treaty on GHG reductions that 196 parties agreed to at the 2015 Paris climate conference (COP 21). The Agreement relies on nationally determined contributions for GHG reductions to keep warming below 2° Celsius. The European Green Deal is the EU's strategy for becoming a carbon neutral continent by 2050, developing a circular economy, reducing pollution and restoring biodiversity. The European Climate Law would legally bind the EU to its Green Deal climate neutrality goals.

[8] Germany also aims to enhance its energy productivity by 2.1 % by 2050. (See https://www.bmuv.de/en/topics/climate-adaptation/energy-efficiency/what-does-energy-efficiency-mean)

Figure 1: Germany's Installed Net Generation Capacity by Fuel Source (2002-2020)



Source: Fraunhofer ISE, 2020.

This rapid growth in renewables was enabled by the Renewable Energy Sources Act (Erneuerbare-Energien-Gesetz or EEG) of 2000, which provided guaranteed feed-in tariffs and prioritized grid-access to renewables.[9,xiv] This helped dramatically grow the market for renewable energy and led to technological advances and economies of scale that have sent wholesale renewable generation costs tumbling.

Following the capacity increase, renewables represented 40.1% and 44.9% in gross electricity production in 2019 and 2020 respectively.[xv] Wind energy represented the largest share at 53% in 2020, of which Northern Germany produced the majority.[xvi] In 2020, over two-thirds of Germany's onshore wind capacity and all of its offshore capacity were concentrated in its northern and northeastern states.[10]

The new government under Chancellor Olaf Scholz is targeting 200 GW of solar photovoltaic (PV) capacity by 2030, which would represent a near four-fold increase from the current capacity levels. The government seeks to increase offshore wind capacity up to 70 GW by 2045 and dedicate 2% of Germany's land area to onshore wind.[xvii]

Coal and Nuclear Exit

As part of the Energiewende, Germany seeks to decommission all of its remaining 4.3 GW of nuclear power and 43.5 GW of coal-fired power plants by the end of 2022 and 2038 respectively.[xviii] Germany committed to decommissioning its nuclear power plants following the 2011 Fukushima nuclear power accident in Japan. As of February 2022, three nuclear power plants remain in operation until the end of 2022, which represent 4.3 GW of capacity in total.[xix] According to the 2020 Act to Reduce and End Coal-Fired Power Generation (Gesetz zur

[9] The EEG also established a surcharge system - equal to about €0.675/kWh or 21% of the average electricity price for households - that was spread across all the electric customers in Germany to help fund renewable energy adoption. (For more information, see https://www.cleanenergywire.org/news/germanys-renewables-levy-rises-slightly-2020).
[10] The primary wind energy producing states are Schleswig-Holstein, Lower Saxony, Mecklenburg West-Pomerania, Brandenburg and Saxony-Anhalt.

Reduzierung und zur Beendigung der Kohleverstromung or KVBG), Germany must reduce its coal power generation capacity based on the following milestones:

- Maximum 30 GW by 31. December 2022;
- Maximum 17 GW by 1. April 2030; and
- A complete phase-out by no later than 31. December 2038.[xx]

By 2023, the BNetzA estimates that an additional 9 GW or more of coal capacity will be decommissioned or converted to other fuels.[xxi] According to the new government Coalition Agreement (Koalitionsvertrag), the government is considering moving the coal exit forward to 2030 following further analysis expected in 2022.[xxii]

German's Grid and Grid Expansion Challenges

The German power grid, serving a population of 83.1 million people and businesses, is about 1.8 million kilometers (km) long in total across all voltage levels and is long enough to wrap around the Earth 45 times.[xxiii] The high-voltage transmission grid, which transmits electricity over long distances (typically hundreds of kilometers), is approximately 37,000 km long, extending through multiple states (known as Länder in German) and consists of voltages ranging from 60 kilovolts (kV) to 380 kV.[xxiv] Over 99% of the transmission lines extend overhead.[xxv] The infrastructure in this grid domain is owned and operated by four transmission system operators (TSOs) (Übertragungsnetzbetreiber) – namely TenneT, Amprion, 50Hertz and TransnetBW.[xxvi] The German transmission system connects with Germany's neighbors and allows Germany to export and import electricity from other countries such as Poland, Czechia, France, the Netherlands and Austria.

Within distribution utility infrastructure, which transmits electricity from substations to load centers (such as cities or industrial areas) and to end-use customers, there are three voltage categories: high, medium and low voltage. As of 2020, there are 874 distribution utilities (Verteilnetzbetreiber) operating in Germany, many of which are municipal owned.[xxvii] Germany's approximately 94,000 km of high-voltage distribution, ranging from 60 kV to 220 kV, distributes electricity primarily to cities and some major industrial enterprises.

The next distribution voltage category is the so-called medium voltage, which ranges from 6 kV to 60 kV and consists of approximately 520,000 km of circuits. The medium voltage grid distributes the electricity over shorter distances to regional transformer substations, or directly to large facilities such as hospitals or factories.

The low voltage grid, which transmits electricity at 230 volts (V) or 400 V, extends approximately 1,190,000 km serving individual households, small commercial and industrial enterprises, including individual office buildings.[xxviii]

Electric Grid Reliability

Germany has one of the most reliable power grids in the world, thanks to its highly meshed network configurations that allows for the re-routing of power during interruption events and due to the fact that the infrastructure is less vulnerable to damage by virtue of being over 82% underground across all voltage levels.[11] When looking at Germany's System Average Interruption Duration Index (SAIDI), which measures the average yearly electric outage time per customer excluding exceptional, sustained outages, Germany's SAIDI in 2019 was 12.2 minutes

[11] According to the German Energy and Water Association, more than 82 % of the 1.84 million kilometers of lines across all voltage levels are underground and only 324,000 kilometers are overhead. (See https://www.bdew.de/presse/presseinformationen/zahl-der-woche-184-millionen-kilometer/)

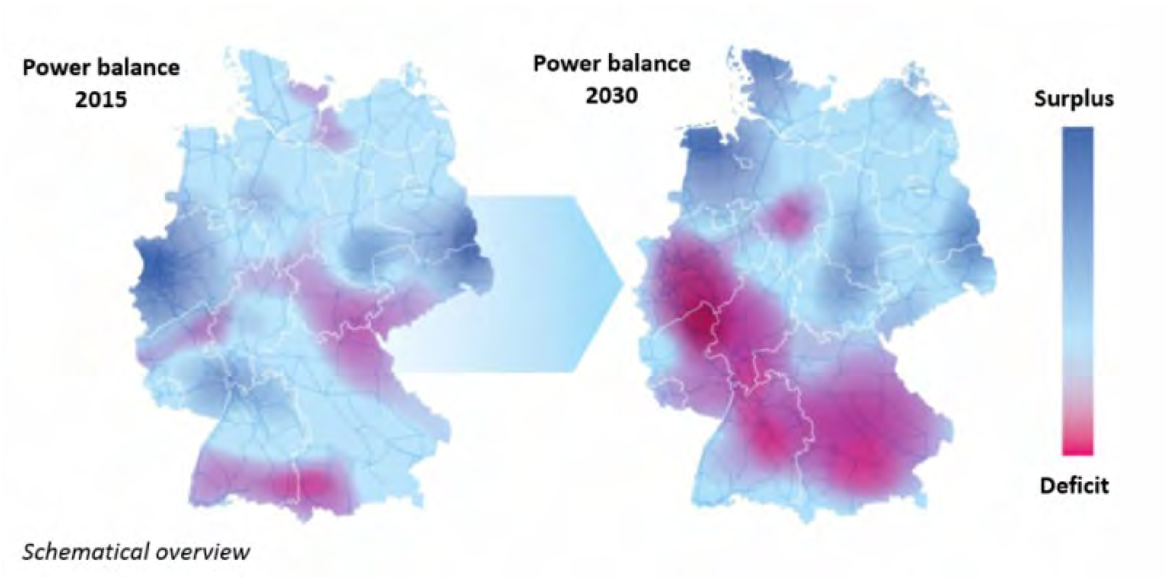
and averaged 15.2 minutes between 2006 and 2019.[xxix] In comparison, the United States, reported a SAIDI figure of 90 minutes in the same year.[12]

Part of this disparity relates back to the capital, operations, and maintenance (O&M) expenditures, which are relatively high in Germany and are reflected in the higher grid charges that Germans pay. To put this into perspective, Germans pay over €0.7/kWh for grid charges (out of a total average volumetric electricity price of €0.30/kWh) while Americans pay half that amount on average (from a total average volumetric electricity price of $0.13/kWh).[xxx,xxxi,xxxii]

Transmission Grid Expansion Efforts

By decommissioning coal and nuclear power plants, Germany's southern load centers will become highly dependent on intermittent renewable energy generation. Since a significant portion of this electricity will come from the North, Germany needs to expand its transmission system to relieve transmission bottlenecks and transport more renewable power to the South. To exemplify how extreme the issue is, the northern state of Schleswig-Holstein produces more electricity than it needs, while Bavaria in southern Germany estimates that it will face a 3 GW capacity shortfall after nuclear power is decommissioned in 2022. This north-south power imbalance is expected to worsen over the next several years as Figure 2 illustrates below.

Figure 2: Power Balance Shift in Germany Looking Forwards to 2030



Source: Amprion, 2020.

Re-dispatch Measures

The expansion of north to south transmission networks has lagged behind the rapid growth of renewables.[xxxiii] This in turn has led to transmission bottlenecks in Germany that threaten to overload the transmission lines and require expensive interventions known as re-dispatch measures (or re-dispatching) in order to relieve the system. Re-dispatching involves power plants on both sides of the bottleneck modulating the electricity they feed into the network in order to counteract the bottleneck and prevent the lines from overloading.[xxxiv] In practice, wind generation in the North must curtail production ("feed-in management")[13] that cannot be

[12] When factoring in the exceptional, sustained outages that SAIDI otherwise excludes, the U.S. figures greatly exceed the German figures as the average American experienced five hours of interruptions in 2019. (See: https://www.eia.gov/todayinenergy/detail.php?id=45796)

[13] Also referred to as "feed-in management", this curtailment of feed-in capacity is conducted at the request of and is compensated by the TSO.

delivered to consumers due to the bottlenecks while reserve power plants[14] in the South (often fossil generation) must ramp-up to meet demand in the South when deliveries from North fail to arrive. However, these re-dispatch measures result in extra costs for customers and may worsen if new planned transmission capacity fails to keep pace with the growth of renewables and decline in conventional generation. For instance, redispatching operations totaled 16,795 gigawatt-hours (GWh) in 2020 at a cost of €443 million, which was significantly higher than the 2019 total of 13,521 GWh at a cost of €373 million. Additionally, feed-in management represented an additional 6,146 GWh at a cost of approximately €761 million, while in 2019, the total was 6,482 GWh at a cost of nearly €710 million.[xxxv]

Transmission Grid Expansion Legislation and Planning Efforts

The two major legislative efforts that have guided transmission grid expansion in Germany are the 2009 Power Grid Expansion Act (Energieleitungsausbaugesetz or EnLAG) and the Federal Requirements Plan (Bundesbedarfsplan or BBPlG). Together these policies mandate the TSOs to upgrade existing and construct new high-voltage lines totaling more than 7,783 km by 2025.[15,xxxvi,xxxvii] In addition to these policies, the Federal Government passed the Grid Expansion Acceleration Act (Netzausbaubeschleunigungsgesetz Übertragungsnetz or NABEG) and the Energy Act (EnWG) in 2011, which were intended to speed up the development of new transmission and place the BNetzA in charge of a reviewing a new joint-TSO scenario framework.[xxxviii] Under the scenario framework, the TSOs specify possible energy market scenarios for energy generation and demand, based on which they develop a joint-TSO transmission Network Development Plan (Netzentwicklungsplan or NEP).

The TSOs propose a new NEP every two years specifying transmission needs into the following decade. The BNetzA reviews and approves the plans, which are then subsequently included as part of the revised BBPlG that the BNetzA submits to the German legislature for approval.[xxxix] In the 2021 NEP which plans out towards 2035, the TSOs have called for an additional 800 to 925 km of transmission expansion and upgrade measures to accommodate expected growth in renewables.[xl]

The German TSOs are also members of the ENTSO-E, which is an association for all the EU TSOs. Similar to the process in the NEP, the ENTSO-E develops a network development plan for the European transmission system called the Ten-Year Network Development Plan (TYNDP). Elements of the TYNDP are included in the NEP and vice versa if German NEP projects are significant for the broader region.[xli]

Status of Transmission Expansion

As of the end of the third quarter of 2021, 22 of the 101 proposed projects (12,241 km in total) for the BBPlG and the ENLAG, were complete representing 1,848 km.[xlii] Six more projects representing 675 km remain under construction and the remaining 73 projects (9,718 km) have thus fare not been approved.[xliii] See the Figure 3 below for more details.

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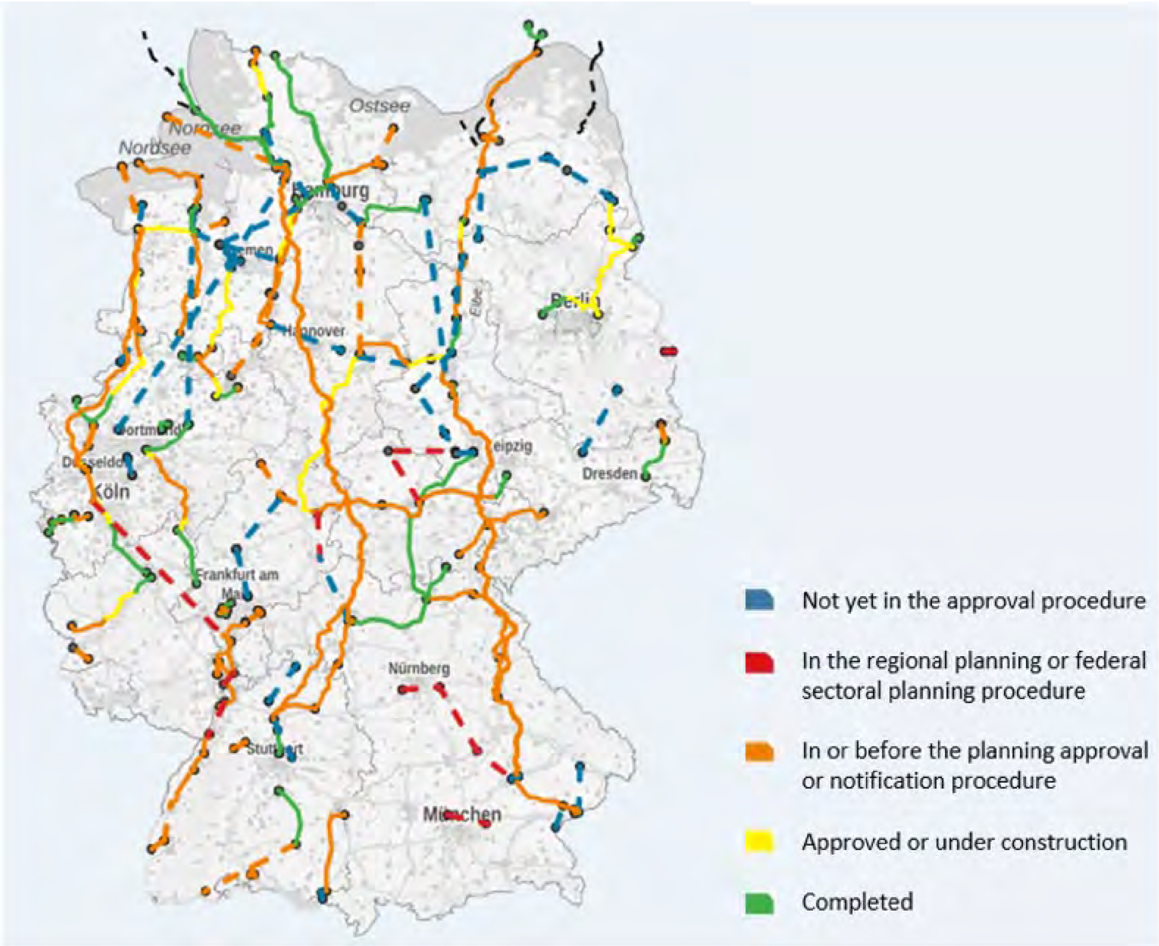
[14] According to the BNetzA, “reserve power plants” refers to generators that deploy reserve electricity capacity to compensate for a capacity deficit according to a contractual arrangement with cost reimbursement.

[15] Notably, four of these new major North-South lines representing thousands of new transmission kilometers (Ultranet, A-Nord, Südlink and Südostlink) will be constructed primarily underground. Also of note, is the Nordlink project, which was completed in May 2021, is a 623 km long line with 1,400 MW of capacity that runs mostly underwater between Germany and Norway allowing Germany to export excess wind to Norway to fill its pumped storage hydropower reservoirs and to import hydropower when needed. (See https://www.tennet.eu/our-grid/international-connections/nordlink/)

Figure 3: Map of EnLAG and BBPlG Status as of the end of Q3 2021



Source: Federal Network Agency, 2022.

The construction of several lines, including all the high-voltage direct current (HVDC) and alternate current lines, will likely be set back by several years due to various delays, such as local opposition, legal challenges and slow planning procedures.[xliv] Despite these delays and the upcoming decommissioning of the remaining nuclear power plants by the end of 2022, the TSOs claim that the security of supply will not be affected. Two of the much-needed North-South "power highways" have reached the final planning stage (Südlink, SüdOstLink). However, two of the other HVDC connections (A-Nord, Ultranet) are facing delays due to further consultations. [xlv]

Distribution System Upgrades

The distribution grid also is undergoing modernization to accommodate growing renewable energy and energy storage penetration, bi-directional power flows (as electric customers with rooftop solar or energy storage export excess electricity back to the grid), and increased sector coupling (including transportation and building electrification).[16] These grid modernization efforts include replacing analog meters with digital smart meters to transmit consumption data directly to the utilities, installing smart inverters to provide voltage regulation and frequency support, peak-shaving with demand response and energy efficiency programs. Grid modernization also includes the deployment of sensors to improve real-time awareness, enhancement of weather forecasting and monitoring, and implementation of various software solutions to

[16] Building electrification refers to substituting the gas heating, cooking and water heating with electric systems.

enable remote distribution monitoring and control.[xlvi] Researchers estimate that distribution upgrade costs required for Germany to achieve its climate change mitigation and Energiewende goals will total more than €100 billion by 2050.[xlvii]

Electricity Consumption Trends

Over the next several decades, German electricity consumption is predicted to grow from approximately 500 TWh in 2019 to 640-780 TWh in 2030 and 1,000-1,570 TWh in 2050.[xlviii,xlix] This growth would be net of energy efficiency gains and would be driven by various sector coupling trends such as vehicle and building electrification (including replacing water heaters with heat pumps), and power-to-X conversion (i.e. using excess electricity to produce hydrogen for fuel cells).[l]

3.2 Political and Regulatory Authorities

Federal Government

The German Parliament, composed of the Bundestag (the lower parliamentary chamber) and the Bundesrat (the upper parliamentary chamber), is responsible for developing the policies and regulations that pertain to the federal and state level. The Parliament often bases these policies on EU precedent or on the Federal Ministries' suggestions.

The Federal Ministry for Economic Affairs and Climate Action (Bundesministerium für Wirtschaft und Klimaschutz or BMWK) (formerly the Federal Ministry for the Economy and Energy, BMWi) is the body primarily responsible for electricity regulation in terms of facilitating network access, rendering balancing services, prescribing new regulations to the Parliament, and oversight through the BNetzA.

Under the auspices of the BMWK, the BNetzA regulates several different industries including energy, communications and rail. In the energy sector, the BNetzA performs tasks and executes powers under the Energy Industry Act of 2015 (Energiewirtschaftsgesetz, or EnWG) in relation to companies with over 100,000 customers and extend beyond state borders.[17]

In addition to the BMWK, the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit und Verbrauchershutz or BMUV), which is the body responsible for environmental regulation, plays an important role concerning the energy sector.[li]

State Government

The 16 German states (Länder) are responsible for regulating distribution utilities and energy suppliers with fewer than 100,000 customers served by their electricity or gas networks, and whose grids are located entirely within the state's borders.[lii] Similar to the BNetzA, the German states regulatory authorities primarily serve as watchdogs for the regulated industries and depend on the federal government to develop regulations for these industries.[18,liii]

[17] The BNetzA's regulatory tasks include: (1) ensuring non-discriminatory network access, (2) regulating the network usage rates levied by the power companies, (3) monitoring for anti-competitive practices, (4) monitoring the unbundling regulations in network areas, and (5) ensuring the electric network operators uphold their system responsibility.

[18] This is contrasted with state regulatory authorities in countries such as the U.S., where the state regulators are in some cases delegated a significant amount of power to develop their own regulations.

European Union

In relation to the laws set in Germany and other EU Member States, European law is superior to the laws and sets precedent for the policies, regulations, decisions, ordinances, etc. on various issues. The Member States may not enact polices that contradict what is enshrined in European law.[liv] Member States such as Germany often either chart their own policy course and influence the EU policy direction on a given matter or adopt national policies following the EU's precedent.

3.3 Climate Change Trends

Germany has experienced significant climate impacts thus far and is among the most vulnerable advanced economies to climate change.[19] Since 2000, there have been more than 20,000 fatalities in Germany related to significant heat waves, storms and floods in major rivers such as the Danube and the Elbe.[lv,lvi,lvii] While there do not appear to be estimates for the total economic costs for this time frame related to such events, they likely run in the tens of billions since events such as the 2002 and 2021 floods were estimated to have cost Germany at least €17-18 billion collectively.[lviii,lix]

Climate Trends and their Implications

Germany has seen its average air temperature climb by roughly 1.6°C (2.88°F) from 1881 to 2019 and has experienced considerable impacts on the regional climate.[20,lx] Nine out of ten of the warmest years since records began occurred after the year 2000 and six of which took place after 2015. [lxi] Notably, 2018 and 2020 were the warmest years on record with annual average temperatures of 10.5°C (50.9°F) and 10.4°C (50.7°F), which exceed the 1960-1991 average of about 8.3°C (46.9°F).[lxii]

The summers in Germany have been trending warmer and drier, while the winters have been getting wetter. For instance, the years 2014–2018 were characterized by both being abnormally warm years with extended drought periods while also having extreme downpours.[lxiii] Reductions in summer precipitation and chronic droughts have caused significant agricultural losses, widespread tree mortality in forests, wildfires, curtailments in thermal power plants and sharp declines in water levels for major rivers. Since the 1960s, time series data for mean water flows for 80 river systems across Germany suggests that summer water levels have been declining.[lxiv] While Germany's river systems have been stressed by heat and drought, the sea levels have been rising. Sea levels on the German North and Baltic Sea coasts have risen by approximately 15-20 centimeters (cm) over the past 100 years.[lxv]

The coming decades will likely see a continuation if not a worsening of the trends described above. Experts estimate that the average annual temperatures in Germany will be 1.5°C (2.7°F) to 2.5°C (4.5°F) higher by 2050 than in 1990.[21,lxvi] By the end of the century, global

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[19] According to Germanwatch, a German non-profit environmental advocacy group, Germany has ranked among the highest in recent years for the annual and the 20-year historical Climate Risk Indices (CRI). The indices, which are based on data on climate-related damages and fatalities from the International Monetary Fund and insurance company Munich RE, list Germany in 3rd and 17th place in the 2018 annual and historical indices respectively following Germany's 2018 drought and record-breaking heat events which were devastating to the agricultural and other sectors. In the 2021 CRI analysis, Germany remains 18th overall in the historical CRI for the years 2000-2019. (See Germanwatch Climate Risk Index for years 2020 and 2021)

[20] According to the World Meteorological Organization, worldwide temperatures as of 2020 have risen 1.2°C (2.2°F) above pre-industrial levels. (See: https://public.wmo.int/en/media/press-release/2020-was-one-of-three-warmest-years-record).

[21] By 2050 temperature increases will range from 1.5°C (2.7°F) to 2.5°C (4.5° F) during the summer and winters will be between 1.5°C (2.7°F) and 3°C (5.4°F) warmer.

temperatures may reach as high as 3.3°C (5.9°F) to 5.7°C (10.3°F) warmer than the 1850-1900 average temperatures according to the Intergovernmental Panel for Climate Change's (IPCC) top-end scenario (Table 1).

Table 1: IPCC Estimated Changes in Global Surface Temperature over Select 20-year Periods by Scenario Relative to 1850-1900 Average

Energy Source	Near-term, 2021-2040		Mid-term, 2041-2060		Long term, 2081-2100	
Scenario	Best estimate (°C)	Very likely range (°C)	Best estimate (°C)	Very likely range (°C)	Best estimate (°C)	Very likely range (°C)
SSP1-1.9	1.5	1.2 to 1.7	1.6	1.2 to 2.0	1.4	1.0 to 1.8
SSP1-2.6	1.5	1.2 to 1.8	1.7	1.3 to 2.2	1.8	1.3 to 2.4
SSP2-4.5	1.5	1.2 to 1.8	2.0	1.6 to 2.5	2.7	2.1 to 3.5
SSP3-7.0	1.5	1.2 to 1.8	2.1	1.7 to 2.6	3.6	2.8 to 4.6
SSP5-8.5	1.6	1.3 to 1.9	2.4	1.9 to 3.0	4.4	3.3 to 5.7

Source: IPCC, Sixth Assessment Report (2021)

Summers will likely see 15% less precipitation, while winters may experience up to 10% more precipitation. [lxvii] Extreme heat and dry spells, such as those seen in 2003, 2018 and 2019 are predicted to occur more frequently in the summer months. According to the European Union (EU) Joint Research Centre (JRC), summer stream flow droughts and heat waves are to become more severe and persistent in Western Europe, with rare, extreme events that may only occur once every 100 years (100-year events) occurring every 2-5 years by the end of the century.[lxviii]

During the winter, storms are likely to become significantly stronger, especially in western Germany. However, extreme cold events are likely to become a rare occurrence if not disappear.[lxix] In terms of river system flooding, the predictions appear to be mixed with some indication for regional increase in Western Europe.[22] The risk of heavy precipitation events, such as those in July 2021 that devastated parts of Germany and neighboring countries, is expected to increase and will further fuel flooding risk. See Figure 4 below. All regions in Germany are at risk and the heavy rain prone northern and western slopes of the Alpine foothills and low mountain ranges are especially vulnerable. [lxx]

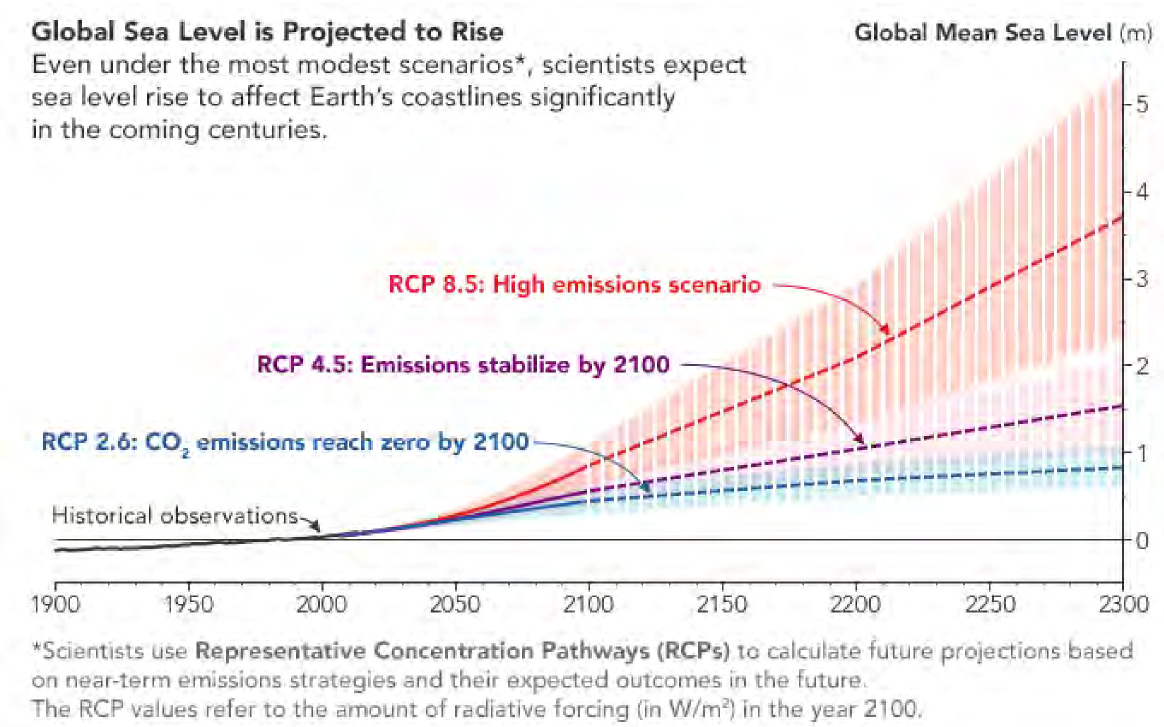
[22] The Interministerial Working Group on Adaptation to Climate Change in its 2019 Monitoring Report of the German Adaptation Strategy indicated that there are no clear historical trends with river floodwater days from 1960-2017. (Interministerial Working Group on Adaptation to Climate Change, 2019, p.8) However, the UBA in a 2015 study on Germany's climate change vulnerability used the EU JRC's LISFLOOD model for simulating hydrological rainfall-runoff and potential floods found that the number of areas in northern Germany affected by river flooding will likely increase in the near future. (UBA 2015, p.528) Similarly, the EU JRC finds that areas in central Europe see their flood risk increase by 26% and others decrease by 15%. They also predict that 100-year river flood events could occur as often as every 30 years in Western Europe. (See EU JRC 2018, p.12).

Figure 4: Heavy Precipitation and Flooding in the Ahr River Valley July 2021 (Before and After)

Source: Deustche Welle, 2021.

Sea level rise will continue to increase by at least 3 mm per year in in the coming decades, increasing by 26-55 centimeters (cm) (0.85–1.8 feet) under the lowest emission scenario to 45-82 cm (1.48–2.69 feet) under the highest emission scenario by the end of the century.[lxxi] Sea levels will continue to rise for hundreds of years approaching between 2.5-5.5 meters (8 to 17.6 feet) by 2300.[lxxii] See Figure 5 below.

Figure 5: Global Projections for Sea Level Rise through 2300 by Warming Scenario



Source: NASA, 2021.

The EU's JRC estimates that 100-year coastal flood events could occur as often as every 2-8 years by 2100.[lxxiii] The UBA in its 2015 vulnerability study also indicate an increased risk of flooding due to storm surges – when seawater moves inland in excess of the typical high tides due to high winds – across almost the entire area of the German North Sea coast.[lxxiv]

3.4 Adaptation and Related Policies – Germany

The EU and German climate adaptation frameworks have been in place for over a decade and have been modified several times over this timeframe. These frameworks have been supplemented by new resilience policies to ensure that the EU and German government and various industry and societal stakeholders are adequately prepared for the evolving threat of climate change. Germany and the EU have engaged with adaptation policies since the 1992 adoption of the United Nations Framework Convention on Climate Change (UNFCCC), through which parties, in addition to committing to climate change mitigation, committed to developing national and regional adaptation programs in accordance with UNFCC Article 4.[lxxv] Dating back to the 2000s, Germany has had an active national adaptation program and the EU similarly adopted a regional program in 2013. Since this time, many of the federal states have similarly formed adaptation plans and begun implementing measures.

German Adaptation Strategy

In 2008, the German Federal Government adopted the German Strategy for Adaptation to Climate Change (Deutsche Anpassungsstrategie or DAS) suggesting potential courses of action in response to possible impacts of climate change on various fields of action (composed of various vulnerable economic sectors, German society, and environmental areas), including the energy sector. The Federal Government considers the DAS to be the second pillar of Germany's climate policy next to climate change mitigation.[lxxvi] The purpose of the DAS is to reduce the vulnerability of German's society, economy and natural environment to climate change and enhance their adaptive capacities to climate risks. In order to achieve this aim, the Federal Government specifies the need to:

- Identify possible long-term climate impacts for Germany and its 16 states;
- Identify and communicate the risks of the various potential climate impacts;
- Raise awareness among various stakeholders;
- Disseminate data and information that can enable stakeholders to incorporate climate change adaptation planning into their overall planning framework;
- Detail options for action, define responsibilities, and devise and implement measures.[lxxvii]

To support the above goals and assist stakeholders, the Federal Government established a few different adaptation clearinghouses for providing adaptation-related data and information to various public and private sector entities:

- **KLiVO** – Launched in 2018, the German Climate Preparedness Portal (Deutsches Klimavorsorge-Portal) is a resource containing data and information on climate change, climate protection (climate change mitigation) and adaptation, as well as services offering guidance for climate change planning and resilience measures;[lxxviii]
- **KomPass** – Since its launch in 2008, the UBA's Competence Center for Climate Impacts and Adaptation (Das Kompetenzzentrum Klimafolgen und Anpassung) has offered various services such as databases, publications, newsletters, climate guides, campaigns, and has hosted events for cooperation and networking;[lxxix]

- **Zentrum KlimaAnpassung** – launched in July 2021, the Climate Adaptation Center offers municipalities and social institutions a central location for obtaining advice on implementing adaptation projects, training opportunities to develop institutional capacity, funding advice, resources, and networking and exchange opportunities.[lxxx]

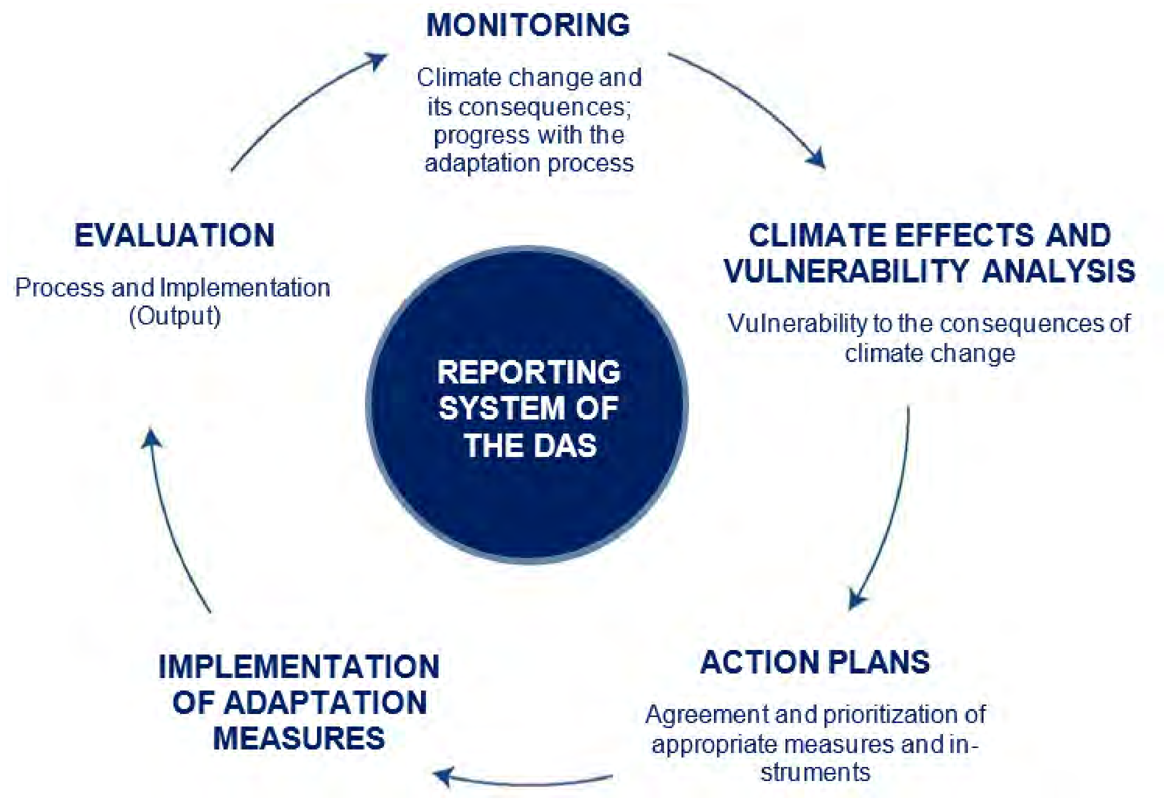
The DAS was designed to be an ongoing, structured, transparent process conducted in consultation with relevant stakeholders, through which the government defines issues and objectives, identifies and resolves potential conflicts, and develops and implements potential adaptation measures.

The BMUV–led Interministerial Working Group on Adaptation to Climate Change (Interministerielle Arbeitsgruppe Anpassung an den Klimawandel or IMAA) is responsible for the monitoring and coordination activities related to the DAS.[lxxxi] Under the DAS framework, the Federal Government is required to regularly prepare the following reports and plans:

- Climate Impact and Risk Analysis (Klimawirkungs- und Risikoanalyse or KWRA) – every six years, the BMUV publishes a vulnerability assessment that identifies the sectors, regions, and climate effects for which actions are required and serves as the basis for the APA. The BMUV published its first version in 2015 and its most recent version in 2021.
- The Adaptation Action Plan (Aktionsplan Anpassung or APA) – every four years, the Federal Government develops an action plan with measures for the various federal departments to carry out based in part on the findings of the vulnerability assessments. The third APA was published in 2020.
- DAS Progress Report – every four years, the Federal Government issues a report assessing the progress made on adaptation measures and presents concrete steps for further development and implementation of the policy framework and measures.
- DAS Monitoring Report – every four years, the UBA provides an overview of the observed impacts of climate change and implemented adaptation measures on various sectors in Germany.[lxxxii] The UBA published the most recent Monitoring Report in 2020.
- Evaluation Report – in 2019, the UBA also published the first of what will become a regular Evaluation Report of the DAS. The evaluation focused on determining if the measures and instruments in the DAS are suitable for achieving the framework's goals and gain insights for further development and optimization of the DAS.[lxxxiii]

The reporting steps are illustrated in Figure 6 below.

Figure 6: German Adaptation Strategy Reporting System



Source: Federal Environment Agency, 2020.

DAS Measures and the Energy Sector

Under the DAS framework, the Federal Government places the responsibility for climate adaptation on the energy sector itself. However, the Federal Government offers that its agencies or the state governments can "provide assistance, contribute knowledge, and set policy priorities" for the energy sector.[lxxxiv] Additionally, the third APA rated the present and near-future risk for thermal power plant cooling water access as medium and included a policy measure for examining how the management of power plant cooling can be optimized, and the state of the art and availability of cooling technologies.[lxxxv] No other concrete measures were named for the energy sector despite the Federal Government identifying moderate risks in the near-future for damage to generation facilities, and changes to demand in energy for cooling and heating.[lxxxvi]

2021 Coalition Agreement Climate Adaptation Agenda

The new ruling coalition under Chancellor Olaf Scholz that came to power in late 2021 has envisioned changes to its climate adaptation policies in light of the catastrophic July 2021 floods that struck Germany. In the Coalition Agreement, the new government plans to issue a Climate Adaptation Law which will include a framework for a new national adaptation strategy and measurable targets. The new government also expresses interest in immediately implementing urgent measures and creating a joint financing plan with federal and state governments for climate adaptation. They describe the need for flood and coastal resilience as a task for society as a whole and intend to financially assist municipalities in these areas and climate resilience more broadly. The government plans to promote innovation, digitization and private-sector initiatives for climate adaptation.[lxxxvii]

UP KRITIS – German Critical Infrastructure Protection

Over the past two decades, Germany's federal and state governments have engaged with critical infrastructure industries to prepare for various crisis scenarios that threaten the German economy and society. This effort began in the early 2000s with the Federal Government's publication of its first Critical Infrastructure Protection Implementation Plan (Umsetzungsplan Kritischer Infrastrukturen) which later became known as UP KRITIS.[lxxxviii] The Federal Government through UP KRITIS has established a robust public-private partnership with federal and state governments and various critical infrastructure providers – identified by the Federal Ministry of the Interior (Bundesministerium des Innern, or BMI) – such as electric utilities and communications companies.[23] UP KRITIS has included various initiatives including nearly two decades of national crisis management exercises (Länder- und Ressortübergreifende Krisenmanagementübung (EXercise) or LÜKEX), including exercises focused on potential climate-related disasters such as storm surges on the North Sea Coast and an extreme winter storm with widespread power outages.[24,lxxxix] Furthermore, the Federal Government through UP KRITIS has fostered close contacts across different industries, developed concepts and protocols (such as for handling confidential information), and a knowledge transfer of best practices for disaster preparedness and response.[xc]

Climate Adaptation at the State Level – Example of Hamburg

At the level of the federal states, most of the state governments have climate adaptation plans and policies that are at various stages of implementation. Similar to the DAS, the state-level plans are focused on major industries and specific risks (e.g., temperature rise, changes in precipitation, heat and cold waves). Most of the states also have contact persons on the topic of adaptation and participate in intergovernmental working groups on the topic.[xci]

A notable example of successful adaptation planning at the state level is at the city-state of Hamburg, which has been implementing sophisticated flood-management measures. Hamburg is the third-largest metropolitan area in Germany with a population of 1.8 million and is home to Germany's largest port.[xcii] Hamburg is in northern Germany and is situated along the Elbe River over 100 km (over 60 miles) from the North Sea.[xciii] Hamburg has a mostly flat topography and is situated at sea-level. It is threatened by river flooding, heavy precipitation, storm surges and sea level rise. The city-state had previously been flooded in 1962 by storm Vincinette, which breached the dike system, inundated about one-fifth of the city, killed 315 people, and left the city-state without power, gas or telephone service for three days.[xciv] Since this disaster, Hamburg has constructed a flood protection system which includes a 25 km (15.6 mile) sea wall and 78 km (49 miles) of dikes, storm surge barriers, locks, pumping stations and dike chutes, and barrier gates.[xcv] Hamburg also incorporates elements such as the Dutch method of building atop artificial mounds called terps which reach up to 8.5 meters (roughly 25 feet) above the high-tide line and have reinforced older, lower-lying neighborhoods to withstand occasional flooding.[xcvi]

In addition to its flood-management efforts, Hamburg has engaged in climate adaptation planning since 2013 and has integrated that effort since 2018 as part of its broader climate plan and a separate Rainwater Structural Plan for 2030. Furthermore, Hamburg's municipal electric

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[23] The BMI classified several different broad critical infrastructure sectors based on how disruptive the consequences of would be to the economy and society if an interruption of such infrastructures were to occur. (See https://www.bmi.bund.de/SharedDocs/downloads/DE/publikationen/themen/bevoelkerungsschutz/kritis.html)

[24] Notably the LÜKEX 4 exercise focused on the extreme winter storm event was carried out one year prior to the Münsterland Winter Storm event that caused widespread outages in Münsterland region in November 2005. (See: https://www.bbk.bund.de/DE/Themen/Krisenmanagement/LUEKEX/_documents/art-luekex04.html;jsessionid=9A957BD0C59215147C32EE0D792B0511.live352)

distribution utility, Stromnetz Hamburg, also conducted a climate vulnerability assessment in advance of its 2020 Sustainability Report and is currently elaborating on a plan for climate adaptation and resilience and will begin implementing adaptation measures in 2022.[25,xcvii] The city has identified rising temperatures, and water-related hazards (flooding and drought) as chief among the climate risks that the city faces. The city plans to monitor and adapt areas at risk of a 200-year and 100-year flood event based on a 6-year review cycle.[xcviii] As for heat management, a notable adaptation measure that the city has planned is to add green roofs and facades on its electric substations to help with passive cooling and rainwater absorption.[xcix]

3.5 Adaptation and Related Policies – European Union

The EU has important policies and regulations in place and under consideration that aim to make the EU a climate resilient society and in particular, prepare the EU's electric utilities and other critical entities to prepare for climate change and other potential threats.

EU 2021 Climate Adaptation Strategy

The European Commission (EC) in February 2021 proposed a new overarching strategy for the EU to become a climate resilient society by 2050.[26] The 2021 EU Adaptation Strategy builds on the 2013 Adaptation Strategy, which required Member States to adopt national adaptation plans or strategies, incorporated adaptation into the EU's policies and long-term budget and established an online data- and knowledge-sharing platform (clearinghouse) called Climate-ADAPT.[c] In June 2021, the European Council formally endorsed the revised Adaptation Strategy.[ci]

The 2021 EU Adaptation Strategy is one of the key elements of the European Green Deal, the EU's sustainable growth strategy, and is to be implemented in tandem with other Green Deal initiatives.[cii] The 2021 Strategy is composed of the following elements:

- Smarter adaptation - The proposed strategy aims to close knowledge gaps to inform effective policymaking, enhance data collection and access, expand upon the Climate-ADAPT clearinghouse, and utilize the latest science and state of the art risk assessment and management tools to enhance societal resilience;
- Faster adaptation – The proposed strategy calls swiftly developing and rolling out adaptation solutions, and supporting the development of additional adaptation solutions such as rapid response decision support tools;
- Systemic adaptation – The EU aims to mainstream climate resilience considerations throughout various national and sub-national levels and across sectors while focusing on integrating adaptation in macro-fiscal policy, utilizing nature-based solutions and prioritizing local adaptation actions; and
- Strengthening international climate resilience – The strategy mentions several options through which the EU could assist other countries such as through supporting EU partner countries in developing incentives and policies to promote adaptation, directing other countries to financing opportunities and collaboration with multilateral development banks, and through stronger international engagement and knowledge exchanges on adaptation.[ciii]

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[25] Stromnetz Hamburg serves 1.1 million households and businesses in Hamburg and operates 55 substations, 7,700 network and customer stations, and has distribution network that is 29,000 km (18,000 miles) long. (See Stromnetz Hamburg)
[26] For more details, see the EC's Communication on a new EU Strategy on Adaptation to Climate Change.

EU 2019 Electricity Sector Risk-Preparedness Regulation

The EU in 2019 established Regulation (EU) 2019/941 on risk preparedness in the electricity sector, otherwise referred to as the 'Risk-Preparedness Regulation', which specifies various requirements for identifying, preventing, preparing for and managing a range of possible electricity crises. This regulation represents a significant step in enhancing the EU's climate adaptive and resilience capacity. Under this regulation, Member States and the ENTSO-E are required to take several actions to ensure that the TSOs adequately prepare for a variety of "rare and extreme natural hazards" among other risks that could have severe national or regional consequences.[civ] As an EU Regulation, the Risk-Preparedness Regulation applies uniformly to all EU Member States and without needing to be transposed into national laws of the Member States.[cv] Prior to establishing this regulation, the Member States identified and managed electric crisis scenarios differently from each other and often disregarded what would happen across their borders during these events.[cvi]

The Risk-Preparedness Regulation requires ENTSO-E to identify the most relevant electricity crisis scenarios for each EU region and submit them to the relevant Member State competent and regulatory authorities and broader regional authorities.[cvii] ENTSO-E is required to reassess these regional crisis scenarios every four years and update its methodology for identifying crisis scenarios whenever significant new information becomes available.[cviii]

Based on the ENTSO-E's regional crisis scenarios, the Member States prepared their first national risk-preparedness plans in consultation with relevant stakeholders such as distribution system operators (DSOs) and electricity producers by January 5, 2022 and shall update their plans every four years thereafter.[cix, 27] Should an electricity crisis occur, the Member States are required to submit an ex-post evaluation report to the EC and EU Electricity Coordination Group (ECG) describing the event, what measures were taken to mitigate the impact and possible improvements for the future.[cx]

2008 European Critical Infrastructure (ECI) Directive and the Proposed 2020 Directive on the Resilience of Critical Entities (CER)

In 2008, the EU established the 2008 European Critical Infrastructure (ECI) Directive, which is exclusively focused on enhancing the resilience of energy and transportation assets.[cxi] The ECI Directive established a common procedure for identifying and designating critical energy and transportation infrastructures and a common approach towards assessing the need to improve the protection of these infrastructures based on reports and security plans. The ECI Directive is a key pillar of the 2006 European Programme for Critical Infrastructure Protection (EPCIP), which articulates the EU's overall policy approach and framework for enhancing critical infrastructure protection based on an all-hazards approach (i.e., all physical and cybersecurity threats).[cxii]

Over the past several years the EU Member States recognized that the existing ECI Directive is too narrow in scope and no longer adequate to address the evolving threat landscape, changes in technology and increasing interdependence between various critical entities. In response to this concern, the EC proposed in 2020 the Directive on the Resilience of Critical

[27] The Member States are required to include but are not limited to the following elements in their national risk-preparedness plans: (1) a summary of the identified electricity crisis scenarios; (2) specify the roles and responsibilities of designated national competent authority; (3) describe procedures and measures in an electricity crisis (including regional and bilateral measures); (4) designate a national crisis coordinator; (5) consult with relevant energy sector stakeholders, such as T&D operators and electricity and natural gas generators; (6) procedures for carrying out emergency testing or exercises;

Entities[28] (CER Directive), to reinforce the resilience of all critical infrastructure owners and operators across various sectors, including those left out of the 2008 ECI Directive. If adopted, the EC's proposed CER Directive would mark a significant step towards establishing a unified and comprehensive policy for preparing critical infrastructure from the energy sector and other critical sectors against climate change and many other potential threats. This proposed policy would serve as one of the building blocks for the new EU Security Union Strategy, which calls for a revised approach to ensuring European physical and cyber-security in light of evolving threats and increasing interdependencies between critical infrastructures.[cxiii]

In contrast to EU Regulations, EU Directives – such as the proposed CER Directive – must be individually transposed into national law by the EU countries (typically within two years from when the Directive is adopted). EU Directives allow the Member States some degree of discretion with their adopted national policies as long as they achieve the Directive's intended result.[cxiv]

The proposed Directive would set requirements for the EU Member States at least every four years to:

- Develop national strategies on the resilience of critical entities;
- Conduct national risk assessments; and
- Identify which infrastructure owners and operators are 'critical entities' based on the national risk assessment and specific, common criteria.[cxv]

In addition to these requirements, Members States shall submit annual progress reports and a final performance report. Under the proposed Directive, the critical entities would also be required to certain requirements, as listed below:

- Carry out their own risk assessments;
- Take appropriate actions to ensure the resilience of their facilities; and
- Notify the Member State competent authorities of any incidents.[cxvi]

4 United States

This section describes key U.S. energy sector trends, the relevant political and regulatory authorities related to the energy sector, the climate change projections for the country and the relevant climate adaptation policies. Additionally, there are two subsections devoted to the case studies for the states of California and Texas.

4.1 Key U.S. Energy Sector Trends

Over the past two decades, the U.S. electric sector has seen a dramatic reduction in coal consumption, increased adoption of renewables, expansion of electric T&D construction and other investments. Many of these trends will continue over the next 20-30 years driven in part by federal climate commitments, the efforts by some states to achieve 100% renewable energy in the 2040s, technological advances and incentives that benefit renewables and the increased investment in grid modernization, hardening reliability and congestion relief.

[28] The full title for the 2020 Directive is "Proposal for a Directive of the European Parliament and of the Council on the Resilience of Critical Entities".

Federal Climate Commitments and Policies

During the April 2021 virtual Climate Leaders Summit, President Joseph Biden announced that the U.S. would cut greenhouse gas emissions 50 to 52% below 2005 levels by 2030.[29,cxvii] President Biden also has set a goal to transition the electricity sector to carbon free by 2035 and net zero emissions by 2050.[cxviii] While the Biden Administration to date has not proposed policies such as a federal renewable energy portfolio standard, a carbon tax or a national coal retirement program, the Biden Administration is leveraging its slim government majority to pass 2 landmark spending packages totalling up to $4.5 trillion. If both bills pass, they could authorize up to $271 billion of funding towards low-carbon energy infrastructure programs and incentives, such as $8 billion for clean hydrogen regional hubs (including production and network capacity) and $7.5 billion for zero emission vehicle infrastructure.[30]

Decline of Coal and Rise of Natural Gas Generation

As recently as 2007, coal-fired generation was the single largest source of net electricity generation representing approximately 50% of the U.S.'s electricity mix with over 2000 billion kWh.[cxix] However, coal generation has plummeted over the past 13 years from its 2007 peak to about 774 billion kWh in 2020, which was the lowest level in approximately 50 years.[cxx] Some of the decline in coal-fired electricity generation is attributable to policy mechanisms in some states to enforce emission standards, but the majority of the decline is due to the falling costs in alternative energy sources such as renewables and natural gas (which coal plants can be converted to utilize), and the development of more efficient natural gas turbine technology.[31.cxxi,cxxii] The U.S. Department of Energy's (DOE) Energy Information Agency (EIA) predicts that coal consumption in 2022 and 2023 will remain at least 11% higher than 2020 levels as the U.S. economy continues to recover from the COVID-19 recession.[cxxiii]

In terms of future trends, researchers predict that more than half of the remaining 218 million kW coal fleet will retire by 2030. [cxxiv,cxxv] However, this decline will eventually taper out and coal is projected to settle around 11% of the U.S. electricity mix – absent of additional policy measures – as the plants that remain after 2030 will be more competitive with renewables (See Figure 7).[cxxvi]

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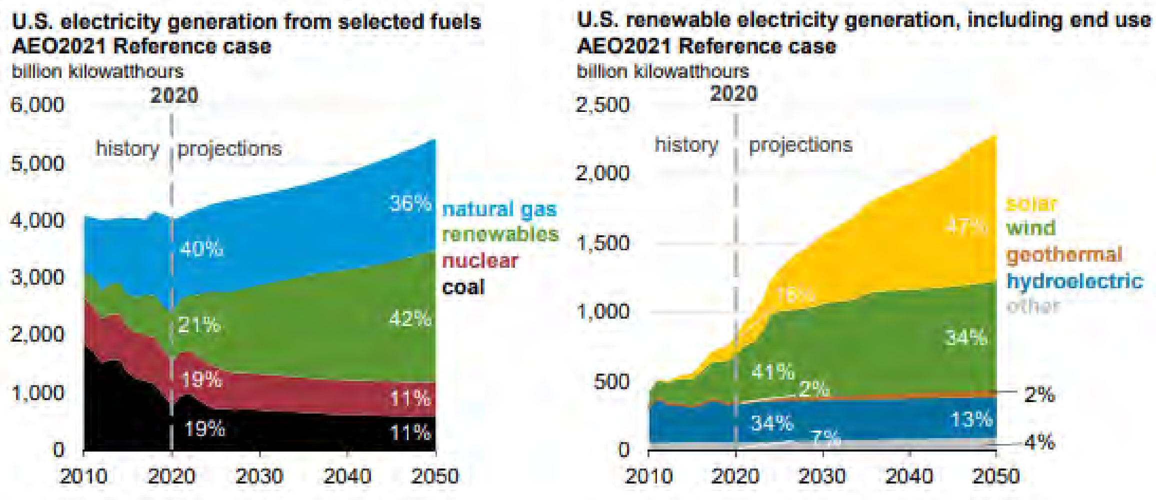
[29] This ambitious target represents a doubling of President Barack Obama's commitment to reduce emissions 26-28% below 2005 levels by 2025. The Biden Administration will prepare a national determined contribution (NDC) outlining the government's plans to achieve this commitment and submit it in advance of November climate change conference COP 26 in Glasgow. (See: https://eelp.law.harvard.edu/portfolios/environmental-governance/bidens-first-100-days-of-climate-action-report/)

[30] The first of the two packages, a $1 trillion bipartisan infrastructure bill entitled the "Infrastructure Investment and Jobs Act,'' was passed by the Senate in August. It includes $73 billion for grid modernization and the zero emission vehicle and hydrogen infrastructure expenditures mentioned above. (See: https://www.utilitydive.com/news/as-senate-passes-infrastructure-bill-dems-eye-opportunity-for-more-energy/604782/ and https://www.theatlantic.com/science/archive/2021/08/bipartisan-infrastructure-deal-kind-climate-bill/619654/) The bipartisan bill awaits potentially weeks of debate and revisions in the House of Representatives before reaching the President's desk. (See: https://www.cnbc.com/2021/08/11/senate-passes-3point5-trillion-budget-resolution-after-infrastructure-bill.html). While the specifics for the larger $3.5 trillion package are still being determined as the Senate Democrats draft their bill, they have decided that a focused on a broad array of clean energy, climate and various social outlays, including $198 billion which may include incentives to utilities that reach clean energy goals, household energy efficiency rebates, and financing for domestic manufacturers of renewable energy technologies. (See: https://www.reuters.com/world/us/paid-leave-clean-energy-preschool-democrats-35-trln-plan-2021-08-09/)

[31] In 2020, the U.S. Energy Information Agency noted that coal-fired generation has been "uneconomical in most regions" in comparison with natural gas-fired generation as natural gas delivery costs were on average $1.81 per million British thermal units versus $1.91 81 per million British thermal units for coal. (See: https://www.eia.gov/todayinenergy/detail.php?id=44716)

Figure 7: U.S. electricity generation and share from selected fuels and renewable sources



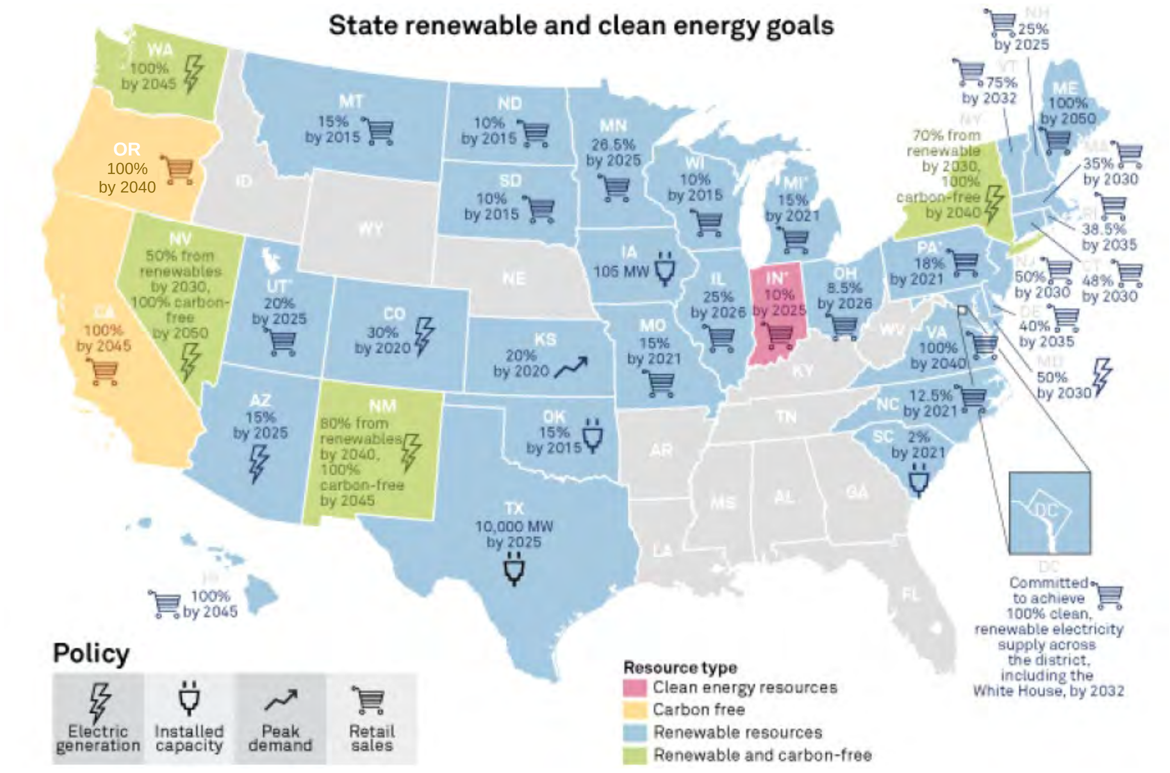
Source: U.S. Energy Information Administration, Annual Energy Outlook 2021 (2021)

While coal's role in the U.S. energy mix is shrinking, natural gas has become the largest fuel source in the U.S. electric system growing from 16% of the electricity mix in 2000 to 40% in 2020.[cxxvii] This growth is largely due to a boom in U.S. domestic natural gas production over the past two decades and more efficient gas turbine technologies.[cxxviii,cxxix] Natural gas will continue to be a key component of the U.S. electricity mix, but is forecast to decline modestly to 36% of electricity production by 2050.[cxxx]

Renewable Energy Growth

Once a fledgling niche of the U.S. electricity market that required significant government support, renewables now represent 20% of U.S. net electricity generation.[cxxxi] Wind and solar combined saw the most growth as they made up a mere 1% of the U.S. electricity mix in 2006 and dramatically grew to 11% in 2020.[cxxxii] This rise can be attributed technological advancements that have led in turn to falling costs and enhanced efficiency, federal policies such as the production and investment tax credits, and to state government's renewable energy portfolio standards or targets which are illustrated in Figure 8 below.[cxxxiii] Notably, progressive states such as California, New York, Oregon and Washington have committed to fully renewable or decarbonized electricity markets in their states by the 2040s. In light of these trends and policies, the EIA forecasts that renewable energy will represent the largest component of U.S. net electricity generation by 2050 at 42%.[cxxxiv]

Figure 8: U.S. State Renewable and Clean Energy Goals by State



* Includes non-renewable alternative resources. Indiana, Kansas, North Dakota, Oklahoma, South Carolina, South Dakota and Utah have renewable portfolio goals instead of standards. In Minnesota, the utility Xcel Energy was required by 2020 to generate 31.5% of its retail sales from renewable sources.
Source: S&P Global Market Intelligence (2021)

Distribution and Transmission Investments

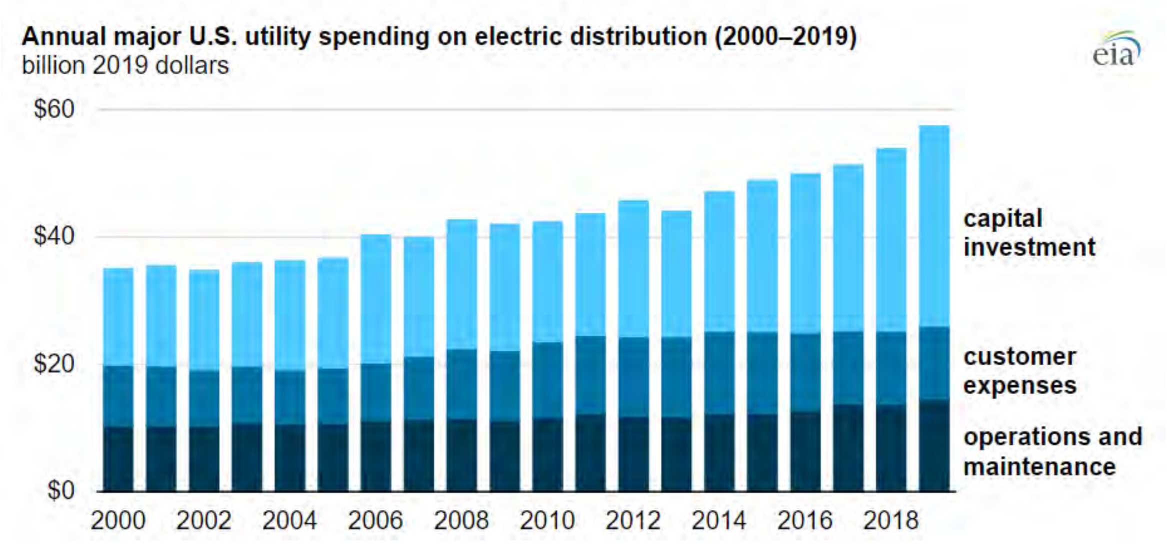
The U.S. electric grid, which is described as the largest machine on Earth, is composed of approximately 8.8 million km of distribution lines and 960,000 km of transmission lines (of which 40% are 230 kV or higher).[cxxxv,cxxxvi] Overhead construction of distributions and transmission lines is the industry standard in most locations and most of the network infrastructure is above ground.[32] Notable exceptions include dense cities such as San Francisco and New York and places where local and state governments have policies for constructing new distribution underground or converting existing overhead lines to underground.[33] While transmission grids are often highly interconnected, often U.S. distribution networks tend to be radial, lacking a meshed circuit construction that would allow for isolating segments during a fault.[34,cxxxvii,cxxxviii] Most of the U.S. transmission and distribution (T&D) lines, which were constructed in the 1950s and

[32] It is worth noting that for new construction, about 20-28% of new distribution lines were constructed underground in the U.S. annually between 1999 and 2011. During this time, 2.8% to 15% of new transmission was constructed underground. (Edison Electric Institute 2011, p.23, see link: https://www.eei.org/issuesand-policy/electricreliability/undergrounding/Documents/UndergroundReport.pdf).
[33] For instance, the State of California has Tariff Rules 15, 16, 20 and Public Utilities Code (P.U.C.) §320 which have various programs (Rule 20) and requirements for new underground construction of distribution lines (Rules 15 and 16 and P.U.C. §320) that have all contributed to the state's 33% level of underground distribution. However, costs can be quite expensive for underground conversion of distribution in California, ranging from $1 to $3 million per kilometer, which is about 10 times higher than simply installing new overhead lines. https://www.cpuc.ca.gov/regulatory-services/safety/electric-safety-and-reliability-branch/electric-reliability-and-safety/program-description
[34] A notable exception to the highly interconnected U.S. transmission system is the Texan grid, which has limited interconnections with other U.S. regions and limited ability to import electricity. (See: https://www.ucsusa.org/resources/how-electricity-grid-works)

1960s, have either reached or surpassed their estimated 50-year life expectancies with some components in operation that are over 100 years old.[35,cxxxix]

Over the past two decades, distribution and transmission utilities have significantly increased their annual grid expenditures on capital investments, operations and maintenance (see Figures 9 and 10). Inflation-adjusted transmission expenditures grew 340% since 2000 as utilities invested in reliability and resiliency enhancements and replaced aging infrastructure.[cxl] Similarly in the distribution grid domain, utility distribution expenditures grew 64% from 2000 to 2019 on an inflation-adjusted basis as utilities spent more on grid modernization (i.e., smart grid investments) and expansion programs as well as replacing aging infrastructure.[36,cxli]

Figure 9: U.S. Annual Inflation-Adjusted Distribution Expenditures

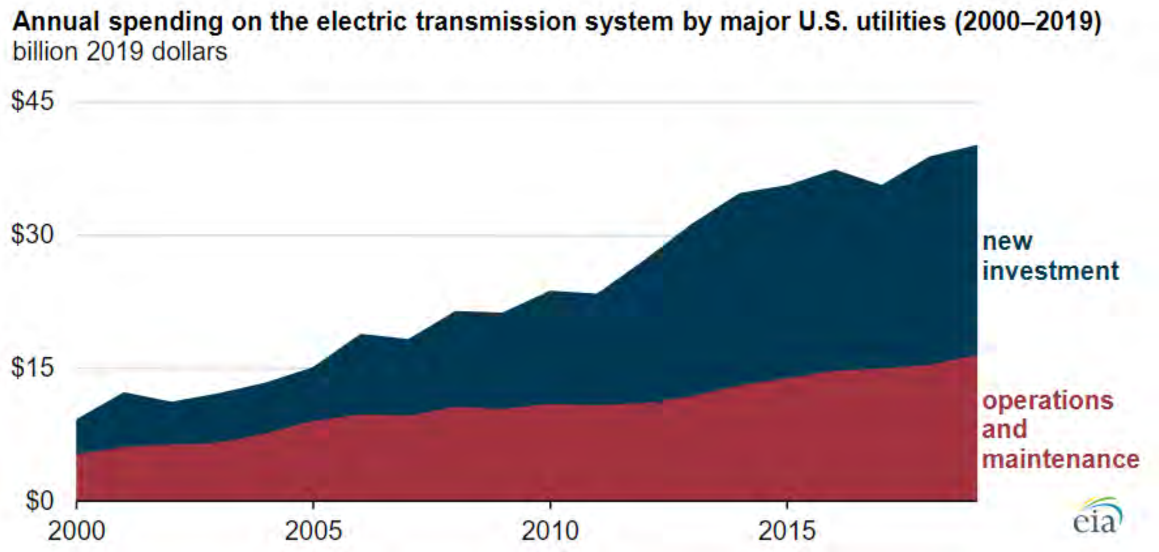


Source: Source: U.S. Energy Information Agency (2021)

[35] For example, California-based Pacific Gas and Electric, which serves electricity and gas to every 1 in 20 Americans, estimated in 2017 that its transmission towers along its approximately 30,000 km transmission system were on average 68 years old, which is in excess of their mean life expectancy of 65 years. The company's oldest tower in use at the time was 108 years old. (See: https://www.wsj.com/articles/pg-e-knew-for-years-its-lines-could-spark-wildfires-and-didnt-fix-them-11562768885)

[36] Similar to distribution grid owners in Germany, American distribution utilities are investing heavily in smart grid technologies to accommodate higher levels of distributed energy technologies (i.e., solar and storage), two-way power flows, and increased electric vehicle adoption. These investments will, among other things, also enhance reliability and resilience enhancing situational awareness, provide volt/VAR optimization and conservation voltage reduction, and by locating, isolating, and self-restoring circuit segments. (See ASCE Failure to Act 2021, p.26-27)

Figure 10: U.S. Annual Inflation-Adjusted Transmission Expenditures



Source: U.S. Energy Information Agency (2021)

Despite the increase in U.S. electric grid expenditures, experts estimate that there remains a growing investment gap which, in the absence of policy interventions, will reach $39 billion and $100 billion by 2040 for electric transmission and distribution respectively.[cxlii] This gap will be driven by challenges that utilities will continue to face with their operations such as severe weather and integrating distributed energy and smart grid technologies.[cxliii]

4.2 Political and Regulatory Authorities

Federal Government

The U.S. Federal Government splits power among three primary branches, Congress (the U.S. legislative body composed of the Senate and the House), the Presidency (and all of the cabinet and federal departments), and the Supreme Court. Congress – with the President's approval – is able to pass laws and authorize taxation and spending. In addition to signing bills into law or vetoing them, the President can issue executive orders which direct actions in the federal departments or clarify and further existing laws.[cxliv] The most important federal department in the energy sector is the DOE, which is responsible for conducting energy research through its various laboratories, financing third-party innovation, and administering the country's energy policy.[cxlv,cxlvi] Within the DOE is the Federal Energy Regulatory Commission (FERC), which is the regulatory agency responsible among other things for the regulation of electric transmission and hydroelectric facilities. The FERC develops the industry's regulations for areas such as reliability and has oversight and enforcement responsibilities.[cxlvii]

State Government

The state governments – including state legislatures, governors, and departmental bodies – are generally similar in their structure but are varied in terms of exact makeup and responsibilities of their electric regulatory authorities and related agencies. Some states, such as California, have regulatory agencies that are well resourced and able to manage a range of oversight, program management and enforcement responsibilities in the energy and other industries.[37] Other states, such as Hawaii, are faced with staffing or funding challenges and have far fewer resources.[38]

4.3 Climate Change Projections for the U.S.

With an observed average temperature increase of 1°C (1.8°F) since the beginning of the last century, the U.S. has seen and will continue to see significant changes to its climate and weather patterns.[cxlviii] The season length for heat waves has increased by more than 40 days relative to the 1960s.[cxlix] The frequency of cold waves has fallen since the beginning of the 20th century.[cl] Since the 1900s, precipitation has increased in the northern and eastern parts of the country while decreasing in the southwest. These trends are projected to continue and compound unique regional challenges such as water scarcity and heavy precipitation events.[39,cli] In fact, climate model projections and observational data suggest that a multi-decadal "mega-drought" not only has an increasingly high risk of occurring in the 21st century, but that it may already be upon California and the Southwest (Figure 11).[clii] Over the past two decades, the region has faced the most severe dry period since late 1500s and the second driest since 800 CE.[cliii] See Figure 11 below.

Hurricane activity in the Atlantic has increased since the 1970s and hurricane rainfall and intensity in the Atlantic and eastern North Pacific are predicted to increase in the future.[40,cliv] Under a 2° Celsius warming scenario, tropical cyclones are predicted to be more damaging with wind speeds up to 10% higher and 10-15% more precipitation.[clv] Trends in other extreme events in the U.S. (such as thunderstorms, riverine flooding, hail, strong wind events and tornadoes) are unclear and future predictions are too difficult to make based on current scientific knowledge of these events.[clvi] Annual median sea levels along U.S. coasts have risen about 23 cm since the beginning of the 20th century and may rise 30 to 130 cm (1 to 4.3 feet) by 2100 relative to 2000 levels.[clvii] The frequency of high tide flooding has increased by a factor of five to ten since the 1960s and will worsen as hurricanes and other coastal storms intensify.[clviii]

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[37] For example, the State of California has the California Public Utilities Commission (CPUC), which is the State's regulatory agency with primary oversight over investor-owned electric utilities (in addition to other industries such as gas, water, rail and communications). With a pre-pandemic annual budget of approximately $1.7 billion and 1,300 staff members, the CPUC is responsible for broad scope of matters that include developing and enforcing many of its own regulations and standard practices, conducting oversight auditing and investigations, administering and overseeing programs, and approving rate recovery on investments. (See https://lao.ca.gov/Publications/Report/4184 and https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/news-and-outreach/reports/annual-reports/2020-annual-report.pdf). The CPUC works closely with sister agencies such as the California Energy Commission (CEC), which is responsible for administering state energy policy and overseeing energy innovation programs, and the Office of Energy Infrastructure Safety (Energy Safety), which reviews the utilities' wildfire mitigation efforts to ensure that they take effective actions to reduce wildfire safety risks.

[38] The Hawaiian Public Utilities Commission has a budget of about $17 million and approximately 30 staff members to help address complex matters such as the electric industry's transition to 100% renewable energy and smart grid deployment while also managing several other regulated industries. (See: https://ballotpedia.org/Hawaii_Public_Utilities_Commission#cite_note-5, https://maxxwww.naruc.org/forms/CompanyFormPublic/viewCommissionRoster?id=764000001C7, and https://www.civilbeat.org/2015/02/public-utilities-commission-dont-short-circuit-energy-regulation/).

[39] For instance, the U.S. West will see large declines in the snowpack as more precipitation falls as rain rather than snow, which will lower the spring run-off levels that are essential for filling reservoirs in the region. Additionally, the West Coast, Northeast, Northern Great Plains and the Upper Midwest will continue see heavy precipitation events increase in frequency and intensity.

[40] Pacific hurricanes rarely make landfall in the continental U.S. and are typically downgraded to a tropical storm before they arrive. (See: https://www.scientificamerican.com/article/why-do-hurricanes-hit-the-east-coast-of-the-u-s-but-never-the-west-coast/)

Figure 11: Extreme Drought – Lake Oroville, California

Source: State of California Department of Water Resources (2014)

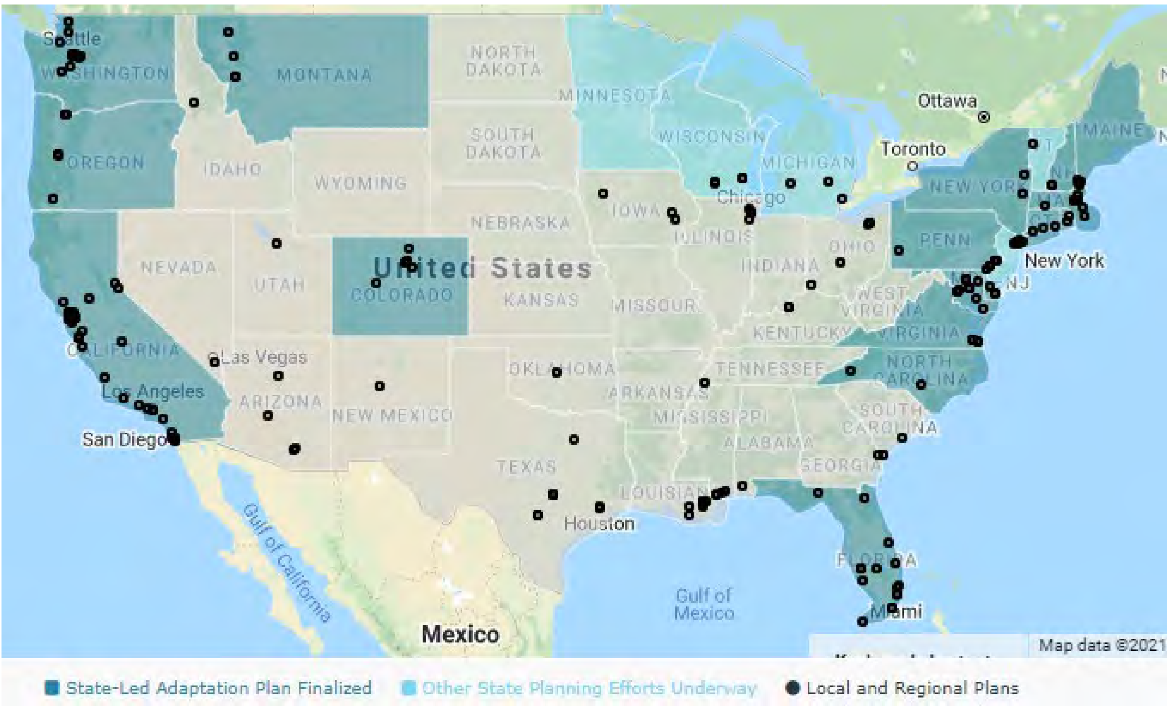
In terms of future warming, the U.S. Federal Government estimates that additional temperature increases of 1.4°C (2.5°F) over the next few decades – regardless of future emissions – and increases ranging from 1.6 (2.9°F) to 6.6°C (11.9°F) by the end of the century.[clix]

4.4 Climate Adaptation Policies in the United States

In contrast to the unified, systematic climate adaptation planning efforts that the EU and Germany have taken with the EU Climate Adaptation Strategy and Germany's DAS, U.S. policy on climate change adaptation has been fragmented and conducted unevenly across the various states and municipalities. Currently only a handful of states and municipalities have adaptation plans or other specific resilience policies to date and the U.S. lacks a comprehensive national policy, despite committing to the 2015 Paris Agreement (Figure 12).[41,clx] Some states such as California and New York not only have statewide adaptation plans, but also have multiple resilience policies at the local and industry level and a depth of policies dating back nearly 20 years.[clxi] Other states, such as Texas, lack a statewide comprehensive policy despite being impacted by a devastating winter storm in 2021 and the 2017 Hurricane Harvey which collectively cost upwards to $265 billion.[clxii,clxiii]

[41] Under Article 7 of the Paris Agreement, countries are required to engage in national adaptation actions such as developing and refining national climate vulnerability assessments and adaptation plans. (See the 2015 Paris Agreement)

Figure 12: U.S. State and Local Adaptation Policies Map



Note: Both the states of Alaska and Hawaii (not pictured) have state-wide and some municipal/regional plans.
Source: Georgetown Climate Center (2021)

State and local governments often lack the resources and institutional capacity to properly adapt to climate change. To help put this in perspective, of the approximately 19,000 municipalities in the U.S., only a few hundred have prepared a vulnerability assessment and only a few dozen are currently implementing adaptation investments.[clxiv]

Federal Climate Adaptation Efforts to Date

The U.S. Federal Government adaptation efforts began in 2009 under the Barack Obama Administration with Executive Order (E.O.) 13514, which required each federal agency to evaluate climate change risks to their missions and operations in annually updated Strategic Sustainability Performance Plans.[clxv] Furthermore, it established the Interagency Climate Adaptation Task Force for developing a U.S. strategy for climate adaptation and guiding adaptive policies and practices for the federal agencies.[clxvi] Additionally, President Obama in 2013 issued E.O. 13653, which superseded E.O. 13514 and required each of the U.S. federal agencies to complete individual climate change adaptation plans to prepare for the adverse impacts of climate change.[clxvii] The Obama Administration set a significant precedent for U.S. climate adaptation policy with E.O. 13653 as it required the U.S. federal government and its agencies – which collectively represent the largest employer and landowner in the nation, as well as one of the largest energy consumers – to begin integrating climate adaptation into their planning processes.[clxviii] E.O. 13653 also created the Interagency Council on Climate Preparedness and Resilience (the Resilience Council), which was tasked with coordinating federal resilience efforts. Additionally, the Order established a short-term task force of state, local and tribal government officials to advise the federal government on actions that it can take to support local resilience efforts. [clxix]

During the Obama Administration, the DOE not only prepared its own adaptation plans to safeguard its operations and facilities, but it also had several initiatives to engage with the energy industry and state, local and tribal governments on adaptation topics. For instance, the DOE worked with 18 U.S. electric utilities as part of the "Partnership for Energy Sector Climate Resilience" to develop and implement strategies for enhancing extreme weather and climate resilience. [clxx] (See Appendix 1 for more details on this and other example projects). In 2019, the DOE began the development of the North American Energy Resilience Model (NAERM) to enhance prediction and real-time situational awareness of man-made and natural threats, including climate-induced extreme weather events.[clxxi] NAERM is envisioned as a comprehensive resilience modeling system for the U.S. and the interconnected parts of Canada and Mexico that would predict of the impact of threats, evaluate and identify effective mitigation strategies, and provide support for black start planning following outages.[clxxii]

During President Donald Trump's term from 2017-2021, little federal action was made in terms of climate resilience planning. In March 2017, President Trump rescinded E.O. 13653, but it was later reinstated by President Joseph Biden on his first day in office.[clxxiii]

Furthermore, President Biden issued E.O. 14008, which required the federal agencies to submit new adaptation action plans for safeguarding their facilities and operations against climate change. The agencies must prepare annual progress reports on the implementation efforts for the adaptation actions, and each shall appoint a Chief Sustainability Officer to oversee the implementation of the plans. The Order further establishes a National Climate Task Force to facilitate the planning and implementation of key Federal actions to address climate change and pollution. The agencies are required to provide a report to the Task Force on ways to expand and improve climate forecasting tools and information products for the public, with local and tribal governments' needs in mind.[clxxiv]

President Biden Climate Resilience and the 2021 Bipartisan Infrastructure Bill

President Biden and his new administration have over their first several months in office brought climate mitigation and adaptation back as a key federal government priority after languishing under the Donald Trump Administration. To date, President Biden has yet to define a climate adaptation agenda for his presidency per his election campaign platform or to appoint cabinet members with adaptation policy experience.[42,43] However, Biden and his fellow Democrats in Congress are leveraging their slim Congressional majority to pass funding bills representing the biggest proposed federal infrastructure investments in generations that will have a significant impact on enhancing electric infrastructure resilience in the face of climate risks.

In November 2021, the Federal Government passed a bipartisan infrastructure bill called the "H.R. 3684 – Infrastructure Investment and Jobs Act" totaling $1 trillion, of which $73 billion have been dedicated to electric grid modernization, including $11.6 billion to enhance grid flexibility, reliability and resiliency.[clxxv,clxxvi]

[42] Among the various proposals included in Biden's presidential campaign website for climate change are to: (1) "boost climate resilience efforts by developing regional climate resilience plans, in partnership with local universities and national labs, for local access to the most relevant science, data, information, tools, and training; (2) define the climate adaptation agenda to prepare for and respond to natural disasters and other natural stresses; (3) build a new resilient infrastructure economy to create new jobs and workforce training focused on resilient industries; and (4) advance international climate change mitigation, adaptation and resilience efforts." (See https://joebiden.com/climate-plan/).

[43] Currently the Biden Administration does not have a cabinet expert for climate resilience and adaptation. The Natural Resources Defense Council and academics from Cornell and Texas A&M suggest a Federal Climate Resilience Officer similar to those employed by U.S. cities for cabinet. (See: https://www.nrdc.org/experts/rob-moore/president-biden-puts-climate-adaptation-back-agenda). Similarly, Dr. Jesse Keenan of Tulane University noted that members of the Obama administration with the adaptation expertise have not found their way back into relevant positions in the Biden administration. For instance, Kevin Bush, who formerly was the U.S. Department of Housing and Urban Development (HUD) resilience lead may have been a good fit for the domestic climate office, rather than being put in charge of grants at HUD. (See: https://www.americaadapts.org/episodes/2021/2/15/assessing-the-biden-climate-adaptation-agenda-with-dr-jesse-keenan?rq=biden).

4.5 California

California is the most populous state in the U.S. with 39.5 million people, one of the largest and most geographically diverse states, and the fifth largest economy in the world.[clxxvii] Like Germany, California is also undertaking an ambitious effort to transition its electric generation to 60% renewable energy by 2030 and fully decarbonize its electricity system by 2045 to minimize the sector's impact on climate change.[clxxviii] Renewables (excluding large hydropower) currently make up about 33% of California's total electricity mix with 14,615 gigawatt-hours (GWh) consumed in 2020.[clxxix] The largest share is natural gas at 37% of the electricity mix with 101,022 GWh in 2020.[clxxx] Coal makes up less than 3% of the mix at 7,474 GWh and is projected to decline to 324 GWh by 2026.[clxxxi,clxxxii] California's net electricity demand is projected to grow to between 326,026 and 354,209 GWh by 2030, driven in part by sector coupling (i.e. adoption of electric vehicles).[clxxxiii] In terms of electric utilities, California is served primarily by three large investor-owned utilities (IOUs) Pacific Gas and Electric (PG&E), which serves most of Northern and Central California, Southern California Edison (SCE), which serves most of Southern California, and San Diego Gas & Electric (SDG&E), which primarily serves San Diego County (Figure 13).[44]

[44] The remainder of the state is served by three other IOUs, PacifiCorp, Liberty Utilities and Bear Valley Electric Service, municipal-owned utilities, such as for the cities of Los Angeles and Sacramento, and small electric cooperatives.

Figure 13: California Electric Utility Service Areas

Source: California Energy Commission (2021)

Climate Projections for California

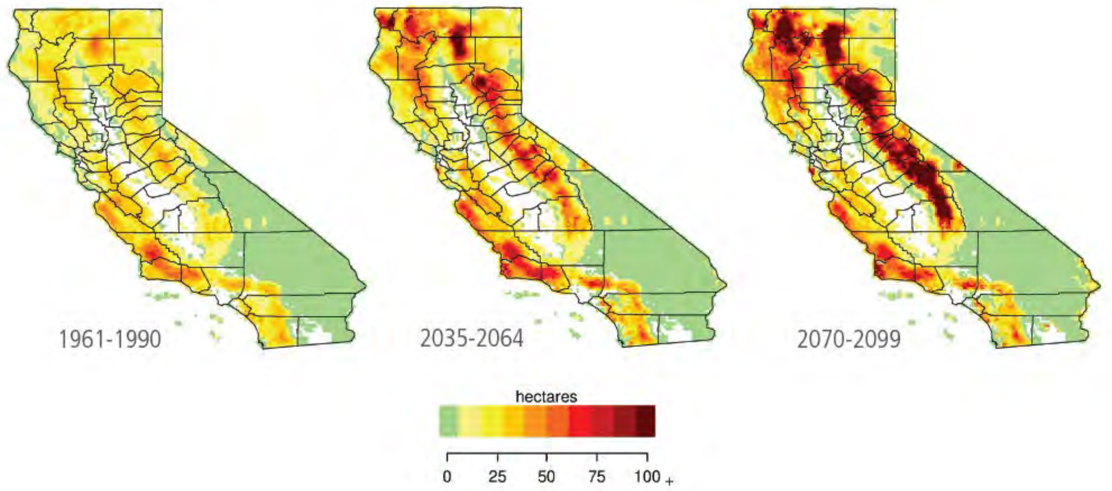
California is particularly vulnerable to climate impacts related to higher temperatures and heat waves, drought, reduced snowpack, sea level rise and heavy precipitation events. The State of California estimates that by 2050 the state will face at least $113.2 billion in annual direct economic costs from climate change.[45,clxxxiv] Temperatures are expected to rise 3.5°C (6.3°F) to 5.5°C (9.9°F) by 2100 and this increase will be accompanied by extreme heat events, such as a 2006 heat wave that killed over 600 people in California and led to nearly $5.4 billion in damages.[clxxxv,clxxxvi] California has the highest variability of year-to-year precipitation in the continental U.S. and is often affected by multi-year dry or wet periods, such as the current multi-decadal drought. Further compounding the issue, the water supply from the winter snowpack is projected to decline to two-thirds of the historical average by 2050 and could decrease to less than one-third by 2100.[clxxxvii] This would be driven by warmer precipitation events that fall as rain

[45] This figure only accounts for potential costs associated with heat-related premature annual mortality with higher ambient temperatures, coastal building damage due to sea level rise, effects of prolonged drought on water supply and agriculture, increased energy demand for cooling, and a mega-flood which becomes statistically more likely with climate change. It does not account for ecological impacts, human morbidity, or impacts from wildfires as the authors had not quantified these impacts.

rather than as snow, which would entail less spring runoff water to fill California's reservoirs.[clxxxviii]

As a consequence of warmer temperatures and prolonged drought, California experienced 15 out of its top 20 most destructive wildfires in the State's history since 2015.[clxxxix] Large wildfires (greater than 10,000 hectares or approximately 25,000 acres) could occur 50% more frequently by 2100 and burn 178% more acreage than the 1961-1990 average (Figure 14).[cxc]

Figure 14: Multi-decadal Model for Future Changes in California Wildfire Burn Area



Source: State of California (2018)

California Overarching Adaptation Policies

The State of California has a long-standing and comprehensive climate adaptation strategy that is composed of three pillars:

- **Climate Research** – This includes investing, utilizing and advancing scientific research to inform the policies and actions in California's adaptation plans. California has produced four Climate Change Vulnerability Assessments since 2006 and an *Indicators of Climate Change in California* report which describes trends in how the state is being impacted by climate change. Furthermore, the State established the Cal-Adapt.org web portal, which provides data and resources for understanding and planning for climate change.[cxci]
- **State Policies, Plans and Programs** – Over the past 13 years, the State has been developing various policies such as requiring agencies to consider climate change with all California planning and investment decisions. Every three years the State updates its comprehensive adaptation action plan called the Safeguarding California Plan, which provides a roadmap to over 1000 actions and next steps the State is taking to address climate change across 11 different sectors.[46]
- **Integrated Local and Regional Action** – Since the passage of the 2015 Senate Bill (SB) 246 (Wieckowski, Chapter 606, Statutes of 2015), California, through its Integrated Climate Adaptation and Resiliency Program (ICARP), has been developing holistic strategies to coordinate climate activities with local, regional and federal government agencies operating in the state. ICARP convenes a Technical Advisory

[46] The third and most recent version of the Safeguarding California Plan was published in 2018 and a new Draft Strategy was released in the third quarter of 2021. (See: https://resources.ca.gov/Initiatives/Building-Climate-Resilience).

Council with state and local government agencies, which helps inform state initiatives for supporting local governments and maintaining a State Adaptation Clearinghouse as a central repository of information to assist local adaptation planning efforts.[47,cxcii]

In terms of overarching policy commitments specific to energy resilience, the 2018 update of Safeguarding California lists the following six:

- Continued support of climate research for the energy sector to better inform climate change adaptation and mitigation strategies (E-1);
- Use common climate scenarios in all energy research and planning, and standardize climate scenarios across state government planning and investment (E-2);
- Continue to incorporate the implications of climate change into all energy sector planning and decision-making (E-3);
- Support local adaptation planning efforts and disseminate available analytical tools (E-4);
- Provide long-term financial support for maintaining and improving the Cal-Adapt web portal (E-5); and
- Increase climate resiliency in low-income, disadvantaged and vulnerable communities (E-6).[cxciii]

Similarly, in the Draft 2021 California Adaptation Strategy, the State identifies three energy-related actions:

- Reduce the risk of utility-related wildfire ignitions;
- Increase the climate resilience of vulnerable energy infrastructure; and
- Coordinate research that informs climate resilient decarbonization.

Electric Utility Risk Assessment and Wildfire Mitigation

Many of the investments, policies and regulations concerning climate change adaptation in the electricity sector have grown out of responses to catastrophes stemming from equipment failures. Following the catastrophic 2007 wildfire season in San Diego County in Southern California, in which three major wildfires were ignited by the SDG&E's electric equipment and caused over $1.5 billion in economic damages, SDG&E invested $1.5 billion in wildfire mitigation investments and protocols over the following decade. [48,cxciv,cxcv] In the years following the 2007 wildfires in San Diego, PG&E and SCE had several equipment failures that ignited catastrophic wildfires beginning in 2015 due to mismanagement of their facilities.[49] Following these events and a deadly 2010 PG&E gas explosion in San Bruno, California, the State's electricity and gas

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[47] The Technical Advisory Council and the Adaptation Clearinghouse together represent the key components of the State's Integrated Climate Adaptation and Resiliency Program (ICARP), which is developed and managed by the Governor's Office of Planning and Research (OPR). (See: http://opr.ca.gov/planning/icarp/)
[48] SDG&E's wildfire mitigation investments included programs to increase situational awareness (building out its own weather network, installing sensors and cameras), fire-harden its infrastructure (including replacing wooden poles with steel poles, installing more durable conductors, and upgrading substations) and improve their outreach and communications with customers. SDG&E also adopted a protocol for proactive de-energization of their lines during high wildfire risk conditions which later became known as public safety power shutoff (PSPS).
[49] These fires include the 2015 Butte Fire, the 2017 Wine Country Fires, the 2017 Thomas Fire, the 2018 Camp Fire and the 2019 Kincaid Fire. These catastrophic fires demonstrate that PG&E and SCE had not adequately invested in maintaining their facilities and were unprepared for growing wildfire risks despite seeing SDG&E's exemplary efforts in wildfire risk mitigation and participating in the DOE Partnership for Energy Sector Climate Resilience and publishing climate vulnerability and resilience strategies reports of their own.

regulator, the CPUC, instituted several risk assessment and planning processes to enhance the safety, reliability and resiliency of the IOUs' facilities.

The first comprehensive effort at evaluating utility risks and risk reduction opportunities is the Risk Assessment and Mitigation Phase (RAMP), which has required the utilities since 2016 to assess their top infrastructural risks and proposed investments to reduce the risk one year prior to submitting their General Rate Case (GRC) applications.[50] The GRC is formal ratemaking proceeding in which a utility seeks approval to recover the cost of capital and operations and maintenance in its monthly rates.

In 2018, the State Legislature passed SB 901 (Dodd, Chapter 626, Statutes of 2018), which requires the IOUs to annually submit a Wildfire Mitigation Plan (WMP) to the CPUC for review and approval. The elements of these plans include:

- a list identifying and prioritizing all of the wildfire risks and drivers that is part of the RAMP filings;
- plans for inspections;
- plans for vegetation management;
- proposed investments in system hardening;
- proposed investments in technologies that enhance situational awareness and weather and fire modeling;
- protocols for disabling reclosers (devices that automatically open and reclose an overhead distribution circuit following momentary contact of foreign objects, like tree branches); and
- protocols for proactive de-energization of lines (commonly referred to as Public Safety Power Shutoff or PSPS).[cxcvi]

In their 2021 WMPs, the three large IOUs forecast nearly $11 billion in capital expenditures and operating expenses for their wildfire mitigation efforts for 2021-2022, with over $7.3 billion this for 2021 alone.[cxcvii,cxcviii] The CPUC estimates that cumulative wildfire mitigation expenses from 2021-2030 for all three large IOUs to reach upwards to a staggering $44.8 billion.[cxcix] Additionally, PG&E has proposed an astonishing $30 billion - $40 billion project to convert about 16,000 kilometers (10,000 miles) of overhead wires to underground (referred to as "undergrounding") in their highest wildfire risk areas.[51,cc]

Utility Climate Vulnerability Assessments

Beginning in 2022 on a staggered, quadrennial basis, California's IOUs will be required to submit climate vulnerability assessments to the CPUC one year prior to submitting their GRCs. The IOU climate vulnerability assessments will cover and comprehensively study how projected climate change factors that may impact their infrastructure and broader businesses, including third-party contracts for power, capacity or reliability.[cci] The key time frame for the vulnerability assessments is the next 20-30 years.[ccii] The utilities are also required to identify possible intermediate-term (the next 10-20 years) and long-term (the next 30-50 years) adaptation measures to inform rate recovery requests in future GRCs.[cciii] The IOUs must consider the following minimum set of criteria in their vulnerability assessments:

[50] The RAMP proceeding is the second of a two-part procedural process which begins with a Safety Model Assessment Proceeding (S-MAP). In the SMAP, the utilities present and explain the models that the utilities use to prioritize and mitigate their risks and the Commission and parties examine and comment on the models. (See p.21 of Decision 14-12-025).
[51] To put these figures into perspective, PG&E maintains over 25,000 miles of overhead distribution in its high-fire threat district and annually collects about $47 billion in rates. Customer rates would balloon over the course of the project and amortization period.

- temperature;
- sea level;
- variations in precipitation (including extreme precipitation events, snowpack, long-term precipitation trends, drought and subsidence);
- wildfire; and
- cascading impacts.[cciv]

The CPUC also requires the IOUs to include in a related Community Engagement Plan how they plan to identify and prioritize climate adaptation investments in disadvantaged and vulnerable communities.[52]

Utility Microgrid and Resiliency Efforts

In 2018, the State of California enacted SB 1339 (Stern, Chapter 566, Statutes of 2018) which required the CPUC to facilitate the commercialization of microgrids and adopt resiliency strategies.[ccv] In January 2021, the CPUC approved $200 million for a statewide Microgrid Incentive Program that would fund clean energy microgrids to support the needs of vulnerable populations that are impacted by outages.[ccvi] In December 2021, the CPUC authorized SDG&E to develop up to four energy storage microgrid projects for a total of 40 MW or 160 MWh that would provide peak and net grid reliability benefits starting in the summers of 2022 or 2023.[ccvii] The CPUC also authorized PG&E to study expanding its Temporary Generation Program which involves transporting mobile generators to provide temporary generation for substation microgrids, distribution microgrids, critical backup power support, and community resource centers. PG&E's program provided 168 MW of temporary generation in 2021.[ccviii]

4.6 Texas

The second case study for the report is the state of Texas, which is the second largest U.S. state by both population (over 29 million people in 2020) and by total area land of 676,585 square km (261,231 square miles).[ccix] Texas also has diverse geographic and climate regions subject to hot summer temperatures, tropical storms and hurricanes, and extreme winter storms.

Texan Electricity Load, Capacity and Generation

Texas is the both the largest electricity producing and consuming state in the U.S. with over 483 million MWh of net generation and 429 million MWh of total retail sales in 2019.[ccx] Texas has growing population, leading the nation with total population increases between 2010 and 2020, with nearly 374,000 residents added in 2020 alone (a 1.29% increase).[ccxi] As the population continues to grow, so are the projected load and the capacity reserves needed to meet that load. See Figure 15 below for the estimated Texas electric capacity and load growth from 2020 through 2024.

[52] In addition to setting requirements for the vulnerability assessments and engagement plans, the IOUs are required to designate cross-departmental "climate change teams" that report directly to the executive level. They also require that utility board members oversee climate adaptation planning for their businesses. (See: D.20-08-046).

Figure 15: Texas Projected Capacity and Load Growth 2020-2024

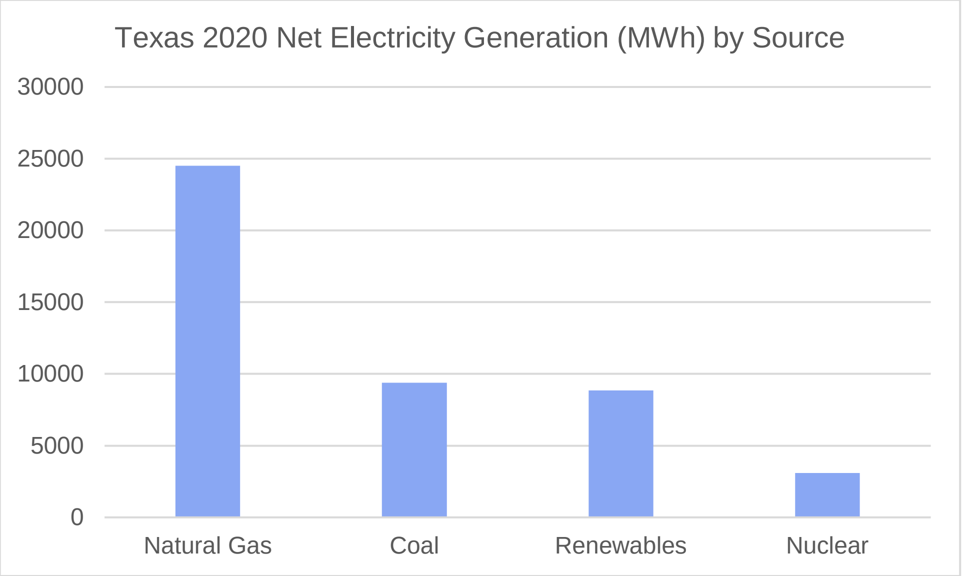
Source: ERCOT (2020)

Texas receives over 53% of its electricity from natural gas-fired power plants, over 16% from coal-fired power plants and nearly 9% from nuclear plants.[ccxii] Non-hydroelectric sources of renewable energy represented over 21% of the net electricity that was generated in Texas in 2020.[53,ccxiii] Wind energy alone represents more than one-fifth of the total generating capacity for the state as well as nearly 90% of the renewable energy capacity. In fact, Texas is America's largest producer of wind energy with more than 30,000 MW of installed wind capacity.[ccxiv] Wind energy is expected to grow up to 36,000 MW by the end of 2022.[ccxv] In terms of solar PV, Texas is currently undergoing a solar energy boom. Thanks in part to the 26% Solar Investment Tax Credit,[54] Texas added 2,500 MW of solar PV in 2020 and solar PV capacity is expected to grow by another 10,000 MW by the end of 2022 reaching up to 14,900 MW.[ccxvi] As of 2020, the state had nearly 10,000 MW of installed solar PV capacity.[ccxvii] Despite the growth in renewables, natural gas is projected to remain the primary fuel source for the ERCOT-managed region through 2033.[ccxviii] Figure 16 below shows the net electricity generation for Texas in 2020.

[53] Hydroelectricity represented 0.23% of Texas's net generation in 2020. (See EIA Texas State Energy Profile).

[54] The 26% Solar Investment Tax Credit applies for solar power projects beginning construction by the end of 2022. After 2022, the credit will later drop to 22% for projects that start construction in 2023 and down to 10% for those that start in 2024 or later.

Figure 16: Electricity Generation by Source in Texas



Source: EIA (2021)

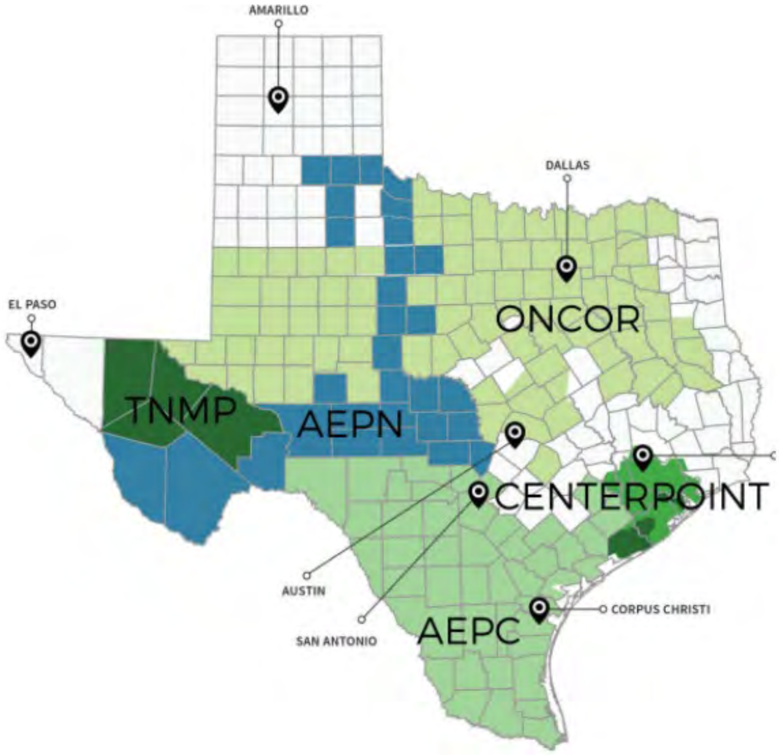
Texan Grid

Texas has approximately 74,400 km of electric transmission lines and more than 710 generation units that are under the purview of the independent system operator (ISO) the Electric Reliability Council of Texas (ERCOT).[ccxix] Texas also has at least 464,000 km of distribution lines throughout the state, of which an estimated 11% are underground.[55,ccxx] Most of the Texan electric grid (with the exception of a small portion of north, east and west Texas) is part of its own largely isolated power grid, called the Texas Interconnection, which is exempt from the FERC's interstate regulations as the ERCOT-managed system does not cross state lines.[ccxxi]

The grid is split up into service territories that are operated primarily by a mix of municipal utilities, and four large IOUs: Oncor, which serves north-eastern and central Texas; American Electric Power (AEP), which serves southern and central Texas; CenterPoint Energy, which serves Houston and the surrounding areas in Southeast Texas; and Texas New Mexico Power Company (TNMPC), which serves West Texas. See Figure 17 below.

[55] In comparison, less than one percent of transmission lines are underground in Texas.

Figure 17: Map of Texas Electric Utilities' Service Territories



Source: Quick Electricity (2021)

Transmission Constraints

The Texan grid faces challenges with transmission bottlenecks between West, North (the Texas "Panhandle"), and South Texas, where most of the commercial-scale wind and solar energy is produced, and load centers elsewhere in the state.[56,ccxxii] This is despite the construction of 3,600 miles of high-voltage transmission lines with 18,500 MW of capacity connecting West Texas to eastern load centers completed in 2014 at a cost of $6.9 billion.[ccxxiii] Since Texas has no immediate plans for new transmission build out or implementing "non-wires solutions", such as peak-shaving programs or energy storage at the scale needed to relieve growing transmission constraints, ERCOT estimates that by 2035 it may need to curtail renewable energy production from West Texas about one-third of the time.[ccxxiv]

Climate Projections for Texas

Texas, like many other states in the U.S., is exposed annually to extreme temperatures and weather events, which are likely to worsen over the coming decades. Texas is vulnerable to extreme events such as heat and cold waves, hurricanes, storm surges and extreme rainfall. Texas is known for having hot summers and between 2000 and 2018, the number of days per year that reached or exceeded 37.8°C (100°F) was 12 days on average for the state. By 2036, the number 37.8°C or hotter days in Texas are predicted to nearly double to 21 days annually.[ccxxv]

While less frequent than extreme heat, Texas also is vulnerable to extreme cold waves, such as those which are caused during stratospheric polar vortex events.[57] In February 2021, for

[56] ERCOT notes that there are currently 12 locations across the Texan transmission system subject to generic transmission constraints, five of which are in South Texas.
[57] Polar vortex events are characterized by a kink in the jet stream that brings arctic air to southern regions and is associated with unusual snowfall and extreme cold temperatures.

instance, Texas was impacted by polar vortex event called Storm Uri that brought 162 consecutive hours of sub-zero temperatures (as low as -2°F in Dallas) and snowfall and led to the third largest power outage in U.S. history.[ccxxvi,ccxxvii] During this event, up to 52,037 MW of generation capacity became unavailable, most of which were natural gas power plants that were unable to operate due to the gas infrastructure being disrupted by the extreme cold.[58,ccxxviii] Up to 4.5 million Texans were without electricity and many were without heat and water during the power outages which lasted 70.5 hours.[ccxxix] This event led up to 700 deaths and an estimated $80 billion to $130 billion in economic losses, eclipsing previous natural disasters such as Hurricane Harvey in 2017 which cost $125 billion.[ccxxx,ccxxxi,ccxxxii] Polar vortex events such as this are predicted to occur with greater frequency due to climate change and will continue pose a threat across the U.S.[59,ccxxxiii]

Figure 18: Texas during Winter Storm Uri February 2021

Source: The Guardian (2021)

In addition to changes in temperature, Texas will likely see increased precipitation variability, with the eastern and southern parts becoming wetter and the arid western region likely seeing increased drought severity. By the late 2030s, extreme rainfall intensity is predicted to increase by 2-3% relative to 2000-2018 and 6-10% relative to the 1950-1999 average.[ccxxxiv] Additionally, the increase in extreme rainfall frequency is estimated as 10%-15% and 30%-50%, respectively. Extreme rainfall poses a proportionate risk of flooding in cities such as Houston and others in the south and east of the state where paved surfaces increase rainwater runoff

[58] According to the FERC and North American Reliability Corporation (NERC) and regional U.S. reliability entities joint study, the ERCOT region averaged 34,000 MW of generation outages while the neighbouring regional transmission organization (RTO) regions Southwest Power Pool (SPP) and the Mid-continent Independent System Operator's (MISO) southern region experienced average generation outages of 20,000 MW and 14,500 MW respectively. (See 2021 FERC – NERC – Regional Entity Staff Report, p.14)
[59] Evidence suggests that polar vortex events could become more frequent in the future due to declines in arctic sea ice, which is associated with greater instability with the jet stream. (See Cohen, et al. 2021)

intensity.[ccxxxv] Despite predicted increases in precipitation and extreme precipitation, river flooding is not predicted to change through the 2030s due in part to the state's dams and reservoirs.[ccxxxvi] Drought trends are difficult to predict on a statewide level. However, droughts may become more severe and subject to significant multi-decadal variability.[ccxxxvii] The combination of increased dryness in the west and higher temperatures across the state will likely extend the areas at risk of wildfire eastward and the length of the wildfire season.[ccxxxviii]

At the Texas coast, three major phenomena that will become more acute in the coming decades are hurricanes and tropical storms and sea level rise. The coastal areas in Texas are seeing a combination of a lowering land-surface elevation due to groundwater and hydrocarbon extraction and sea level rise increase the risk of storm surges due to hurricanes and tropical storms. Some parts of the Texas coastline may see storm surge risk double by 2050 due to sea level rise, land subsidence, and more intense hurricanes.[ccxxxix]

Climate Adaptation in Texas

Unlike California, the State of Texas does not have a comprehensive climate adaptation plan, nor does it require electric companies in the state to complete climate vulnerability assessments or adaptation plans for their assets. Historically, the Texan government has taken limited action to promote climate adaptation and resilience and instead has left it to electric utilities and generation companies to undertake measures. For instance, in the wake of the 2017 Hurricane Harvey – which drove over 1.67 million reported customer outages in ERCOT's territory, took 10,992 MW of generation capacity offline, and damaged hundreds of electric utility assets – affected utilities such as AEP Texas and Entergy developed their own resilience plans independent of state government action. [60,ccxl,ccxli] Following a winter storm event in 2011 that drove widespread outages that impacted 4.4 million people not unlike that of the February 2021 winter storm, the Texas government failed to mandate winterization measures. The State did not give the Public Utility Commission of Texas (Texas PUC or PUCT) the authority to penalize plants that did not implement winterization measures, thus effectively making such measures voluntary.[ccxlii] However, in aftermath of the February 2021 winter storm event, which brought the electricity system within five minutes of total collapse, the Texas state government has required changes to resilience planning for extreme winter storms and plans to redesign the market for the bulk electricity system.[ccxliii]

In May 2021, the Texas State Legislature passed the bill SB 3, which requires the state regulatory agencies for the energy sector – the PUCT and the Texas Railroad Commission (RRC), which regulates the natural gas industry – to develop regulations that would require the energy industry to improve their reliability and resilience for future extreme weather events.[ccxliv] In October 2021, the PUCT ordered the generation and transmission companies to implement winterization measures by December 1, 2021 and submit a "winter weather readiness report" to the PUCT outlining their winterization activities. [61,ccxlv] The PUCT, in the same regulatory proceeding, is also considering year-round weather emergency preparedness measures for generation entities and transmission service providers that would take effect as early as November 2022.[62,ccxlvi] ERCOT, in consultation with the Texas State Climatologist, would prepare a weather study by January 1, 2022 and a revised version every five years thereafter to serve the basis of the reliability standards for generation and TSOs.[ccxlvii] The weather study would include

[60] AEP Texas had pre-existing plans to invest $1 billion per year over several years for grid hardening and enhancing its reliability before Hurricane Harvey hit. Entergy Texas was also investing in strengthening their infrastructure against future storms, including elevating critical substation equipment and other measures.
[61] These winterization measures included weatherization, storing onsite auxiliary fuels, installation of insulation and enclosures for critical components, and establishing a schedule for monthly inspections of freeze protection components for November through March.
[62] The PUCT regulatory proceeding is called Project Number 51840.

a comprehensive range of weather event scenarios that could impact generation and transmission and their statistical probabilities.[ccxlviii] For the time being, the consideration of the year-round weather emergency preparedness measures has been postponed until the second phase of the rulemaking begins which may delay the implementation of these measures.[ccxlix] Any mention of distribution utilities have been notably absent from the PUCT's rulemaking despite distribution's vulnerability to extreme weather events.

The PUCT is also considering a market redesign for the bulk-power system to incentivize generation companies to ensure that enough capacity is available under extreme weather conditions. One option for doing this would be to adapt the market from an energy-only market – in which generators are compensated only for the power that they produce and not for maintaining spare capacity – to a capacity market, where companies would also be compensated for maintaining spare capacity even when it is not used.[ccl] The PUCT chairman Peter Lake has said previously that the ERCOT market will not become a capacity market and has not offered an alternative vision for a redesigned market.[ccli] Stakeholders are currently providing input in an open rulemaking (Project NO. 52373), which is expected to be a slow process.[cclii]

Similarly, reforms in the natural gas industry by the RRC are expected to be slow and may not ultimately reduce the risk of future widespread power outages. SB 3 gave the RRC until February 2023 to develop new regulations for natural gas industry weatherization.[ccliii] This is much slower than the PUCT's requirement for the electric industry to winterize before the 2021-2022 winter season despite the fact that natural gas supply issues represented over 60% causes of all the outages in February 2021.[ccliv] The RRC also created a loophole that allows natural gas companies to be exempt from weatherization requirements by submitting paperwork and a one-time $150 fee for exemption from being designated as critical infrastructure providers.[cclv,cclvi] In the absence of any mandated weatherization for the natural gas industry, there may be only limited, voluntary implementation of weatherization measures by the industry until winter 2023-2024. Meanwhile, the Texan grid will remain vulnerable to natural gas shortages and widespread outages should another extreme winter storm strike.

5 Impacts of Climate Change on the U.S. and German Electric Sectors

5.1 Impacts on Electricity Generation in Germany and the U.S.

Different types of generation technologies and fuel sources are at greater risk to potential climate change impacts. For instance, thermal generation facilities (i.e., coal, natural gas and nuclear power) which require fresh water for cooling tend to be at the highest risk of climate impacts, while wind and solar generation have lower risks.

Thermal Generation

Thermal generation, which refers to coal, natural gas and nuclear power generation, is considered the most vulnerable to the effects of climate change due to their reliance on variable freshwater to discharge process heat.

German Thermal Generation

In Germany, water use for cooling purposes in the energy industry accounts for more than half of all the country's freshwater use.[63,cclvii] Thermal power plants are typically situated along rivers – most importantly, many coal facilities are located along the Rhine River in Western Germany. This high dependence on fresh water makes thermal power plants vulnerable to droughts and heat events that could require operators to curtail generation. Curtailment drivers include the lack of cooling water availability due to drought or low snow runoff levels and regulations that restrict water discharge after the cooling process into rivers. Such regulations prevent river temperatures from heating to dangerous levels for the wildlife.[cclviii] Low riverine water levels also constrain coal transport via barges.[cclix]

The hot and dry summers of 2003, 2006, 2018 and 2019 were particularly challenging for thermal power plant operators. In 2003, thermal power generators curtailed approximately 2,500 GWh, which was significantly higher than the 2001-2017 average annual curtailment of approximately 700 GWh.[cclx] In 2018, low water levels along the Rhine River led to significant supply disruptions for the shipping of goods, including coal and petroleum, for about two months that year. There were 18.6 GW of unavailable thermal generation capacity in the months of June and July 2018; the peak was between July 23 and August 12, 2018 with 19.9 GW that were offline; however, the security of supply was not threatened.[cclxi] The disruptions were related to insufficient fuel supply due to low water level bottlenecks and restrictions on cooling water use and discharge, though in many cases, exemptions to the discharge temperatures were granted.[cclxii] In addition to being vulnerable to low water levels and cooling water unavailability, thermal generation can also be vulnerable to flooding in some, flood-prone areas such as in some districts of Lower-Saxony and around Munich.[cclxiii]

Despite these challenges related to cooling water, fuel supply and potential flooding, there are promising trends underway that point to reduced dependence on variable cooling water and on thermal generation more broadly. Fresh water use has more than halved from 1991 to 2017 in single use cooling for thermal energy production.[cclxiv] Additionally, electricity generation from thermal power plants has fallen by approximately 20% from these facilities during this time.[cclxv] As nuclear and coal generation are further phased out across Germany by 2022 and 2038 respectively, electricity generation will become less and less dependent on fresh water.

U.S. Thermal Generation

Thermal generation in the U.S. is vulnerable to a variety of natural hazards and extreme weather events including heat and cold waves, droughts and sea level rise. During heat waves, thermal generation efficiency can decline significantly. For instance, natural gas power plants that utilize air cooling operate most efficiently at 15°C (59°F). Every 1°C (1.8°F) increase in ambient temperature is associated with capacity declines of 0.7% and 1% for combined cycle natural gas plants and open cycle natural gas plants respectively.[64,cclxvi] Higher temperatures are also associated with higher demand for cooling water and in some cases mandatory shutdowns of thermal generation plants based on environmental regulations.[cclxvii] Consumption of freshwater in many areas is expected to decrease as coal-fired generation retires and as air-cooled combined cycle natural gas plants become more widespread.[cclxviii]

In some regions, thermal generation plants are vulnerable to inundation from rising sea levels, high tides, storm surges (such as from hurricanes) and tsunamis. In California, approximately 25 coastal power plants were classified as being at risk of inundation from a 100-year flood with

[63] According to the UBA, the energy sector consumed 12.7 billion cubic meters of water in 2016, which was nearly 53% of the total water demand in Germany that year. (See: https://www.umweltbundesamt.de/daten/wasser/wasserressourcen-ihre-nutzung#wassernachfrage)
[64] To put this in perspective, climate change-driven increases in average temperature in California could lead to state-wide peak natural gas capacity reductions of 1.7% – 4.5% by the end of the century (2070-2099).

1.4 meters (about five feet) of sea level rise.[cclxix] Storms and storm surges also pose a risk to the natural gas pipeline system that supplies natural gas-fired power plants. Events such as hurricanes can damage above ground pipeline infrastructure such as compressor and pumping stations with debris from high winds and flooding.[cclxx] Buried pipelines are at risk of saltwater corrosion and damage from soil shifting and erosion.[cclxxi] In other regions, such as the Great Plains, thermal generation may be impacted by extreme precipitation which could damage facilities through flooding.[cclxxii]

Extreme cold waves can also pose significant risk to generation in areas such as Texas where many generation facilities or their fuel supply chains (i.e., natural gas pipelines) were not adequately winterized. During the February 2021 polar vortex event, 64% of the unplanned generator outages, derates or failures to start were experienced by natural gas- and coal-fired power plants and these were largely due to freezing or fuel issues.[cclxxiii]

Wind

German Wind Generation

There is considerable uncertainty around specific changes to wind energy potential in Germany and throughout Europe due to climate change. However, if the wind speeds are not excessive, the projections of increased wind speeds in the region could be beneficial for wind energy generation in the future. Some studies project an increase in wind energy potential in the Baltic Sea region, in particular for offshore wind.[65,cclxxiv,cclxxv] In a 2016 report on critical infrastructure resilience, the EU JRC suggests that windstorm events may become more frequent in Western, Eastern & Northern Europe but cautions that evidence of changes in windstorm frequency is elusive.[cclxxvi] If the wind speeds are not excessive, the wind turbines can continue to operate. Any winds in excess would be potentially dangerous and require the turbines to temporarily cease, or "cut-out", operation until they can safely operate later. In addition to being able to withstand high winds, modern wind turbines are designed to work with temperatures as low as -30°C (-22°F) and can operate in the Arctic Circle. Some units come equipped with ice mitigation systems that heat up core components and the wings, which allow them to continue operating under extremely low temperatures.[cclxxvii]

U.S. Wind Generation

Similar to the case in Europe, it is uncertain as to how climate change will affect wind resources in the US.[cclxxviii] However, the February 2021 polar vortex event in Texas shows that climate change can negatively impact wind energy production for companies that fail to adequately winterize. During the event, up to 18 GW of renewables, primarily wind, were offline during the severe winter storm.[cclxxix] This was primarily the result of "blade icing," which refers to when precipitation and condensation cause ice to build up on the wind turbine blades and lead to balancing, bearing and other equipment problems.[cclxxx] Additionally, wind turbines that are located near the Gulf Coast or by the Eastern Seaboard may be vulnerable to damage from hurricanes.[cclxxxi]

Solar

Based on research to date, the projected impacts of climate change on solar energy production will likely be small. [cclxxxii] However, this assessment is based on inconclusive modeling results. The current projections for the solar irradiance in Europe are not robust and climate models do not show any clear direction on future changes in cloud coverage and insolation in Europe.[cclxxxiii]

[65] Wind energy potential may increase in the near future based on based on model data from the Potsdam Institute for Climate Impact Research.

Similarly in the US, the research to date is not consistent in either direction in terms of future irradiance in the US.[cclxxxiv]

As in the case of wind energy, temperature extremes do not appear to pose much of a threat to solar energy operations. They can continue to work at high temperatures, albeit with reduced output: solar photovoltaic power output declines by half a percent for every degree it is higher than the 25°C (77°C) optimum. [cclxxxv] Even on an extreme 45°C (113°F) day, the solar panels would continue to operate though at about 25% less than normal.[cclxxxvi] In the Western U.S., utility-scale solar PV is predicted to see summertime capacity reductions of 0.7-1.7% due to higher air temperatures.[cclxxxvii] Under cold snowy conditions, solar panels perform well, as long as the panels are frameless and do not have significant snow build up that stresses the mounting points. However, generally snow melts and slides off so that panels can continue to operate efficiently.[cclxxxviii]

Hydroelectricity

German Hydroelectricity

With hydroelectricity representing approximately 2.2% of the net generation capacity in Germany, it is among the least vulnerable energy sources to climate change and among the least consequential in terms of the potential broader electric system implications for Germany. According to a 2020 study by the EU JRC, water availability for hydropower is expected to increase in Central and Northern Europe, but the impact on the grid will likely be small as hydropower makes up only a small fraction of the regional generation mix and it is not projected to grow significantly.[cclxxxix]

U.S. Hydroelectricity

In contrast to Germany, the U.S. is highly dependent on hydroelectricity that is threatened by a warming planet. Across the Western US, decreases in summer hydropower production are expected due to reduced snowpack, earlier spring snowmelt, declining summer precipitation, and increasing evaporation of reservoirs and evapotranspiration of agricultural crops relying on the same water supply.[ccxc] For instance, between 2012 and 2014, California saw historic drought conditions that led to a reduction of 34,000 GWh of hydroelectricity relative to average precipitation years. The costs of the reduced hydroelectricity and the use of additional natural gas resources to meet demand were estimated at $1.4 billion.[ccxci] The 2020s have also begun with exceptional drought in the West and 2021 saw an estimated hydroelectric generation reduction of 150 terawatt-hours (TWh) relative to 2020, a 9% decline.[ccxcii]

Another risk that hydroelectric facilities, primarily those east of the Rocky Mountains, are at risk of is flooding from heavy precipitation. During flood events, large sediment and debris can block the dam spillways and large masses of water can damage structural components.[ccxciii] Furthermore, variations in flood intensity make it difficult to manage reservoir water supply for hydroelectricity generation.[ccxciv]

Bioenergy

German Bioenergy

In Germany 2,577,000 hectares (6,368,000 acres) or about 7% of the land area is currently being used to produce bioenergy from feedstocks such as maize, grasses, cereals, beets, sunflowers, and wood.[ccxcv,ccxcvi] Most of the crops (1.55 million hectares, or 3.83 million acres) are used to produce biogas, which is then used to produce electricity onsite.[ccxcvii] Wood also accounts for a minor portion of Germany's biomass energy supply with about 6,500 hectares (16,000 acres) utilized in biomass cogeneration plants, wood gasifiers and heating systems.[ccxcviii] In some cases, wood is also being considered as a fuel supply for converted coal-fired power plants.[66]

Energy crop potential will likely improve in Germany due to higher year-round temperatures. Efficient energy crops such as sorghum and miscanthus may see their growing range extend into Germany.[ccxcix] However, droughts and heat waves may negatively impact energy crop yields and increase dependence on fresh water for irrigation. Collectively, bioenergy from these various feedstocks represented 8% of Germany's electricity supply in 2008 and it is unlikely that bioenergy will become a bigger factor in Germany's electricity supply mix.[ccc,ccci]

U.S. Bioenergy

At least 15.2 million hectares (38.1 million acres) or about 9.7% of the land area in the U.S. is devoted to bioenergy production.[cccii] Depending on the region and the crops in question, some bioenergy feedstock crops may benefit from aspects of a changing climate while other crops may do worse. For instance, increasing temperatures and milder winters in some regions could benefit species, such as sorghum and miscanthus, and growing regions and seasons could expand.[ccciii] However, these conditions may also benefit pests, weeds and diseases. Changes in precipitation could benefit some growing regions where precipitation increases or harm others where flooding or drought become more prevalent.[67,ccciv] All regions will see higher evapotranspiration and likely increased water needs for irrigated crops due to higher summer temperatures.[cccv] Extreme heat or cold waves can also damage crops.[cccvi] Furthermore, coastal growing regions may see increased saltwater intrusion and storm surges that could harm crops.[cccvii]

Geothermal

Geothermal power plants, which use hydrothermal resources from either hot water or steam from underground wells to power turbines, are vulnerable to shortages of fresh water for cooling similar to fossil and nuclear generation.[68,cccviii] While U.S. experts predict that geothermal may face the same challenges as thermal electricity generation, German experts do not envision noticeable effects of climate change on geothermal energy production.[cccix]

5.2 German Electric Grid Vulnerability

Extreme weather events such as storms or floods can impact overhead power lines. For example, during the Münsterland Snow Chaos in 2005, many electric pylons collapsed from the snow and ice loads. The storm cut electricity supply to 250,000 electric customers for more than four days and caused roughly €100 million in damages to the electric system. See Figure 19. Following this event, German grid owners expended an additional €500 million to replace the remaining 28,000 transmission pylons in Germany with more robust steel pylons.[cccx]

[66] Domestic wood utilization for energy in Germany has remained relatively flat at this level since 2009. However, there have been some controversial proposals for importing wood pellets from abroad to fuel converted coal-fired power plants that would otherwise be slated for retirement. (See https://www.spiegel.de/wissenschaft/natur/energiewende-wirtschaftsministerium-will-kohle-kraftwerke-fuer-holz-verbrennung-umruesten-a-0403118b-22cd-41da-958f-f6b3ce1c6ec9).
[67] In 2008 for instance, the upper Midwest saw disruption to its early season planting operations due to heavy precipitation and extreme flooding that lasted for weeks.
[68] In fact, geothermal generation can consume as much or more fresh water than fossil generation for cooling.

Figure 19: Collapsed Electric Pylons – 2005 Münsterland Snow Chaos

Source: WDR, 2021.

In 2002, a one hundred-year flood struck the Elbe River basin in Eastern Germany, drove widespread power outages and caused more than €50 million in damages to the energy industry there.[cccxi] In February 2020, Germany was impacted by Storm Sabine, which brought gale-force winds and gusts up to 100 kilometers per hour (about 60 miles per hour), damaged overhead electric infrastructure and resulted in over 100,000 households losing power across Bavaria.[69,cccxii]

More recently, widespread flooding in Western Germany in July 2021 due to unprecedented, torrential rains and overflowing rivers left at least 200,000 customers without electricity in the states of North Rhine-Westphalia and Rhineland Palatinate.[cccxiii] Some of the substations in the region were badly damaged and difficult to restore.[cccxiv] One large energy company reported tens of millions of euros in damage across its Rhineland operations.[70,cccxv]

In the broader European context, damages from climate extremes in the energy sector are expected to grow from less than €1 billion in 2016 to nearly €5 billion in the 2050s and about €8 billion in the 2080s.[cccxvi]

While research on the German electric sector's climate change vulnerability has been limited to date, there are a few studies suggesting that the German electric grid is not very vulnerable to climate impacts. In a UBA 2015 study, "Vulnerabilität Deutschlands gegenüber dem Klimawandel" (Germany's vulnerability to climate change), the authors argued that the energy industry is highly adaptable to climate impacts. This is due in part to the transition away from centralized thermal power plants to decentralized renewable energy generation that is less affected

[69] Another notable impact of the storm was the flooding of the Elbe River in Hamburg which rose 2.7 meters (almost 9 feet) above the mean flood level and flooded part of the city. (See: https://www.t-online.de/region/hamburg/news/id_87316246/hamburg-fischmarkt-nach-orkantief-sabine-unter-wasser.html)

[70] North Rhine-Westphalia-based energy giant, RWE, reported tens of millions of euros in damage across its operations from the flooding which took several hydropower plants temporarily out of service in the Eifel region and on the Moselle, Saar and Ruhr rivers and partially suspended operations at its Weisweiler coal-fired power plant.

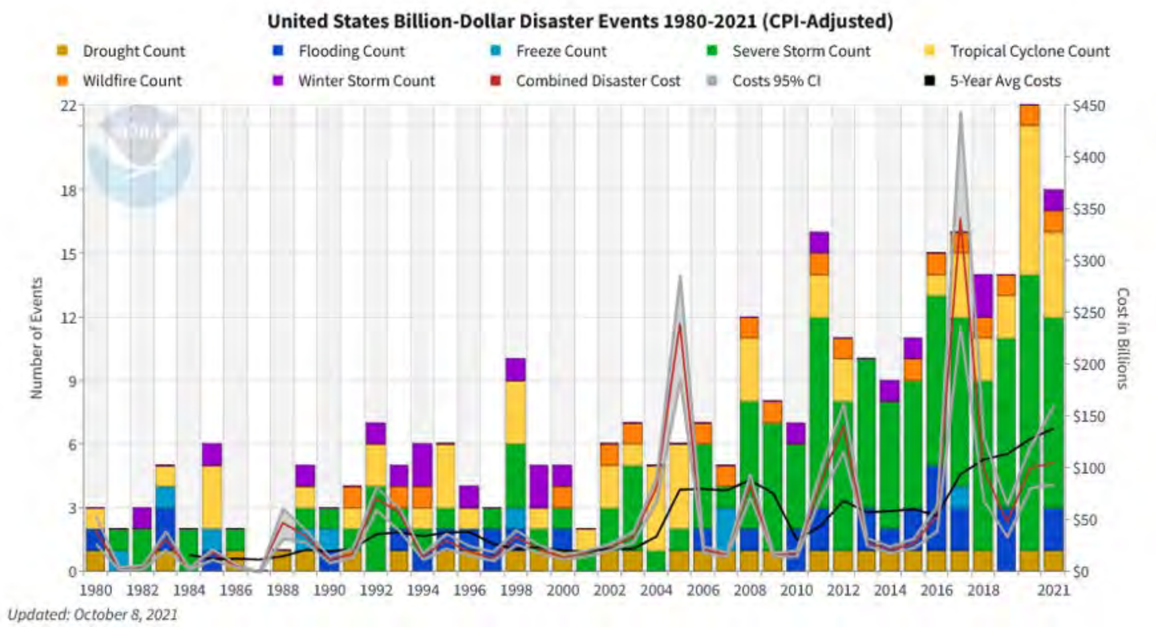
by climate change.[71, cccxvii] Furthermore, thermal power plants that remain in operation and are retrofitted with closed-loop cooling systems or outfitted with cooling towers can be made much more resilient to hot and dry periods.[cccxviii] The UBA study also credits the use of network redundancies in accordance with N-1 criterion, which is a planning principle used primarily for the transmission grid for limiting the impact of failures in system components (e.g. a transformer or conductor). TSOs achieve this through system configuration that allows them to re-route power without overloading the remaining lines and guarantee system security.[cccxix] The UBA also mentions that underground conductors, which make up the majority of distribution lines in Germany, are safe from extreme weather and other hazards such as vegetation contact (i.e., falling trees or branches) that could potentially lead to outages. Similarly, regular inspections, maintenance, and adequate vegetation clearance of overhead lines can maintain reliability.[cccxx] Additionally, the UBA also credits a broad knowledge base and sufficient human capital in Germany for enhancing the energy sector's adaptive capacity.[cccxxi]

5.3 Climate Change Vulnerability of U.S. Electricity Grid Systems

The U.S. electric industry has become increasingly vulnerable to extreme weather events in recent years and climate change and underinvestment in the grid will likely worsen this trend. From the 1950s to the 1980s, the U.S. used to see two to five major weather events that would cause widespread outages and weather events used to represent between 17 to 21 percent of all root causes for outages.[cccxxii] From 1984 – when data collection on outages began – to 2013, the frequency of outages increased by 285% to 70 to 130 outages per year and weather accounted for up to 73% of the outages. The U.S. DOE estimates that weather-related power outages cost the U.S. $70 billion annually.[cccxxiii] The White House notes that there were 22 billion-dollar weather and climate disasters that caused a total of $95 billion in damages in 2020.[cccxxiv] From 1980 through December 2021, the U.S. has been impacted by 308 billion-dollar extreme weather and climate events that approximate $2.1 trillion in total.[cccxxv] See Figure 20 below.

[71] The authors of the 2015 study consulted with the following experts in preparation of the section on the energy industry: Anna Pechan (Universität Oldenburg), Christine Eismann (Federal Office of Civil Protection and Disaster Relief (Bundesamt für Bevölkerungsschutz und Katastrophenhilfe or BBK)), Sebastian Boley (Association of German Chambers of Industry and Commerce (Deustche Industrie und Handelskammer (DIHK)), Jakob Waschsmuth (Universität Bremen), and Ullrich Sattler (Federal Office of Economics and Export Control (Bundesamt für Wirtschaft und Ausfuhrkontrolle or BAFA)).

Figure 20: 1980-2021 United States Billion-Dollar Disaster Events Cost (Inflation-Adjusted)

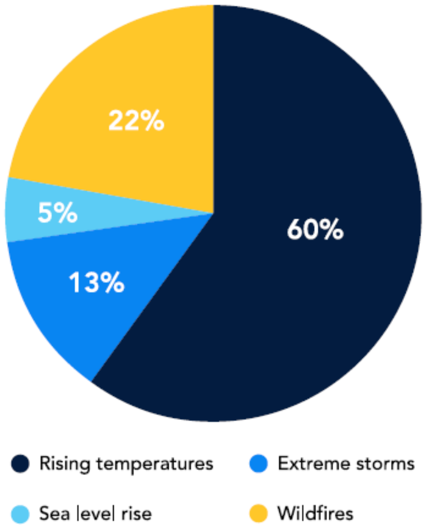


Source: U.S. National Oceanographic and Atmospheric Administration, 2021.

With the increasing in intensity of extreme weather events, aging grid assets throughout the U.S. and increasing penetration of distributed energy resources (DERs, which primarily consist of distributed renewables and storage), the American Society of Civil Engineers (ASCE) predicts that there will be a growing infrastructure investment gap over the next two decades. The ASCE estimates that across the U.S., the investment gap for the electric system (including generation) between the expenditures needed to ensure a reliable grid and what the ASCE estimates the utilities will actually invest in will reach $208 billion by 2029 and $338 billion by 2039.[cccxxvi] The ASCE estimates a high cost of underinvestment at the household level, with the average U.S. household will losing $5,800 between 2020 and 2039 with an annual cost reaching $563 by 2039.[cccxxvii] At the aggregate level, the U.S. could see its gross domestic product (GDP) $394 billion lower in 2029 and $1.7 trillion lower in 2039 specifically due to underinvestment in electric T&D and generation.[72,cccxxviii] Furthermore, this could result in 287,000 fewer jobs in 2029 and 540,000 fewer jobs in 2039.[cccxxix] ICF International, an international management consulting firm, estimates that by mid-century the utility investment gap specific to resilience will exceed $500 billion.[cccxxx] ICF estimates that 60% of the costs will be associated with increasing temperatures, which will likely drive higher customer electricity demand while reducing utility equipment efficiency (such as transformers and conductors).[cccxxxi] See Figure 21 below.

[72] To put these costs in perspective, the U.S. in 2020 had a GDP of approximately $21 trillion. (See https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=US)

Figure 21: Breakdown of Cost Drivers of Estimated $500 Billion Resilience Gap for U.S. Utilities



Source: ICF International, 2021.

The following sections below describe how different weather events and phenomena impact or dangerously interact with generation and T&D facilities in the U.S., and in particular in California and Texas.

Extreme temperature events

Extreme heat events are likely to stress the grid through increases in customer demand for cooling while simultaneously decreasing transmission efficiency and capacity.[cccxxxii] High temperatures can stress and reduce the lifespan of electric equipment. For instance, transformers can get overloaded and overheat during high heat events and their insulation breaks down at an increasingly exponential rate.[cccxxxiii] Heat events also increase the risk of wildfire ignitions by electric infrastructure as heat causes conductors to sag and can contact nearby vegetation and arc and spark.[cccxxxiv] Furthermore, heat events heighten wildfire risk by drying vegetation and are often associated with lower ambient humidity in the West.

Another key risk associated with extreme heat is blackouts from supply and demand imbalances. A prominent example of this occurred in California in August 2020, where up to 491,600 customers lost power during a 1-in-35 year heat event that had 56 million people across the western U.S. under heat advisories.[cccxxxv,cccxxxvi] The California Independent System Operator (CAISO) failed to anticipate the severity of this event and called upon the utilities to schedule rotating outages and safeguard the grid.[73] Since this event, California has had 1,493 MW of energy storage come online and has instituted numerous summer reliability measures, including procuring an additional 565 MW of capacity through 2021 and will procure between 2,000 and 3,000 MW of supply and demand side resources by 2023, and provide new incentives for demand-side programs.[74,cccxxxvii,cccxxxviii,cccxxxix]

[73] According to the post-event report, the CAISO had mistakenly scheduled electricity exports and did not have enough capacity available as solar power was falling in the early evening hours and neighbouring states were struggling to meet their own electricity needs and thus unable to export electricity that otherwise would be available for California.
[74] A few of the notable demand-side programs changes include doubling the existing Emergency Load Reduction Program (ELRP) to $2/kWh and expanding the program to include residential customers in addition to business customers and providing $22.5 million in incentives to install smart thermostats that would allow customers to reduce air conditioning usage during critical times and get paid for energy savings. (See:
Footnote continues on the next page

Extreme cold events (cold waves) with ice, snow, and high winds can damage power lines and drive outages.[cccxl] Such events are infrequent in much of the continental U.S. and are predicted to become less common and less intense in a warming climate.[cccxli] However, it is possible that cold waves from polar vortex events may occur more frequently as the jet stream becomes increasingly unstable with the decline of arctic sea ice.[cccxlii]

Wildfires

As was described earlier in Section 2.9, California and much of western North America are expected to see longer and more destructive annual wildfire seasons. With more frequent, widespread and destructive wildfires, the electric T&D is at risk of direct damage from the flames (e.g., burning wooden poles or damaging transformers), heat, falling vegetation, soot and application of fire retardants.[cccxliii] Not only are wildfires associated with direct damage to T&D infrastructure, but they can also drive widespread outages. For instance, the 2007 wildfires in Southern California knocked out over 20 transmission lines, 35 miles of conductors and 1,500 poles which in turn took out the power for nearly 80,000 customers in San Diego County for more than two weeks in some cases.[cccxliv]

Storms and high wind events

Storms and high wind events can be devastating to overhead electric systems in the U.S. and cause widespread damage and outages. Storms and high winds can topple power poles and cause vegetation to crash into and damage power lines possibly even igniting wildfires. These vegetation-related damages alone accounted for about 23.2% of U.S. power outages in 2019, according to a survey of major electric utilities. [75,cccxlv] Hurricanes, in particular, have proven destructive and have left millions of people without power in the past. For instance, Hurricane Harvey in 2017 damaged hundreds of electric T&D assets and caused over 2 million people in Texas and Louisiana to lose power.[cccxlvi]

Flooding

Flooding from extreme precipitation, sea level rise, river floods, and coastal storm surges are becoming a growing threat for low-lying T&D infrastructure. Storm surges can inundate substations and underground facilities, corrode equipment with salt water, complicate restoration operations, and wash away facilities altogether.[cccxlvii] To date, the U.S. has already seen how devastating storm surges can be with events such as Superstorm Sandy in 2012, which created record 4.3 meter (14 feet) high storm surges, inundated more than 100 electric substations in four states and damaged underground distribution. This led to outages for nearly 9 million people, which lasted weeks in some cases.[cccxlviii,cccxlix]

Projections for sea level rise and coastal soil subsidence point to a grim future. In California for instance, 3% of the state's substations are vulnerable to sea level rise of 1.2-1.8 meters (4-6 feet).[cccl] In the Gulf of Mexico, the number of electric substations at risk of storm surges from Category 1 hurricanes could increase by 30% and 60% by 2030 and 2050 respectively under a high warming scenario (RCP8.5).[cccli] Elsewhere in the Southeast, the number of substations exposed to storm surge from Category 1 hurricanes in 2030 with projected sea level rise could range from 255 to 337 substations.[ccclii]

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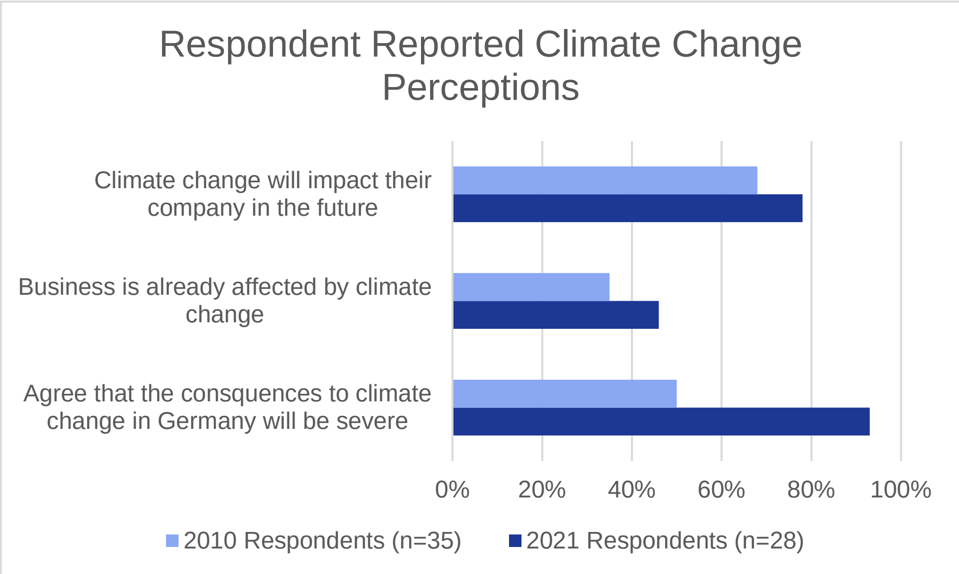
https://www.cpuc.ca.gov/news-and-updates/all-news/cpuc-ensures-electricity-reliability-during-extreme-weather-for-summers-2022-and-2023)

[75] The survey was conducted in late 2019 through early 2020 by the University of Wisconsin – Stevens Point and CN Utility Consulting and had 71 utility respondents. Responding utilities accounted for over 52 million customers, 107,000 miles of transmission, nearly 80,000 miles of sub transmission and 1.1 million miles of distribution lines across the U.S.

5.4 Survey Results

To supplement the literature review and industry interviews, I used an industry survey of energy sector entities belonging to the BDEW to gauge the energy sector's level of concern and preparation for potential climate change impacts to their businesses. Of the approximately 1,400 German energy sector entities that were contacted in July 2021, 28 entities, consisting of municipal utilities, renewable and conventional energy generation, distribution utilities, energy suppliers, electric vehicle charging infrastructure, and others that operate across Germany and internationally responded to the survey. Relative to the responses that the 35 of the BDEW energy sector members provided to the Chameleon Research Group's survey in the summer of 2010, the results from the current study's survey suggests both a heightened level awareness among companies about the current and future impacts of climate change on their businesses and an increased level of adaptation activity.[76] Figures 22 and 23 illustrate these comparisons below.

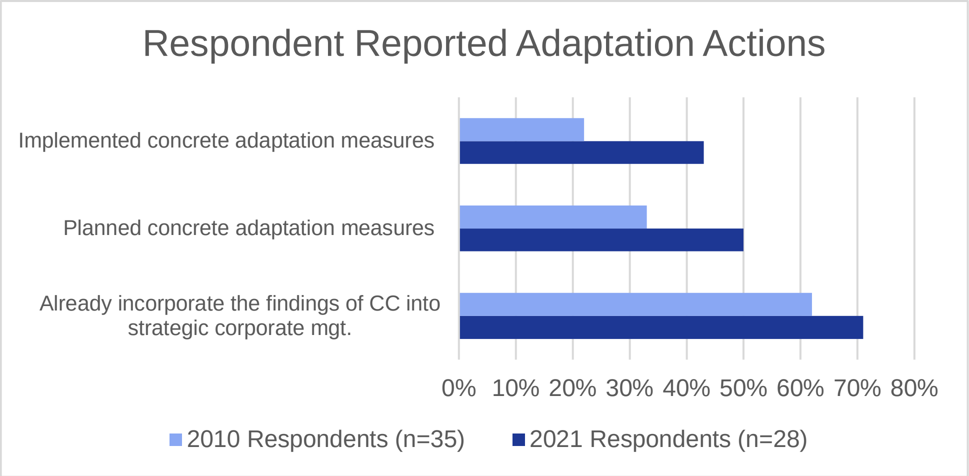
Figure 22: BDEW Member Survey – Reported Climate Change Perceptions in 2010 Chameleon Research Group and Author's 2021 Survey Compared



Source: Author (2021), Chameleon Research Group, (2011).

[76] While it remains unclear why the results from the 2021 survey are markedly higher than in terms of both the level of awareness and increased adaptation activity, it is worth noting that the survey took place during the widespread July 2021 flooding in Germany.

Figure 23: BDEW Member Survey – Reported Climate Adaptation Actions in 2010 Chameleon Research Group and Author's 2021 Survey Compared



Source: Author (2021), Chameleon Research Group, (2011).

Some of the respondent's planned and implemented measures include:

- Expansion of renewable energy generation and/or energy storage;
- Enhancing energy efficiency;
- Network expansion;
- Increased planning for flood scenarios; and
- Reinforced cooling fans.

Some of the survey respondents also provided recommendations for additional policies and practices that the German government can implement to facilitate further adaptation in the energy sector. These recommendations include:

- Provide incentives;
- Information sharing initiatives and platforms;
- Reduce bureaucracy, and streamline processes and planning and reporting requirements;
- Dovetail adaptation policies with disaster prevention policies;
- Promote knowledge building, information exchange, and consistent collaboration among the industry stakeholders; and
- Revision of existing codes and standards, and creation of new ones.

6 Policy Recommendations to Enhance Climate Adaptation and Resilience

The following section describes various policy and investment recommendations that could promote adaptation in both Germany and the U.S. focusing primarily on the national-level, but also on the state-level. The recommendations for both countries are intended to reform existing adaptation efforts, enhance the planning processes at the government and industry level, address policy gaps, and lower the risk of future catastrophic events. Some policy recommendations for the U.S. are based on learning from good established and prospective policies from Germany and vice versa. For example, the U.S. federal government and Texas state government should consider adopting a national adaptation strategy like Germany has as well as require critical infrastructure resilience plans with an all-hazards approach as are included in the EU's proposed CER Directive. Likewise, Germany should consider long-term climate vulnerability assessments and suitable measures similar to the climate adaptation planning timeframe that the State of California requires for its electric utilities.

6.1 Recommendations for Germany

Overarching Policies

1. Proactive adoption of new critical infrastructure resilience regulations

   In light of the EU's proposed CER Directive, Germany's regulatory agencies, such as the BNetzA, should begin identifying critical infrastructure entities and developing resilience plans. The BNetzA similarly should require regulated electric sector entities to conduct their own vulnerability assessments, prepare resilience plans and begin implementing measures. Although it is unclear how long the EU will take to adopt the proposed CER Directive, the German government could get a head start preparing legislation in advance and positively influencing the EU process.

   One specific recommendation for the risk assessments and resilience plans would be to require critical entities to consider risks and measures out to at least 2070. This would compel companies that otherwise may only focus up to a horizon of 5-10 years out to consider longer-term risks, including climate change, towards the end of the century.

2. Issue a Climate Adaptation Law and reform the German Adaptation Strategy

   The new government should enshrine its commitment to addressing climate change risks by passing a Climate Adaptation Act as described in the Coalition Agreement. Such a law would designate climate adaptation as a joint priority for all levels of government and facilitate financial assistance to state and municipal governments where needed. A climate change law could modify Article 91a of the Basic Law (Grundgesetz), which regulates agrarian structure and coastal protection as a federal and state government joint responsibility, such that it includes climate adaptation as an additional joint governmental responsibility.[cccliii]

   Should the German government issue a Climate Adaptation Act, then the government should use the opportunity to reform the current adaptation strategy (DAS) to enhance transparency in the industries' adaptation processes. A DAS reform should also include monitoring of relevant sectors and developing a new enforcement scheme to ensure mandatory compliance. Under the DAS, the energy industry is not required to publicly report on their individual climate vulnerabilities, devise adaptation and resilience plans or report on the implementation status of their climate adaptation measures. Furthermore, the DAS currently does not have any monitoring or enforcement mechanisms, so measures are essentially voluntary (provided that the industries comply with their existing regulatory obligations for their services).[cccliv]

3. Germany should develop common, climate resilient reconstruction standards

   Germany should establish reconstruction standards to ensure that when communities and the infrastructure that serve them are rebuilt post-disaster, that they are built back more environmentally sustainable and resilient. Allowing localities discretion to rebuild virtually all of the buildings in flood-stricken areas in Germany post July 2021 without uniform standards for resilience retrofits was not only a missed opportunity but also leaves them vulnerable to future devastating flood events.[77,ccclv] While the energy industry may rebuild their facilities to the latest state-of-the-art design standards, they will remain at risk of damage and/or service disruptions by building back in locations such as in the narrow Ahr river valley that was severely flooded in July 2021. With resilient reconstruction standards, the German government can ensure that only limited, highly resilient reconstruction would occur below the flood lines of not only historical events, but a one in 10,000-year event.

4. Conduct a nation-wide, granular vulnerability assessment and evaluate proactive measures

   While the government has conducted vulnerability assessments in the past, Germany did not anticipate the magnitude of the July 2021 floods and was inadequately prepared. In the aftermath of the July 2021 floods, former Chancellor Angela Merkel called for a flood vulnerability assessment to better understand the risk of future devastating floods of occurring.[ccclvi] Such an assessment should be part of a comprehensive and granular vulnerability assessment evaluating a broad scope of risks.

   Developing publicly available, nation-wide and regional hazard maps, which are currently in use in Switzerland (nation-wide and regional) and in limited German localities such as in Hamburg and Cologne, could provide useful insight and help inform future policies.[ccclvii,ccclviii]

   In these studies, the German government should assess various resilience measures for either relocating communities and infrastructure (often referred to as "managed retreat") or enhancing their resilience in-place. For instance, the government could study the deployment of microgrids to serve isolated communities to allow them to maintain electric service needed at least for essential services if the lines from the bulk system are damaged. The government should also evaluate potential restrictions or prohibitions on new development in areas vulnerable to natural hazards.

5. Enhance local natural disaster preparation, simulation exercises

   In the aftermath of the July 2021 floods, the state and local governments in Germany should review their disaster preparation and response protocols and measures and improve for future events. For instance, despite the early warnings of extreme precipitation and flooding risk by the European Flood Awareness System and the German Meteorological Service, local authorities failed to adequately communicate this risk to the public and issue emergency alerts the day of the event which contributed to many unnecessary deaths.[ccclix]

   Localities should coordinate with first responders and critical infrastructure providers, such as the energy industry, to develop and practice new emergency response protocols and measures during exercises. This will help prepare mass evacuations in advance of future events and allow first responders and energy and other critical infrastructure providers to more efficiently mobilize their resources to respond and restore essential services.

[77] For instance, in the Ahr River Valley, where thousands of homes were either damaged or destroyed, local authorities will allow all but 34 homes to be rebuilt in the same location based on their updated flood zone maps for the region.

Power Generation

6. Power Plant Retrofit Study to Reduce Dependence on Fresh Water for Cooling

   Thermal power plants (including geothermal) that have a remaining lifespan of at least 16 years and currently rely on fresh water for cooling should be studied for retrofitting once-through cooling systems to hybrid cooling, dry cooling or recirculating cooling systems. Similarly, retrofitting power plants with recirculating cooling systems to hybrid or dry cooling systems should be part of such a study. While the volume of water used for once-through cooling is less than half of levels used in the 1990s, the energy sector still accounts for over 12 billion cubic meters (m^3) of water used each year in Germany.[ccclx] Thus, there is still opportunity to reduce water consumption in thermal power plants that will continue to operate at least until 2038, when all coal and nuclear decommissioning has been completed. Additionally, such a study should evaluate retrofitting cooling systems to utilize saline or brackish water rather than freshwater. This recommended study is consistent with the DAS APA III which specifically identifies the need to examine power plant management and state of the art cooling technologies to reduce the discharge of heated water into watercourses.[ccclxi]

   Some possible mechanisms for reducing thermal generation freshwater dependence include incentives for retrofits; incentives for reducing water use from the government, or re-evaluating existing regulations, such as limitations on water discharge to protect aquatic life.

7. Vulnerability assessments and adaptation plans for power generation

   If Germany's adopted version of the proposed CER Directive does not adequately cover the assessment of climate risks and resilience measures through the entire lifespan of the facilities, then the German government should make this a specific requirement for electric generation. The government should require generation entities to prepare climate vulnerability assessments and adaptation plans with updates at least every 5 years. In these plans, generation entities should consider a comprehensive scope of risks not only to their facilities and operations, but also to their supply chains (e.g., fuel supply, critical components). The generation entities should be required to submit public versions of these assessments and plans for public review and comment.

8. Climate risk in planning and permitting process for generation

   Permitting processes for new generation facilities should require climate risk assessments to ensure that new facilities will be climate resilient over the course of their lifespans. This will help ensure that the facilities can operate optimally and minimize future costs and disruptions despite the changing climate. Planning projects based on historical conditions and risk is no longer adequate as the operating environment is changing and risks such as heat waves and flooding continue to grow.

Transmission and Distribution

9. Vulnerability assessments and adaptation plans for transmission and distribution

   Similar to the recommendation for electric generation vulnerability assessments and adaptation plans, Germany should similarly require the TSOs and DSOs to prepare climate vulnerability assessments and adaptation plans with an outlook towards 2070 (if not otherwise required to by the CER Directive). These plans should consider the full scope of risks to their operations and facilities as well as to the third-party generation located domestically and internationally that is the source of their electricity. Updates should be issued at least every 5 years looking out to at least the next five decades.

These documents should have a public version that is open for public review and comment prior to final submission to the BNetzA or state regulatory authorities.

10. Long-term climate risk in planning and permitting process for transmission and distribution

    All major T&D infrastructure planning efforts, including the NEP, should have an evaluation of long-term potential climate risk and specify how such risks will be addressed in the proposed projects. Currently, the NEP does take climate risk into account as part of its planning process for proposed transmission lines.[ccclxii,ccclxiii] By proactively assessing climate vulnerabilities outwards to at least 2070 in the planning and permitting process for T&D projects, TSOs and DSOs can incorporate climate adaptive elements into the new infrastructure or re-route the lines to minimize future risks.

6.2 Recommendations for the U.S. – Federal Level

Overarching Policies – Inspired by Germany and the EU

11. Prepare a National Climate Adaptation Plan

    The U.S. Federal Government should adopt a National Climate Adaptation Plan similar to that of Germany and its peers in the EU. A national adaptation plan could help define the nation's climate adaptation priorities and actionable goals and efficiently direct efforts to coordinate with the relevant industries and local and tribal governments. The adaption plan should be based on standardized climate scenarios to be used across all government research, planning and investments, including for the energy sector. Such a plan could be issued every four years in concert with the issuance of the U.S. National Climate Assessment Reports. The U.S. government should legislate this effort and provide a budget not only for its quadrennial report preparation, but also to help facilitate the actions in coordination with public and private partners of impacted regions and sectors.

12. Electricity crisis scenario response planning

    The federal government should legislate a requirement for electric crises scenario response planning for TSOs and DSOs based on the example of the EU's Risk Preparedness Regulation. Such a policy would ensure that the federal and state governments, TSOs and DSOs identify, better plan for and limit the impact of various electric crisis scenarios, including those driven by extreme weather events. Similar to the EU countries, such plans should be updated every four years.

13. Establish a policy for critical infrastructure resilience plans and measures

    The U.S. should legislate a national policy for critical infrastructure resilience planning similar to that of the EU's proposed CER Directive. Currently, critical entities in the U.S. only conduct risk assessments and engage in resilience planning on a voluntary basis. This leads to uneven levels of resilience among and between industries and in most cases, the companies are not incentivized to consider long-term climate impacts. Additionally, the U.S. does not develop its own resilience plans for the industries. By following the outline set in the proposed CER Directive, the U.S. government could enhance transparency in climate risks for critical industries and promote them to adopt proactive resilience measures and minimize the impact of future extreme weather events.

Overarching Policies – Other

14. Require the adoption of consensus-based standards for T&D

    The federal government, either through legislation or through FERC regulations (for transmission), should require the electricity sector to adopt consensus-based standards for facility design and construction. Groups such as the ASCE and the Institute of Electrical and Electronics Engineers (IEEE) have developed many engineering standards that can guide safe, reliable and efficient construction and operation of electric facilities. Currently, standards are put into practice in a decentralized manner in the U.S., with each of the state government authorities deciding for themselves which standards to adopt, rather than through a centralized, and uniform approach.[ccclxiv] With this decentralized approach, state regulators face trade-offs between cost and reliability when determining the standards to adopt for distribution.[ccclxv] However, uniform adoption of standards could be a cost-effective means to enhance distribution system reliability and save lives.[78] Not only are common design standards important, but adaptive standards such as for distribution vegetation management could be valuable to help reduce the risk of outages and catastrophic wildfires.

15. Close the electric infrastructure gap for reliability and resilience needs

    The federal government should consider a variety of funding mechanisms to reduce the infrastructure investment gap in the electricity sector for reliability and resilience costs that are expected to run into the hundreds of billions by mid-century. Some options could include expansive funding legislation to provide tax dollars to specific projects and promote innovation (such as in the 2021 bipartisan infrastructure bill), tax breaks for large resilience projects, or continue to leverage disaster relief funds to not only rebuild communities' infrastructure but to rebuild them to the latest state-of-the-art and resilient designs. The government should develop a grant program in the model of the Rebuild by Design Hurricane Sandy Design Challenge to award innovative projects that can protect vulnerable communities and infrastructure.[79]

Recommendations for the U.S. Department of Energy

16. Restart Obama-era DOE adaption initiatives, enhance public tools and data

    The DOE should consider restarting various Obama-era adaptation initiatives, including the 2016 DOE Partnership for Energy Sector Climate Resilience, to engage energy sector stakeholders and local and tribal governments with programs to enhance their adaptive capacities. The DOE should also adopt an adaptation clearinghouse, similar to the German government's KLiVO, the Cal-Adapt platform or the clearinghouses that the U.S. Department of Transportation and the Environmental Protection Agency currently use. A DOE adaptation clearinghouse could serve as a comprehensive single resource for data, tools and information concerning the potential impacts of climate change on the energy sector and adaption and resilience options.

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[78] However, the ASCE notes that at the modest cost increase of $681 per mile ($426 per kilometer) on average to properly design a distribution line to the latest standards, this is a cost-effective approach to prevent damage and loss of life. (See ASCE 2021 p.50)

[79] The Rebuild by Design program was a public-private collaboration and design contest created by the Obama Administration to rebuild the areas damaged by Hurricane Sandy and award nearly $1 billion to the most innovative resilience projects for the affected areas. (See http://www.rebuildbydesign.org/our-work/sandy-projects)

17. The DOE should issue regular vulnerability assessments needed to guide adaptation policy

    The U.S. DOE should be tasked with issuing quadrennial reports on vulnerability in the energy sector to accompany the U.S. Climate Change Assessment Reports. Similar to the 2015 DOE report on regional energy sector vulnerabilities and resilience options, the reports should similarly focus on regions, natural hazards and technologies.

18. Conduct a cost-benefit analysis for adaptation and resilience measures

    In order to better inform utilities and municipal governments how to evaluate cost-effective adaptation options, the DOE should conduct a study on the costs and benefits for different adaptation strategies and technologies. For instance, such as study could include an evaluation of different fire hardening measures for electric infrastructure such as overhead-to-underground conversion of T&D facilities and replacing wooden poles with steel or concrete poles and covering the overhead conductors with insulating materials (referred to as “covered conductors”) to prevent sparking with vegetation contact. It should also include technology pilots for different areas to test promising technologies at scale. Such a study should be updated every 4-5 years to account for changes in costs for technology and labor.

19. Prepare a national grid hardening strategy

    Based on the vulnerability assessment and the data from an adaptation costs-benefit study, the DOE should partner with state governments and consult with the electricity industry to prepare a national grid hardening strategy. Such a strategy would lay out the national priorities and a targeted timeline for hardening the T&D systems across the nation against a myriad of risks. It would provide a plan for raising taxpayer and ratepayer funds over a 50-year period to reduce the growing risks that climate change poses. The plan could assign clear responsibilities to the appropriate state and regional government agencies and develop clear guidelines for monitoring, data tracking and management, and assessment of progress. The need for a grid hardening plan was identified by the ASCE, which found that such a plan could help minimize the impacts from catastrophic events and enable rapid restoration of power.[ccclxvi]

6.3 Recommendations for California

20. California should deny PG&E’s ambitious 10,000-mile undergrounding proposal

    While the risk of utility-driven wildfire ignitions remains high in California and in PG&E’s service territory in particular, California should not allow PG&E to pass the costs of the 10,000-mile (about 16,000 kilometer) undergrounding project in the high-fire threat district into customer rates. PG&E should rely on more cost-effective alternatives such as replacing wooden utility poles with steel or concrete poles and covered conductors to reduce the risk of ignitions from vegetation contact. The CPUC reported in 2018 that the cost for underground conversion of overhead distribution facilities ranges from about $2 million to $6 million per mile ($1.25 million to $3.75 million per kilometer).[ccclxvii] This is significantly more expensive than the cost of covered conductors and fire-resistant poles which in 2018 was estimated to cost $480,000 per mile ($300,000 per kilometer).[ccclxviii]

21. Legislate climate vulnerability assessments and adaptation planning for all critical infrastructure entities

    In the absence of federal government action, the State should pass legislation requiring all critical infrastructure entities to assess their climate vulnerabilities at least through 2070 and engage in adaptation planning. In the electricity sector, currently only the electric IOUs under CPUC jurisdiction are subject to such requirements. The municipal-owned utilities, small and multi-jurisdictional utilities, and generation companies are currently exempt from these requirements. Through legislative action, the State can ensure that these other utilities and power producers are no longer left out from these requirements.

22. Study potential building code changes to enhance energy efficiency and resiliency

    California should conduct a study to evaluate potential changes to residential and commercial building codes that could lower electricity demand and enhance adaptation and resilience. For instance, the state could study the costs and benefits for requiring or incentivizing all new buildings to be zero-net energy and have energy storage units to meet peak evening demand, provide grid services or provide power during outages. Currently, California requires all new homes to be equipped with solar panels but does not have any incentives or requirements for them to be paired with energy storage. The State should also evaluate adaptive design and landscaping features. For instance, new standards could include passive cooling elements such as shading from trees, smaller windows, and improved insulation to minimize air conditioning demand and thus stress on the grid.

23. Develop resilient reconstruction standards for areas impacted by natural disasters

    The State of California should legislate and/or adopt new regulations for resilient reconstruction standards for areas destroyed by climate-related disasters to that ensure where possible that rebuilt electric facilities are more intelligent, resilient and better able to accommodate renewables. Such policies would be aligned with the U.S. Department of Homeland Security's Federal Emergency Management Agency (FEMA) policy that was adopted in 2018, which requires buildings and infrastructure to rebuilt to the latest, state-of-the-art hazard resistant designs in order to receive federal grants.[ccclxix] One option for the CPUC-regulated utilities would be to amend the IOUs' Tariff Rules 15 and 16, which govern distribution and service line extensions, to specifically require reconstructed lines to be built underground or with covered conductors and fire-resistant poles.

24. Conduct a study to incentivize relocation of communities and services from high-risk areas and pass related pending legislation for wildfire risk areas

    The State should conduct a comprehensive study for a managed retreat for communities and infrastructure away from areas at risk of climate-influenced natural disasters. For instance, currently 11 million people, over one-quarter of California's population of 39.5 million, live in wildfire risk areas in the wildland urban interface (WUI) and this population continues to grow each year.[ccclxx] State and local governments should consider a mix of incentives and regulations to move communities and infrastructure out of such areas. There have been some studies and efforts to date to provide incentives for new development that is outside of the WUI areas, such as in the case of the proposed 2021 proposed bill SB 55 (Stern), which would prohibit development in high fire risk areas unless certain resilience requirements are met. The bill also would provide tiered incentives for development outside of the wildfire risk areas.[ccclxxi] The State should approve this bill and a related 2021 bill SB 12 (Stern) that would require, among other things, resilient retrofits to buildings in the high wildfire threat areas.[ccclxxii] However, the State should consider broadening these policies or related legislation to include all potential climate impacted areas, such as coastal areas at risk of sea-level rise.

6.4 Recommendations for Texas

25. Comprehensive vulnerability assessments and adaptation and resilience planning

In order to get a clearer picture in the vulnerabilities that the energy sector and other sectors face, the State of Texas should conduct a state-wide climate vulnerability assessment and update it at least on a triennial basis. The State of Texas should also issue an adaptation and resilience plan following the release of the vulnerability assessments. The vulnerability assessments and adaptation and resilience plans should focus on a comprehensive range of climate risks outwards to at least 2070 that could impact the state. Such risks to consider should include but not be limited to temperature rise, changes in precipitation, extreme temperature events, wildfires, extreme storms, and sea level rise. State-level adaptation and resilience planning can help identify the range of risks, prioritize the response to them and assist industry and local government decision-makers successfully plan measures.

26. Establish an adaptation clearinghouse or other central, online adaptation resource

The Texas state government should develop a central, online adaptation clearinghouse or similar resource for industry, academics and municipal governments among others. Such a website could serve as a knowledge sharing platform on climate adaptation topics and include useful datasets, information, and other resources to assist with climate adaptive planning. Texas should consider the examples set by Germany's KLiVO, California's Cal-Adapt, or the EU's Climate-ADAPT.

27. Critical infrastructure industries should be required to engage in adaptation planning

The State of Texas should legislate requirements for critical infrastructure sectors to engage in comprehensive vulnerability assessments and adaption planning considering risks through at least 2070. Specific to the electricity sector, the Texas PUC should modify the quinquennial ERCOT weather study to require a range of climate projections that are informed by the latest data and warming scenarios from the IPCC. The Texas PUC should also require their regulated generation, transmission, and distribution utilities to climate vulnerability assessments and adaptation plans for their assets and operations and those of third-party fuel suppliers and infrastructure operators (e.g., the natural gas industry) through at least 2070. Such plans should be subject to triennial updates and public review and comment. The PUCT should make adaptation and resilience measures mandatory and impose stiff penalties for non-compliance or negligence that leads to failures. Additionally, the PUCT should go further than requiring a winterization plan for 2021-2022 and require comprehensive assessments and measures to safeguard against year-round risks well into the century.

Furthermore, the Texas RRC should similarly require a comprehensive climate vulnerability assessment at least every five years that could serve the basis of year-round climate resilience standards for the natural gas industry. Similar to the above recommendations for the PUCT's regulated entities, the RRC should require comprehensive vulnerability assessments and adaptation and resilience plans. They should be on a triennial basis, look forward to at least 2070 and be subject to public review and comment. Similarly, the RRC should make compliance mandatory and subject to penalties. The RRC should also consider removing its exception clause for critical entity designation for natural gas companies as it allows natural gas companies to opt out of any weatherization standards and they may not be prioritized by the electric utilities to as a critical load.[ccclxxiii,ccclxxiv]

28. Expedite the year-round weather emergency preparedness measures for generation, transmission, distribution and natural gas

    Currently, the only mandated resilience measures in effect for the winter 2021-2022 season are specific to winterization of generation and transmission entities. The PUCT and RRC need to expedite their regulatory review for year-round weather emergency preparedness such that regulatory review can finish by third quarter 2022 and measures can be implemented for all entities against all risks by first quarter 2023. At a minimum, the RRC should at least prioritize winterization of natural gas facilities prior to the winter 2022-2023 season. By waiting until the February 2023 deadline set by the Texas Legislature in SB 3 to implement winterization regulations, the RRC has failed to act within the same timeline as the PUCT and implement the regulations in advance of the 2021-2022 winter season. The RRC may also miss the following 2022-2023 winter season as well.[ccclxxv] Unless the natural gas system can resolve its vulnerabilities to extreme weather and temperatures, then the Texan electric grid will remain at risk of another disaster similar to that of February 2021.[ccclxxvi]

29. Texas should study opportunities for microgrids, distributed energy resources and temporary generation to meet resilience needs

    Texas should examine the opportunities to utilize distribution technologies such as microgrids, DERs (i.e., solar and energy storage) that are both customer and utility-owned, and mobile, temporary generation through a study or pilot projects. By deploying technologies such as energy storage to strategic locations such as substations, medical centers, or central business districts, Texas may be able to significantly enhance the reliability of essential services and reduce the impact of outages.

30. Develop resilient reconstruction standards for areas impacted by natural disasters

    Similar to the recommendation for California, adopting such standards in Texas would align with FEMA disaster relief policy and lower the risk of future events such as hurricanes devastating places that had previously been damaged from such events.

31. Conduct a study to incentivize relocation of communities and infrastructure from high-risk areas

    Texas should evaluate incentives for communities and critical infrastructure to move away from places such as those at risk of storm surges, wildfires, or other natural hazards. For instance, an estimated 244,000 people living along the Texas Gulf Coast will be at risk of coastal flooding due to sea level rise.[ccclxxvii] Texas should proactively develop incentives for development out of all risk areas similar to how California aims to incentivize development out of wildfire risk areas.

32. Conduct a study on interconnecting Texas with the rest of the North American grid

    The State of Texas should conduct a study to assess the costs and benefits of building new transmission lines and interconnecting with the broader North American grid. Had Texas been connected with the broader grid, it could have imported electricity from neighbouring states and reduced the extent of outages in February. Texas and its neighbours could improve their grids' reliability and open to new markets for renewable energy export. However, Texas will have to weigh this against the opportunity cost of shorter-term reliability and resiliency measures, cost of new transmission build-out, challenges of obtaining permits and operating under federal interstate transmission regulations and other potential challenges. Texas did complete such a study in 1999, but it did not consider such dramatic growth in renewable energy, the extreme weather events that the state has seen in recent years, or climate change projections through the end of the century.[ccclxxviii]

33. Conduct a study and/or solicit stakeholder input on establishing a capacity market

As part of Texas's electric market redesign, the State should consider establishing a capacity market to incentivize more reserve capacity for meet future summer or winter peak demand events. Texas should consider commissioning a study to better understand the costs and benefits, or at least solicit stakeholder input to its PUCT rulemaking concerning the electric sector reforms post February 2021. Even if Texas ultimately decides not to create a capacity market, it can at least draw some ideas from successful capacity markets elsewhere. Additionally, Texas can gain useful stakeholder input that could shape a better electricity market that is more successful at incentivizing resource adequacy and limiting the risk of blackouts.

34. Conduct a study to determine the opportunities for demand-side energy programs

Texas should study a mix of programs and incentives to encourage higher rates of energy efficiency, adoption of time-of-use or other price-responsive electricity rates, and demand response participation among all customer classes. Currently, Texas ranks 27th among all the U.S. states in energy efficiency (the Texas Energy Efficiency Resource Standard represents only 0.2% of MWh sales) and less than 5% of customers in ERCOT participate in any price-responsive rates.[ccclxxix,ccclxxx] Aggressively deployed demand-side management programs in Texas for 2023-2027 could reduce the summer and winter peak loads by 7,650 MW and 11,400 MW respectively at just 61% of the $8 billion that it would cost for new natural gas generation to meet this level of demand.[ccclxxxi]

As part of this broader study, Texas should explore building code reforms or developer incentives to build new residential and commercial buildings as zero-net energy and be equipped with solar and energy storage. Such homes would lower the strain on the electric grid during peak demand events and be able to maintain power for some time even during an outage on the grid. Passive cooling elements should be considered as well to reduce electricity demand during hot weather.

7 Opportunities for Additional Research

While this study explored a wide spectrum of climate risks to the U.S. and German electricity sectors and numerous policies for enhancing electric sector climate resilience, there remain multiple areas that could benefit from further research. Below are some recommended topics for future studies.

- Climate impacts on utility and generation hardware supply chains – Climate change impacts on utility supply chains for materials, components and devices were not part of the project but deserve further research. It is not clear from the existing literature how disruptive climate change could be to these supply chains, such as for Asian-produced rare-earth metals, components and devices, and if that will ultimately affect costs. While fuel and feedstocks and their supply chains (e.g., natural gas infrastructure) were not a major focus in this study, the literature is more robust for these elements than for hardware supply chain issues specific to the energy sector.
- Studying the direct and downstream economic, human health and other societal impacts of catastrophic events that impact electric infrastructure – Having a better understanding of the direct costs of events (e.g., damaged utility poles and conductors) and the downstream economic impacts (e.g., economic losses and premature deaths due to outages) would help decision makers better understand the risk and severities of climate change related natural catastrophes. To provide a more complete picture of the costs, it is also important to understand the cost of lingering impacts such as higher borrowing and insurance costs for utilities continue to operate in areas at high-risk for natural hazards.
- Assessment of costs and benefits of adaptation and resilience measures – An assessment of costs, both to inaction and deployment of various adaptation and resilience solutions, and the benefits of these solutions should be studied to help private energy companies and governments decide the optimal mix of policies and technologies to prioritize. For instance, it may simply be cheaper for a utility (particularly in the U.S.) to build a microgrid in an isolated area to maintain resilience than engage in grid hardening in an area that is at high risk of outages from storms or wildfires.
- Improving utility safety culture – Relative to their German counterparts, some U.S. utilities and power producers have had a poorer track record for safety and reliability. For instance, U.S. utilities operate facilities that are either at or past their useful life and some have been negligent with inspecting and maintaining their facilities, which has led to catastrophic wildfires or other accidents. German utilities, while also similarly investor-owned, driven by profit motives and not necessarily focused on long-term risks (like climate change through the end of the century), seem to have better track records for safely operating and maintaining their equipment. It is unclear if this has the result of different executive structures, laws or regulations, or down to luck.
- Studying nature-based solutions to understand more potential adaptation measures – Measures such as coastal restoration, forest management and greening urban areas were not a focus of this study, but they hold potential for reducing damage and stress on the electric grid. For instance, planting trees in urban areas may reduce peak electricity demand and stress on the grid during heat waves by shading homes and offices.[ccclxxxii] Future research may be warranted to help inform policymakers and electric infrastructure owners of potential nature-based investments to achieve the co-benefits of improving resilience and biodiversity.

8 Conclusion

Risks and adaptation options

Climate change already has proven a risk to society in Germany and in the U.S. and threatens critical infrastructure sectors, such as the electricity sector which forms part of the backbone of the economy. As the climate becomes more unstable, electricity systems will be confronted by an increasingly challenging operating environment with more frequent and dangerous natural hazards. Ultimately, is up to governments, industries, and society to decide if they are willing to make the necessary investments to adapt to a challenging new climate or risk future damages from catastrophes such as mega-fires, hurricanes, or sea level rise.

In this context, Germany and the U.S. should:

a) Conduct vulnerability assessments and long-term adaptation and resilience planning.

All levels of U.S. and German government and electric infrastructure owners and operators need to carry out climate change vulnerability assessments and plans to address these risks that extend out to the end of the century and regularly update these plans. The current planning paradigm based on historical trends and planning up to five and ten years in the future is no longer sufficient as formerly rare, extreme weather events increasingly threaten the electricity sector. Vulnerability assessments and planning should be informed by climate models in addition to historical data and entities should plan for many decades in the future. Similarly, the U.S. and German governments need to plan for how to respond and recover as quickly as possible from crises that arise from extreme weather events impacting the electricity system.

b) Establish monitoring and enforcement mechanisms.

Germany and the U.S. need to develop monitoring protocols and enforcement mechanisms to ensure that electric generation and utility companies make progress on necessary adaptation investments and practices. Part of the monitoring should include requiring energy companies to submit regular public reports subject to regulatory review on their vulnerabilities and the implementation status of their adaptation measures.

c) Develop adaptive and resilient permitting and standards regulations.

Governments in both countries need to develop permitting requirements and standards that require utilities and generation companies to plan new and rebuilt facilities to be adaptive and resilient. Climate risk assessment is not currently part of the permitting and planning of new facilities, rather historical data and planning for events such as a historical 100-year event are more commonplace. For facilities that are destroyed from extreme weather events, reconstruction should be subject to national standards to mitigate future risk not left to the discretion of the facilities' owners or local authorities which is often the case.

Taking advantage of the transition to carbon neutrality

Despite these challenges from climate change, this remains a unique historical moment which presents significant opportunities for improving our electric systems and, in turn, our societies. We have the benefit of hindsight from past extreme weather events, foresight aided by robust data on climate change and its risks, and a wholesale economic transition away from fossil fuels to decentralized, renewable electricity generation and electrification of areas such as transportation and buildings. With these factors and the right amount of political will and resources, we have an opportunity to build resilient and carbon neutral infrastructure that will benefit our societies for years to come. As two of the leading advanced economies, the U.S. and Germany should lead by example in achieving sustainable and resilient economies and help other nations build up their adaptive capacities by sharing information and best practices.

a) **Promote policies and investments that achieve sustainability and resilience goals**.

The U.S. and Germany should continue to pass legislation and regulations to facilitate their energy transitions away from centralized, fossil fuel generation to decentralized and renewable sources of electricity and invest further in supportive smart grid technologies. These investments in smart grid technologies can increase the adoption of renewable technologies and enhance resilience by providing greater insight to grid conditions, increasing hosting capacity, minimizing outage impacts and restoration time, reducing peak load, providing back-up generation and storing excess renewable power. Additionally, these investments will further reduce our dependence on large, fossil generation plants that emit GHGs and are less resilient to events such as heat waves and droughts.

b) Promote knowledge sharing for internal stakeholders and international entities alike.

The two countries should continue to share knowledge on climate adaptation and make it accessible to help build up adaptive capacity within and beyond their borders as a supplement to aid and diplomatic efforts. These knowledge sharing initiatives include maintaining online adaptation clearinghouses, hosting workshops and conferences, fostering industry engagement and public-private partnerships, and promoting exchange programs.

c) Conduct further studies to determine optimal policy and investment mixes.

Both countries should conduct studies such as cost-benefit analyses for the deployment for renewable and resilient technologies, and electricity market structure and incentives to promote the procurement of resource adequacy to reduce the risk of blackouts and further adoption of carbon-neutral technologies.

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Appendix I – DOE Climate Adaptation Initiatives

- **Climate Action Champions** – A national competition to identify local and tribal community organizations pursuing resilience activities that could serve as models for other communities. Federal agencies facilitated peer-to-peer learning and mentorship, provided targeted support, and fostered communication and support among different agencies and organizations.
- **Preparedness Pilots** – In another community-focused effort, the DOE work with the State of Colorado to connect local communities with key federal agencies to assess and plan for region-specific interdependencies and climate risks.
- **State Energy Assurance Plan Assistance and Risk Assessment Initiative** – the DOE collaborated with state and local governments on enhancing energy resilience, developing information and tools and conducting forums, training, and tabletop exercises with government officials, emergency responders, and industry stakeholders. DOE initiatives helped states develop in-house expertise and increased state officials' awareness of vulnerabilities and ability to make informed decisions related to resilience strategies, investments, and asset management.
- **Strengthening Tribal Energy Systems** – The DOE is providing technical assistance to help tribes identify, assess, and respond to specific climate risks and adaptation opportunities. In 2015, the DOE published a report describing the biggest climate risks threatening the economic and energy security facing various tribes.
- **Partnership for Energy Sector Climate Resilience** – Through the Partnership, the DOE worked with its 18 electric utility partners to develop and implement strategies for enhancing extreme weather and climate resilience. The DOE issued guidance on conducting vulnerability assessments and disseminated information and analytical methods.

Appendix II – German Electric Sector Survey 2021

Company background/ general data

No.	Question	Your Response
1	Respondent Name and email address (for internal use only)	open
2	Name of your company (for internal use only)	open
3	Please indicate your department, position, and area of responsibility in your company	open
4	What is the legal status of your company?	GBR, GmbH, GmbH & Co.KG, KG, AG, AG & Co.KG, AdöR, further
5	How many employees does your company have?	1-99, 100-249, 250-499, 500-1,000, 1,000 - 9,999, 10,000 and more
6	Company focus	(e.g., conventional generation, renewable generation, transmission, distribution, electricity supply, municipal utility)
7	Geographic area(s) of operation	(German states, countries outside of Germany)

Climate Change Awareness and Policies

8	To what extent do you personally agree with the following statements?	
	The consequences of climate change will be severe in Germany.	fully agree; mostly agree; mostly disagree; fully disagree; no opinion
	The developments of the climate are too uncertain to make statements about the effects.	fully agree; mostly agree; mostly disagree; fully disagree; no opinion
	Our company is already affected by the consequences of climate change.	fully agree; mostly agree; mostly disagree; fully disagree; no opinion
	The consequences of climate change will not affect our company in the future.	fully agree; mostly agree; mostly disagree; fully disagree; no opinion
9	Are you aware of the following documents/policies?	
	The German Strategy for Adaptation to Climate Change (DAS)	unfamiliar; have only heard about it; know the contents; have dealt with it in detail
	The Federal Government's Integrated Energy and Climate Programme	unfamiliar; have only heard about it; know the contents; have dealt with it in detail

	European Union proposed Directive on the Resilience of Critical Entities (CER Directive)	unfamiliar; have only heard about it; know the contents; have dealt with it in detail
	Regulation (EU) 2019/941 - Risk Preparedness Regulation	unfamiliar; have only heard about it; know the contents; have dealt with it in detail
	European Union Climate Adaptation Strategy	unfamiliar; have only heard about it; know the contents; have dealt with it in detail
10	What, if any, additional EU or German policies/regulations should be developed to facilitate further adaptation and knowledge sharing in the energy sector?	for instance, changing codes and standards, incentives, information sharing initiatives, streamlining processes, planning and reporting requirements, etc.
	Please explain each suggestion in a sentence or two	open
11	Is your company discussing how to deal with the consequences of climate change?	yes; no
	if so, in which departments?	open
12	How do you assess your level of understanding about:	
	The consequences of climate change in Germany?	high level of understanding/awareness; informed; somewhat aware; unaware
	The consequences of climate change on your business in general?	high level of understanding/awareness; informed; somewhat aware; unaware
	Possible adaptation measures to the consequences of climate change in your company?	high level of understanding/awareness; informed; somewhat aware; unaware

Concern of the company

13	How has the frequency and/or intensity of the following weather phenomena changed during the last 15 years at the locations of your company's grids/power plants?	
	Heat waves (e.g., in the summers of 2003, 2018, and 2019)	Greatly increased, increased, remained the same, decreased, greatly decreased, do not know
	Storms (e.g., Kyrill, 2007)	Greatly increased, increased, remained the same, decreased, greatly decreased, do not know

	Drought or low water levels (needed for energy generation or navigation)	Greatly increased, increased, remained the same, decreased, greatly decreased, do not know
	Other weather phenomena that have affected operations:	open
	How has the frequency/and or intensity changed of other weather phenomena?	Greatly increased, increased, remained the same, decreased, greatly decreased, do not know
14	Were the actions your company took during or after such an event due to the impact "ad hoc" (such as curtailing a power plant; disconnecting a section of the grid) or long-term, operational actions (such as changing the cooling system; retrofitting the grid)?	only ad hoc; only long-term / operational; both; no measures were taken
	What were the main measures?	open

Consideration of climate and weather data

15	Do you record the percentage that weather-related outages make up of your company's total outages?	yes, no
16	If so, what is this percentage?	open
17	How has this proportion changed in the last 10 years?	greatly increased, increased, remained the same, decreased, greatly diminished, unknown
18	To what extent is weather data taken into account in planning decisions for capital assets (such as grid/generation assets)?	very strong, strong, medium, weak, very weak, not at all
19	Are current findings on the consequences of climate change already being incorporated into strategic corporate management today?	yes, no
20	(if 19 “no”) In your view, why have the consequences of climate change not yet been taken into account in strategic corporate management?	open
21	(if 19 “yes”) Are concrete measures for adaptation to the consequences of climate change already planned in your company?	yes, no
	if so, what concrete measures for adaptation are currently planned by your company?	open
22	(if 21 “no” and no concrete measures are currently planned) In your view, why are no concrete measures for adaptation to climate change consequences planned in your company so far?	open

23	(if 21 "yes" and concrete measures are currently planned) Have concrete measures for adaptation to climate change impacts already been implemented in your company?	yes, no
	if so, what concrete adaptation measures have already been implemented in your company?	open
24	(if 23 "no" and no measures have been implemented) In your view, why have no concrete measures for adaptation to climate change consequences been implemented in your company so far?	open

Investment decisions on long-lasting infrastructure

25	What average service life do you expect	
	Electric grid facilities	1-10 years; 10-20 years; 20-30 years; over 30 years; not present in the company
	large thermal power plants (>20 MW)?	1-10 years; 10-20 years; 20-30 years; over 30 years; not present in the company
	small thermal power plants (< 20 MW)?	1-10 years; 10-20 years; 20-30 years; over 30 years; not present in the company
	Wind turbines?	1-10 years; 10-20 years; 20-30 years; over 30 years; not present in the company
	Solar photovoltaic arrays?	1-10 years; 10-20 years; 20-30 years; over 30 years; not present in the company
	Hydroelectric facilities?	1-10 years; 10-20 years; 20-30 years; over 30 years; not present in the company
26	After how many years, will your company be facing the first retrofits/replacements of the most cost-intensive components...	
	Electric grid facilities	1-10 years; 10-20 years; 20-30 years; over 30 years; not present in the company
	large thermal power plants (>20 MW)?	1-10 years; 10-20 years; 20-30 years; over 30 years; not present in the company

	small thermal power plants (< 20 MW)?	1-10 years; 10-20 years; 20-30 years; over 30 years; not present in the company
	Wind turbines?	1-10 years; 10-20 years; 20-30 years; over 30 years; not present in the company
	Solar photovoltaic arrays?	1-10 years; 10-20 years; 20-30 years; over 30 years; not present in the company
	Hydroelectric facilities?	1-10 years; 10-20 years; 20-30 years; over 30 years; not present in the company
27	What are the investments that your company is planning over the next 10 years?	
	... for networks?	
	a) New construction / retrofits / upgrades	none planned; less than €1 million; €0- 10 million; €10 - 50 million; €50 - 100 million; €100 - 500 million; €500 million - €1 billion; €1 billion or more
	b) Maintenance / replacement	none planned; less than €1 million; €0- 10 million; €10 - 50 million; €50 - 100 million; €100 - 500 million; €500 million - €1 billion; €1 billion or more
	... For generation facilities	
	a) New construction / retrofits / upgrades	none planned; less than €1 million; €0- 10 million; €10 - 50 million; €50 - 100 million; €100 - 500 million; €500 million - €1 billion; €1 billion or more
	b) Maintenance / replacement	none planned; less than €1 million; €0- 10 million; €10 - 50 million; €50 - 100 million; €100 - 500 million; €500 million - €1 billion; €1 billion or more

Options for further contact

28	(Optional) If you would like to be informed about the results of the survey, please enter your email address here	email address
29	(Optional) Would you be willing to elaborate on your responses or share additional information in a brief interview for research purposes?	yes, no

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