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CLIMATE RISKS TO ELECTRICITY INFRASTRUCTURE

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I. INTRODUCTION

Climate change is already causing major shifts in weather patterns and environmental conditions. Extreme weather events, such as drought, heat waves, and flooding, are increasing in frequency, severity, and duration. In 2021 alone, the United States experienced twenty individual billion-dollar weather disasters, which resulted in a combined total of at least 688 fatalities and $145 billion in damages.[2] Electricity systems were severely impacted during each billion-dollar event, leading to widespread and often long-lasting service outages that often exacerbated the harms caused by the initial disaster. For example, Winter Storm Uri brought anomalously cold surface temperatures to the southern United States in February 2021. Across the state of Texas, cascading failures of natural gas production, power generation, transportation, and water systems left millions of Texans without electricity, heat, and water for several days.[3] An estimated sixty-nine percent of Texans lost electricity, on average for 42 hours, during or immediately after the storm.[4] As a result of the outages, many turned to generators, outdoor grills, and similar equipment to stay warm, leading to an increase in deaths and illnesses from carbon monoxide poisoning.

In coming years, as climate change accelerates, the frequency and severity of extreme weather events is likely to further increase. Changes in baseline weather patterns and environmental conditions (e.g., average temperatures and sea levels) are also expected to become more pronounced.[5] Current electricity system infrastructure is designed to operate reliably under historic conditions and will, due to climate change, be exposed to new and mounting risks that it was not designed to withstand. Unless concrete actions are taken to adapt to, prepare for, and manage these risks, the electricity sector will come under greater stress, and the risk of outages and other service disruptions will increase.

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[1] This document is part of the electric resilience toolkit, https://www.icrrl.org/electric-resilience-toolkit/, and complements sections one through three of the report, Romany M. Webb et al., Climate Risk in the Electricity Sector: Legal Obligations to Advance Climate Resilience Planning by Electric Utilities, 51 Envtl. L. Rev. 577 (2021). The authors would like to thank Jeffrey Fralick, Climate Risk Analyst at Environmental Defense Fund, for his assistance in preparing this document. Disclaimer: This document is the responsibility of the Sabin Center for Climate Change Law and Environmental Defense Fund, and does not reflect the views of Columbia Law School, Columbia University, or any ICRRL partner organization. This document is an academic study provided for informational purposes only and does not constitute legal advice. Transmission of the information is not intended to create, and the receipt does not constitute, an attorney-client relationship between sender and receiver. No party should act or rely on any information contained in this paper without first seeking the advice of an attorney.

[2] Adam B. Smith*, 2021 U.S. billion-dollar weather and climate disasters in historical context*, CLIMATE.GOV (Jan. 24, 2022), https://perma.cc/9GVT-7FW3.

[3] Doss-Gollin, James, et al., *How Unprecedented Was the February 2021 Texas Cold Snap?* INSTITUTE OF PHYSICS (2021) https://doi.org/10.1088/1748-9326/ac0278

[4] Jess Donald, *Winter Storm Uri 2021: The Economic Impact of the Storm,* TEXAS COMPTROLLER OF PUBLIC ACCOUNTS (Oct. 2021), https://perma.cc/45M4-HHLN.

[5] *See* U.S. DEP'T OF ENERGY, CLIMATE CHANGE AND THE U.S. ENERGY SECTOR: REGIONAL VULNERABILITIES AND RESILIENCE SOLUTIONS 1-1 (2015), https://perma.cc/3YEC-NFJ7; *see also* Craig D. Zamuda et al., *Energy Supply, Delivery, and Demand, in* IMPACTS, RISKS, AND ADAPTATION IN THE UNITED STATES: FOURTH NATIONAL CLIMATE ASSESSMENT, VOLUME II 174, 176 (D.R. Reidmiller et al. eds., 2018), https://perma.cc/ZP2G-JJRK.

This supplement summarizes the findings of prior research examining how the impacts of climate change—both weather-related and environmental—could impair electricity system reliability. The research makes clear that all electricity infrastructure—i.e., generation, transmission, and distribution—across the U.S. is at risk from the impacts of climate change. It is essential that electric utilities understand the climate change impacts that are already occurring, or are expected to occur in the future, in their service territory and the consequences for infrastructure they own, operate, or rely on.

I. ELECTRICITY SYSTEM BASICS

The electricity system can be divided into three key parts:[6]

(1) **Generation**: Electricity is produced by generating facilities (also known as power plants), which convert primary energy sources into electricity. Primary energy sources include natural gas, petroleum, coal, nuclear, and renewable sources such as wind, sun, and water.[7] Power plant infrastructure varies based on the energy source that is being converted. Power plants may need other resources to operate, such as water for cooling.[8]

(2) **Transmission**: High voltage transmission lines are used to transport electricity long-distances from generating facilities to demand centers (e.g., cities and towns). Transmission lines consist of structural frames, conductor lines, cables, transformers, circuit breakers, and switches.[9] Substations positioned along transmission lines adjust the voltage of the electricity. Following generation, before electricity enters a transmission line, its voltage must be increased or "stepped up."[10] The voltage is then decreased or "stepped down" at the point where the electricity enters the distribution system.[11]

(3) **Distribution**: The distribution system carries electricity out of the transmission system to individual consumers. After electricity is "stepped down" via a substation, it is routed over distribution lines to end-consumers (e.g., households and businesses).[12]

In much of the U.S., end-consumers obtain electricity services from private for-profit companies, known as investor-owned utilities. In some areas, however, electricity services are provided by non-profit public utilities that are owned by the municipality or electric cooperatives that are owned by the consumers they serve.

Due to the high cost of developing electricity infrastructure, and in order to avoid unnecessary duplication of that infrastructure, states historically granted utilities exclusive rights to provide electricity services within their service territory. In many states, utilities are vertically-integrated, meaning that they own and operate electricity generation, transmission, and distribution assets.[13] Some vertically-integrated utilities generate all or most of the electricity they supply at power plants they own, while others purchase significant electricity from other independent power producers.[14]

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[6] U.S. DEP'T OF ENERGY, UNITED STATES ELECTRICITY SYSTEM PRIMER 6 (2015), https://perma.cc/M6Q7-MC8H.
[7] *See id.*
[8] *See id*. at 9.
[9] *Id*. at 13.
[10] *See id*. at 12–13, 15.
[11] *See id*. at 15, 21.
[12] *Id.* at 21.
[13] *See* REGUL. ASSISTANCE PROJECT, ELECTRICITY REGULATION IN THE US: A GUIDE 10 (2011), https://perma.cc/V82A-7S2F.
[14] *Id.*

Some states have required electric utilities to sell their generation assets. In these so-called "restructured" states, electric utilities purchase electricity through bilateral agreements with independent power producers, or in wholesale markets.[15] Some utilities in restructured states continue to own transmission infrastructure, but that infrastructure is managed by independent non-profit entities, known as Regional Transmission Organizations or Independent System Operators.[16]

Some states have also deregulated the retail electricity market to introduce "retail choice." Where this is the case, consumers may elect to purchase electricity from the monopoly utility, or from a competitive supplier. In both cases, however, the utility continues to be responsible for electricity distribution. Utilities have a "duty to serve," meaning that they are obligated to provide electricity and distribution services to all customers within their service territory (see *Petitioning for Regulation from State Utility Commissions*). The state utility commission typically determines the allowable rate of return (see *Advancing Climate Resilience Planning Through Rate Case Proceedings*) on utility investments and rates that consumers pay.[17]

II. ELECTRICITY SYSTEMS AND CLIMATE CHANGE

Climate conditions have a major influence on the design, construction, and operation of electricity infrastructure.[18] For example, historic precipitation patterns and associated river flows have influenced the siting of hydroelectric generating facilities. Similarly, water availability has influenced the siting of thermoelectric power plants that require water for cooling. Air temperature ranges also affect the need for, and design of, cooling systems at thermoelectric power plants and other facilities. Pipeline, electricity transmission line, and other infrastructure developers also consider the prevalence of extreme weather events when constructing and operating facilities.[19]

Climate change is already altering historic weather patterns and environmental conditions, and will likely continue to do so in the future, exposing electricity infrastructure to new risks.[20] The nature and extent of those risks varies because of regional differences in how climate change manifests, as well as in the design and operation of electricity systems. For example, hydropower facilities in northwestern states are at high risk from changing precipitation patterns, reduced snowpack, and earlier snow melt.[21] Drought is becoming an increasing problem in southwestern states, affecting the operation of oil refineries and thermoelectric generating plants that rely on water for cooling.[22] Flooding is a greater risk to refineries and generating plants in the southeast, which is experiencing more intense hurricanes.[23]

Climate impacts on one type of infrastructure or in one region could affect the operation of other parts of the electricity system. An example of this occurred in Washington state in summer 2015, when a wildfire forced the shutdown of a transmission line which, in turn, necessitated the curtailment of output from a hydroelectric

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[15] *See id*. at 10.

[16] *See id*. at 17–18.

[17] See *id*. at 24.

[18] *See* U.S. DEP'T OF ENERGY, *supra* note 5, at 1-1 ("Energy production, transport, and delivery infrastructure and operations are typically tailored either to take advantage of or to address regional differences in climate conditions.").

[19] *See id.* at 1-2 ("[O]il and gas infrastructure along the Gulf Coast . . . typically incorporate the historical likelihood of severe hurricanes into risk management planning.").

[20] *See* Zamuda, *supra* note 5, at 177.

[21] U.S. DEP'T OF ENERGY, *supra* note 5, at ii.

[22] *Id.* at 3-4, 3-12

[23] *Id.* at 8-1.

generating facility.[24] Similarly, natural gas supply disruptions during Winter Storm Uri in Texas in 2021 led to electricity outages in the state, and price spikes elsewhere.[25]

III. KEY CLIMATE CHANGE IMPACTS AND RISKS TO ELECTRICITY INFRASTRUCTURE

Because the nature and extent of climate change impacts will vary regionally, each electric utility must undertake its own climate risk assessment to determine when and how its assets and operations will be affected, and evaluate measures to enhance its climate resilience (see *Climate Resilience Planning Process*). However, generally speaking, utilities will need to plan for the following key climate impacts (at a minimum).

- **Increasing average air temperatures and heat waves:** According to the Fourth National Climate Assessment, annual average temperatures are forecasted to increase by 2.5°F between 2021 and 2050.[26] However, some areas may be subject to significantly larger temperature increases. In parts of the northeast, for example, maximum summer temperatures are expected to increase by up to 6.7°F.[27] Increasing temperatures pose various risks to electricity generation, transmission, and distribution systems.[28] These risks are amplified if above-average temperatures persist over several consecutive days, which is commonly referred to as a heat wave. The frequency at which heat waves occur has increased due to climate change—in the 1960s, there was an average of two heat waves per year across the country; during the 2010s, this number increased to six.[29]

  Higher temperatures can reduce the efficiency of certain types of generators and accelerate the aging of transmission and distribution equipment.[30] Higher temperatures can also increase transmission line losses, and cause lines to expand and sag, which can lead to wildfires.[31] Together, the impacts on generation, transmission, and distribution may make electricity more difficult to produce and deliver, which could strain electricity supplies. At the same time, higher temperatures will cause increased demand for electricity, potentially

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[24] CRYSTAL RAYMOND, SEATTLE CITY LIGHT CLIMATE CHANGE VULNERABILITY ASSESSMENT AND ADAPTATION PLAN 49 (2015), https://perma.cc/2ER3-LLAD.

[25] HOBBY SCHOOL OF PUBLIC AFFAIRS, UNIVERSITY OF HOUSTON, THE WINTER STORM OF 2021 (2021), https://perma.cc/VN7N-BCX5; HARC, WINTERSTORM URI'S IMPACTS & PATHWAYS TO RESILIENCE IN TEXAS., https://perma.cc/AJE7-UQZ8 (last visited April 28, 2022).

[26] R.S. Vose et al., *Temperature Changes in the United States, in* CLIMATE SCIENCE SPECIAL REPORT: FOURTH NATIONAL CLIMATE ASSESSMENT: VOLUME I 185, 185 (D.J. Wuebbels et al. eds., 2017), https://perma.cc/TD85-T3H8. According to the Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report, global surface temperatures have increased by 1.09° Celsius during the period from 2011 to 2020 compared to the 1850-1900 average baseline. *See* Hans O-Portner et al., *Climate Change 2022: Impacts, Adaptation and Vulnerability,* in SIXTH ASSESSMENT REPORT (AR6) OF THE INTERGOVERNMENTAL PANEL CLIMATE CHANGE, SPM-7 (2022), https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_FinalDraft_FullReport.pdf [hereinafter IPCC Report]. The IPCC also estimates there is "at least" a greater than 50% likelihood of exceeding 1.5° Celsius – largely considered a tipping point for the Earth's climate – in the near term, which is defined as the period from 2021 to 2040. *Id.*

[27] *See, e.g.*, *Rising Temperatures*, MASS. CLIMATE CHANGE CLEARINGHOUSE, https://perma.cc/9QMS-BCKE (predicting that maximum summer temperatures in Massachusetts will increase by 2.6 to 6.7 °F by 2050).

[28] *See* U.S. DEP'T OF ENERGY, *supra* note 5, at 1-1; Zamuda, *supra* note 5, at 176.

[29] *Climate Change Indicators: Heat Waves*, U.S. EPA, https://perma.cc/V8VQ-7U57 (last visited Apr. 1, 2022).

[30] *See* U.S. DEP'T OF ENERGY, CLIMATE CHANGE & THE ELECTRICITY SECTOR: GUIDE FOR CLIMATE CHANGE RESILIENCE PLANNING 10 (2016), https://perma.cc/29MD-XWEE [hereinafter DOE Planning Guide]

[31] *See generally* JAYANT SATHAYE ET AL., ESTIMATING RISK TO CALIFORNIA ENERGY INFRASTRUCTURE FROM PROJECTED CLIMATE CHANGE 25–26 (2011), https://doi.org/10.2172/1026811.

leading to supply shortfalls and outages.[32] For example, a multi-day heat wave in August 2020 triggered higher electricity demand for air conditioning across the state of California, while also reducing output from natural gas generating plants, leading to outages.[33]

- **Increasing Water Temperatures:** Higher average air temperatures will increase water temperatures,[34] which may cause thermoelectric power plants to exceed regulated thermal limits for wastewater discharges. Nuclear power plants that draw cooling water from rivers or streams could also be impacted if the water temperature rises above set thresholds.[35] Plants may be forced to shut down temporarily, curtail generation, or request permission to exceed regulatory discharge limits when water temperatures are too warm.[36] An example of this occurred in 2012, when Dominion Resources had to shut down one reactor at its Connecticut-based Millstone Nuclear Power Station because the temperature of the intake cooling water from the Long Island Sound was too warm.[37] This resulted in a two-week closure of the facility, which experienced a loss of 255,000 megawatt-hours of electricity, amounting to several million dollars.[38]

- **Cold Weather Events:** Global cold extremes are expected to decrease in frequency and intensity under most warming scenarios—however, anomalous cold waves will remain regionally and locally important threats to the operation of electricity systems.[39] Electricity infrastructure that is not appropriately winterized is particularly vulnerable to extreme cold and other cold weather hazards, including ice, snow, and freezing rain events, which can damage transmission and distribution lines, impact fuel supplies, and increase electricity demand for heating, leading to power outages.[40] As discussed above, Winter Storm Uri forced the shutdown of oil and gas wells, pipelines, wind turbines, and other power plants across Texas in February 2021.[41]

- **Changing precipitation patterns:** Warmer temperatures associated with climate change will cause more precipitation to fall as rain rather than snow.[42] Shifts from snow to rain will impair the operation of hydroelectric power plants, particularly in areas that rely on snowmelt to

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[32] *See* Zamuda, *supra* note 5, at 181.

[33] *See* CAL. INDEP. SYS. OPERATOR, CAL. PUB. UTILS. COMM'N, & CAL. ENERGY COMM'N, PRELIMINARY ROOT CAUSE ANALYSIS: MID-AUGUST 2020 HEAT STORM 2–3 (2020), https://perma.cc/KAF2-SQWQ

[34] U.S. DEP'T OF ENERGY, U.S. ENERGY SECTOR VULNERABILITIES TO CLIMATE CHANGE AND EXTREME WEATHER 10–11 (2013), https://perma.cc/FMB6-RSRK [2013 DOE Report].

[35] *Id.*

[36] *See id.* at 2.

[37] *Id.*

[38] *Id.*

[39] IPCC Report, *supra* note 26, at 6–27. While study on climate change's influence on the frequency and severity of cold weather events continues, advancements in attribution science have allowed for researchers to identify potential links between Arctic warming and cold waves—such as the February 2021 event—in mid-latitude regions. *See, e.g.,* Judah Cohen et al*., Linking Arctic variability and change with extreme winter weather in the United States*, 373 SCIENCE 1116, 111–1121 (2021).

[40] *See* Zamuda, *supra* note 5, 176, 179.

[41] *See* Benji Jones, *Texas blackouts explained: Arctic weather shut down power plants as demand for heat surged, and the state's grid is on its own*, BUSINESS INSIDER (Feb. 18, 2021), https://perma.cc/4VV3-PPNJ; see THE FEBRUARY 2021 COLD WEATHER OUTAGES IN TEXAS AND THE SOUTH CENTRAL UNITED STATES, FED. ENERGY REG. COMM'N ET AL. 18–20 (2021), https://perma.cc/4KER-7VXX (recommending improved weatherization practices).

[42] *See* D.R. Easterling et al., *Precipitation Change in the United States, in* CLIMATE SCIENCE SPECIAL REPORT: FOURTH NATIONAL CLIMATE ASSESSMENT, VOLUME I 207, 207, 217 (D.J. Wuebbels et al. eds., 2017), https://perma.cc/MV9S-NMAS.

augment stream flows in summer.[43] The total amount of precipitation could also change, with some areas likely to experience an increase in total precipitation, while other areas may be subject to prolonged periods of drought.[44] In all areas, there is likely to be an increase in heavy precipitation events, with longer dry periods in between.[45] Each of these shifts could impact electricity generation. In fact, impacts are already being felt in some areas. For example, record dry conditions across California in August of 2021 resulted in a five-month shutdown of a hydroelectric power plant for the first time since the facility began operating in 1967, causing electricity prices to spike.[46] Thermoelectric power plants that rely on water for cooling could also be forced to shut down or curtail output during periods of low rainfall.[47] Flooding caused by heavy downpours can also impair the operation of those and other generating facilities (see below).

- **Storms, hurricanes, and flooding:** Climate change is increasing the severity of hurricanes and heavy rainfall events which are, in turn, leading to more flood events.[48] Infrastructure in the southern,[49] midwestern, and northeastern regions of the United States is at particular risk.[50] In these areas, generating facilities and transmission and distribution equipment located on the coast or along inland waterways may be inundated or otherwise damaged by flood waters and storm surge, potentially leading to outages. An example of this occurred in 2012, when storm surge flooding associated with Hurricane Sandy inundated more than 100 electric substations across four states, leaving almost 9 million customers without power.[51] The high winds associated with hurricanes and other storms also pose a major threat to electricity infrastructure. During Hurricane Ida in 2021, 150-mile-per-hour winds damaged the eight transmission lines used to deliver electricity to New Orleans, causing widespread outages.[52]

- **Sea-level Rise:** Sea levels along the contiguous United States coastline increased by an average of 0.25-0.3 meters between 1920 and 2020.[53] Sea levels are expected to increase by the same amount again, on average, over the next thirty years (i.e., through 2050).[54] The extent of longer-term sea level rise will depend on future greenhouse gas emissions and associated warming.[55] While all coastal regions will be impacted by rising seas, the extent of sea level rise will vary regionally.[56] To illustrate, the East and Gulf coasts will be subject to

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[43] *See* DOE Planning Guide, *supra* note 30, at 10–11.

[44] Easterling et al., *supra* note 42, at 216.

[45] *Id.* at 218–220.

[46] Alexandra Meeks and Dakine Andone, *California hydropower plant forced to shut down as water levels fall at Lake Oroville*, CNN (Aug. 6, 2021), https://perma.cc/E5FA-VNYL; Scott Van Vorhis, *Historic drought slashes hydropower generation in California, other Western states* (Aug. 24, 2021), https://perma.cc/97X5-H8QJ; Rob Nikolewski, *Once depleted, Lake Oroville restarts hydroelectric power plant*, SAN DIEGO TRIBUNE (Jan. 6, 2022), https://perma.cc/L3YF-GQWP.

[47] JUSTIN GUNDLACH & ROMANY WEBB, CLIMATE CHANGE IMPACTS ON THE BULK POWER SYSTEM: ASSESSING VULNERABILITIES AND PLANNING FOR RESILIENCE 9 (2018), https://perma.cc/A2ZH-BBED.

[48] *See* 2013 DOE Report, *supra* note 34, at 28.

[49] U.S. DEP'T OF ENERGY, *supra* note 5, at iii-iv

[50] Zamuda, *supra* note 5, at 178.

[51] U.S. DEP'T OF ENERGY, *supra* note 5, at 7-7.

[52] David Baker et al., *Ida Death Toll Rises to 4 as New Orleans Faces Long Blackout,* BLOOMBERG (Aug. 30, 2021) https://perma.cc/TA85-GPEJ.

[53] W.V. SWEET ET AL., GLOBAL AND REGIONAL SEA LEVEL RISE SCENARIOS FOR THE UNITED STATES xii (2022), https://perma.cc/NC98-UD9Y.

[54] *Id*.

[55] *Id*. at xiii.

[56] *See id.* at 60.

higher rates of sea level rise, while the West Coast, Hawaii, and the Caribbean will be subject to lower rates.[57]

Sea level rise can put infrastructure at risk of nuisance flooding (i.e., flooding that occurs during high tides), storm surge, and permanent inundation.[58] According to the National Oceanic and Atmospheric Administration ("NOAA"), "between May 2020 and April 2021, coastal communities saw twice as many [nuisance] high tide flooding days than they did 20 years ago."[59] NOAA estimates that the frequency of "major" nuisance flooding events (i.e., when coastal water levels exceed four feet above the mean higher high water level) will increase by 400 percent between 2020 and 2050.[60] That could have major implications for coastal energy facilities. Past studies have identified almost 300 energy facilities in coastal areas of the contiguous U.S. that are within four feet of ordinary high tide levels.[61] Those and other facilities could also be impacted by higher storm surge. A Department of Energy ("DOE") study found that by 2060, sea level rise could increase the number of energy facilities exposed to storm surge from category 1 hurricanes from 711 to 1,025 facilities, representing a 67% increase.[62]

- **Wildfires:** Climate change is expected to increase wildfire risk, particularly across the western U.S. where prolonged periods of drought are becoming more common.[63] Parts of the west are also experiencing changing wind patterns which further increase wildfire risk.[64] Wildfires can damage, destroy, or force the shutdown of above-ground electricity infrastructure.[65] For example, a wildfire in Washington state in 2015 forced the shutdown of a transmission line, which then resulted in the curtailment of output from a hydroelectric power plant.[66] More recently, in parts of California, there have been forced pre-emptive shutdowns of transmission and distribution lines to mitigate wildfire risk in times of extreme dry conditions.[67]

While each climate impact is discussed separately, multiple impacts may occur simultaneously and have compounding effects on the electricity system. An example of this occurred in July 2021 when utilities in

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[57] *Id.*

[58] *See* U.S. DEP'T OF ENERGY, CLIMATE CHANGE AND THE ELECTRICITY SECTOR: GUIDE FOR ASSESSING VULNERABILITIES AND DEVELOPING RESILIENCE SOLUTIONS TO SEA LEVEL RISE 8 (2016), https://perma.cc/AAA7-P448.

[59] *The State of High Tide Flooding and Annual Outlook*, NAT. OCEANIC AND ATMOSPHERIC ASS'N, https://perma.cc/4FU4-ADN4 (last visited Apr. 27, 2022).

[60] *See* Sweet et al., *supra* note 53, at xiii.

[61] *See Vulnerability of U.S. Energy Infrastructure to Coastal Flooding*, NAT. ACAD. OF SCI., ENG'G, AND MED., https://perma.cc/4ERX-8NW5 (last visited Apr. 27, 2022).

[62] JAMES BRADBURY ET AL., CLIMATE CHANGE AND ENERGY INFRASTRUCTURE EXPOSURE TO STORM SURGE AND SEA-LEVEL RISE 3, 15 (2015), https://perma.cc/3WKY-CVY9.

[63] *See* M.F. Wehner et al., *Droughts, Floods, and Wildfires*, in CLIMATE SCIENCE SPECIAL REPORT: FOURTH NATIONAL CLIMATE ASSESSMENT, Volume I 231 (D.J. Wuebbles et al. eds., 2017), https://perma.cc/QD9PXY26.

[64] *See, e.g.,* Norman L. Miller & Nicole J. Schlegel, *Climate change projected weather sensitivity: California Santa Ana wind occurrence*, 33 GEOPHYSICAL RESEARCH LETTERS L15711 (2006).

[65] Zamuda, *supra* note 5, at 182–183.

[66] CRYSTAL RAYMOND, SEATTLE CITY LIGHT CLIMATE CHANGE VULNERABILITY ASSESSMENT AND ADAPTATION PLAN 49 (2015), https://perma.cc/LYQ6-ZT3L

[67] *PG&E shutdown: 800,000 people to lose power to prevent California wildfires*, THE GUARDIAN (Oct. 9, 2019), https://perma.cc/2BTB-MJLV.

California struggled to provide reliable electricity services and urged customers to limit their use of electricity during a period of both high temperatures and wildfires.[68]

IV. ENHANCING THE CLIMATE RESILIENCE OF ELECTRICITY SYSTEMS

Electric utilities and system operators can take multiple steps to reduce climate-related risks to electricity infrastructure. These steps are often referred to as resilience measures. Generally, climate resilience refers to an electricity system's ability to withstand, and quickly recover from, disruptions caused by the impacts of climate change. While the precise meaning of resilience in the context of the electric sector is up for some debate, a resilient electric system is generally regarded as "one that acknowledges that [electricity] outages can occur, prepares to deal with them, minimizes their impact when they occur, is able to restore service quickly, and draws lessons from the experience to improve performance in the future."[69]

Resilience measures could include changes in the siting, design, construction, and operation of electricity infrastructure to reduce its exposure to climate-related risks.[70] For example, strengthening power lines and towers to resist physical damage—e.g., by replacing wood towers with steel towers—can improve individual lines' resilience to wildfires. Elevating coastal generating plants or building floodwalls around them can similarly reduce their exposure to storm surge damage. Critically, utilities can avoid costly retrofits in the future by incorporating resilience measures from the start (i.e., when designing new facilities).[71] A recent study found that designing transmission and distribution infrastructure with future climate impacts in mind could reduce costs by up to 50% by 2090.[72] Utilities can also take non-capital-intensive actions to reduce their exposure to climate-related risks, for example, by making operational changes or through planning updates or design modification.[73]

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[68] Anne C. Mulkern, *Soaring Temperatures and Wildfire Threaten California's Power Grid*, SCIENTIFIC AMERICAN (July 12, 2021), https://perma.cc/ZEH3-NSSU.

[69] NAT'L ACAD. OF THE SCI., ENG'G, AND MED., ENHANCING THE RESILIENCE OF THE NATION'S ELECTRICITY SYSTEM 10, https://perma.cc/K22S-2QM8 (2022)*; See also* Order Terminating Rulemaking Proceeding, Initiating New Proceeding, and Establishing Additional Procedures, 162 FERC ¶ 61,012 P 13 (2018), https://perma.cc/V9EJ-63FY (A system is considered resilient if it has "the capability to anticipate, absorb adapt to, and/or rapidly recover from" a disruptive event).

[70] *See* DOE Planning Guide, supra note 31, at 61–69, 94–99. For a discussion on obstacles utilities may face when recovering costs for investments in climate resilience planning and the use of cost tracking, *see* Romany M. Webb et al., *Climate Risk in the Electricity Sector: Legal Obligations to Advance Climate Resilience Planning by Electric Utilities*, 51 ENVTL. L. REV. 577, 618–20 (2021), https://perma.cc/WV5Y-U2HL.

[71] CRYSTAL RAYMOND, SEATTLE CITY LIGHT CLIMATE CHANGE VULNERABILITY ASSESSMENT AND ADAPTATION PLAN 1 (2015), https://perma.cc/LYQ6-ZT3L (noting that "[i]t will be easier and more cost-effective to consider the impacts of climate change in the planning and design of new infrastructure and power resources now than it will be to retrofit infrastructure or replace resources once the impacts of climate change intensify").

[72] Charles Fant et al., *Climate Change Impacts and Costs to U.S. Electricity Transmission and Distribution Infrastructure*, 195 ENERGY 116899, 7 (2020).

[73] It should be noted that climate resilience planning and investment can often involve significant upfront costs, which may necessitate consumer rate increases, at least in the short term. In the longer term, however, climate resilience planning and investments should generate cost savings that can be passed onto ratepayers.