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CLIMATE CHANGE IMPACTS ON THE BULK POWER SYSTEM:

Assessing Vulnerabilities and Planning for Resilience

By Justin Gundlach and Romany Webb

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The Sabin Center for Climate Change Law develops legal techniques to fight climate change, trains law students and lawyers in their use, and provides the legal profession and the public with up-to-date resources on key topics in climate law and regulation. It works closely with the scientists at Columbia University's Earth Institute and with a wide range of governmental, non-governmental and academic organizations.

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EXECUTIVE SUMMARY

As the scale, speed, and implications of climate change come into focus, stakeholders in the electricity sector are finding it increasingly difficult to turn a blind eye. However, many have opted to attend to climate impacts in a piecemeal fashion, often merely responding to particular extreme events—or types of extreme events, such as coastal storms or floods—and failing to consider the larger phenomenon. This is true of the bulk power system (BPS) in regions overseen by Independent System Operators and Regional Transmission Organizations (collectively, ISO/RTOs), none of which have comprehensively assessed their systems' vulnerabilities to climate change. Lacking such assessments, ISO/RTOs cannot plan for the impacts of climate change, and thereby ensure the continued reliability and resilience of the BPS.

The higher temperatures, more intense storms, and other weather extremes associated with climate change pose numerous threats to the BPS. These threats are summarized in a table in the appendix to this paper. As shown there, the impacts of climate change could force generating facilities to curtail output or shutdown, and lead to widespread transmission outages. These disruptions will be accompanied by other climate-driven phenomenon, including increases in electricity load and the height of load peaks, which will further strain facilities.

While the nature and extent of generation and transmission impairments will vary across the U.S.—due to differences in the nature and extent of climatic changes seen—no region will go unscathed. It is, therefore, vital that all ISO/RTOs begin planning now for a future in which climate change will feature. Otherwise, in the future, the BPS may be unable to deliver reliable electricity services at just and reasonable rates as required by the Federal Power Act.

This paper offers ISO/RTOs advice on how to plan for climate change and identifies resources and processes they could employ in the planning process. The regional variation in climate change impacts, as well as differences in generation and transmission resources, prevent formulation of a "one-size fits-all" approach to planning across ISO/RTO regions. Nevertheless, there are a number of general principles which we recommend all ISO/RTOs follow, namely:

- A detailed climate change vulnerability assessment should be undertaken to determine how the components and operations of each ISO/RTO's system will be affected by increasing temperatures, changing precipitation patterns, more intense storms, droughts, and other climate-driven weather extremes.

- Vulnerability assessments should be based on downscaled projections of future climate change in the ISO/RTOs' respective operating regions. Many projections are available in existing datasets, including those developed by NASA and the U.S. Geological Survey. Gaps in available datasets (if any) should be noted and, if possible, filled by sponsoring supplemental research.
- Vulnerability assessments should consider multiple projections that reflect a range of possible climate change scenarios, including a "worst case" (i.e., assuming continued high greenhouse gas emissions lead to large temperature increases and rates of sea level rise).
- The timeframe for each vulnerability assessment should reflect the anticipated useful life of existing facilities or facilities scheduled for construction in the relevant ISO/RTO's region.
- Vulnerability assessments should be periodically reviewed and updated as new information becomes available.

- Building on the vulnerability assessment, a plan should be developed for how to adapt and thereby prevent or manage the system disruptions that could threaten BPS reliability and resilience.

CONTENTS

1. INTRODUCTION

The resilience of the bulk power system (BPS) to various types of disruption has been the subject of much discussion in recent months. It was a key focus of the "Grid Reliability and Resiliency Pricing" proceeding before the Federal Energy Regulatory Commission (FERC),[1] the agency responsible for overseeing six Independent System Operators and Regional Transmission Organizations (collectively, ISO/RTOs) that manage much of the BPS.[2] The proceeding, which FERC opened on October 2, 2017 in response to a request from the Secretary of Energy, considered the need for ISO/RTO-level reforms to support so-called "resilience resources" that have a ninety-day fuel supply on-site. Concluding that a legal basis for such reforms was missing, FERC terminated the proceeding on January 8, 2018. FERC noted, however, that resilience "warrants further attention" and therefore opened another proceeding "to explore resilience issues in the RTOs/ISOs" (resilience proceeding).[3]

For the purposes of the resilience proceeding, FERC proposes to define "resilience" as "[t]he ability to withstand and reduce the magnitude and/or duration of disruptive events, which includes the capability to anticipate, absorb, adapt to, and/or rapidly recover from such an event."[4] Notably, resilience is distinct from reliability. In the short term, reliability is defined as the frequency and duration of outages due to "high frequency, low impact" events experienced in a given service territory[5] and, in the long-term, as the adequacy of energy supply vis-à-vis load in

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[1] *Grid Resiliency Pricing Rule*, 82 Fed. Reg. 46,940 (Oct. 10, 2017).

[2] FERC, *Regional Transmission Organizations (RTO)/Independent System Operators (ISO)*, https://perma.cc/EVQ6-TZFJ (updated Dec. 21, 2017). FERC does not regulate the Electric Reliability Council of Texas. See FERC, *ERCOT*, https://perma.cc/84GU-5W2P (updated Nov. 17, 2017).

[3] Order Terminating Rulemaking Proceeding, Initiating New Proceeding, and Establishing Additional Procedures, 162 FERC ¶ 61,012, P 10 (2018). It is possible, though not certain, that the current phase of the proceeding will result in FERC calling for a full technical conference to address one or more sources of risk to BPS resilience.

[4] *Id.* at P 13 (citing the National Infrastructure Advisory Council's 2009 Critical Infrastructure Resilience Final Report and Recommendations at 8).

[5] Examples of short-term reliability metrics include: System Average Interruption Frequency Index (SAIFI), which captures the ratio of sustained outages over a year to the number of customers served (including both affected and unaffected customers); System Average Interruption Duration Index (SAIDI), is similar, and is often expressed as "consumer minutes" or "hours" to convey the average annual outage duration per consumer in a given service territory; and Consumer Average Interruption Frequency Index (CAIFI), which

that territory.[6] Resilience, by contrast, is concerned with preparation for, responses to, and recovery from less predictable "high impact, low frequency events."[7]

The order convening the resilience proceeding noted that FERC has already examined and addressed several types of risks to BPS reliability, both directly and via the North American Electric Reliability Corporation (NERC)'s development of reliability standards.[8] According to FERC, "[w]hile none of the Commission's efforts . . . were specifically targeted at 'resilience' by name, they were directed at elements of resilience, in that they sought to ensure the uninterrupted supply of electricity in the face of fuel disruptions" or other risks.[9] Risks addressed in a systematic fashion include "fuel assurance," "fuel supply issues during periods of system stress" (including due to extreme weather events), and "cybersecurity and physical security threats, as well as geomagnetic disturbances."[10] Missing from this list are risks arising from the effects of climate

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captures the ratio of sustained outages over a year to the number of customers affected by those outages. NATIONAL ACADEMY OF SCIENCES, ENHANCING THE RESILIENCE OF THE NATION'S ELECTRICITY SYSTEM 13 (Apr. 2017).

[6] NORTH AMERICAN ELECTRICITY RELIABILITY CORPORATION (NERC), 2016 LONG-TERM RELIABILITY ASSESSMENT (2016) ("NERC's primary objective with the [Long-Term Reliability Assessment] is to assess resource and transmission adequacy across the NERC footprint, and to assess emerging issues that have an impact on BPS reliability over the next ten years.").

[7] Mathaios Panteli & Pierluigi Mancarella, *The Grid: Stronger, Bigger, Smarter?*, IEEE POWER ENERGY MAG., May/June 2015, at 58 (describing key parameters of resilience in electricity systems).

[8] Section 215 of the Federal Power Act, which became law in 2005, invites FERC to certify as the Electricity Reliability Organization (ERO) an entity able "to develop and enforce . . . reliability standards that provide for an adequate level of reliability of the bulk-power system" in an objective and procedurally sound manner. *See* Federal Power Act § 215(c)(1), *codified at* 16 U.S.C. § 824o; Energy Policy Act of 2005, Pub. L. 109–58, § 1211(a), 119 Stat. 941 (Aug. 8, 2005). FERC certified the North American Electric Reliability Council (NERC) as the ERO in 2006 (since 2007, the "C" has stood for "Corporation"). *See* 116 FERC ¶ 61,062 (2006). NERC's standards have been legally enforceable since 2007. *See* Mandatory Reliability Standards for the Bulk Power System, Order No. 693, 72 Fed. Reg. 16,416 (April 4, 2007), FERC Stats. & Regs. ¶ 31,242 (2007), *order on reh'g*, Order No. 693-A, 120 FERC ¶ 61,053 (2007).

[9] *Id.* at 7.

[10] *Id.* at 5–7. The Order cites the following past orders to illustrate and support these points: Centralized Capacity Markets in Regional Transmission Organizations and Independent System Operators, 149 FERC ¶ 61,145 (2014) (order addressing technical conferences on, among other things, the 2014 Polar Vortex); ISO New England Inc. and New England Power Pool, 147 FERC ¶ 61,172 (2014), *reh'g denied*, 153 FERC ¶ 61,223 (2015), *appeal pending sub nom.*, New England Power Generators Ass'n v. FERC, No. 16-1023 (D.C. Cir. filed Jan. 19, 2016); PJM Interconnection, L.L.C., 151 FERC ¶ 61,208 (2015), *reh'g denied*, 155 FERC ¶ 61,157 (2016), *aff'd sub nom.*, Advanced Energy Mgmt. All. v. FERC, 860 F.3d 656 (D.C. Cir. 2017); Physical Security Reliability Standard, Order No. 802, 149 FERC ¶ 61,140 (2014); Revised Critical Infrastructure Protection Reliability Standards, Order No. 822, 154 FERC ¶ 61,037 (2016), *reh'g denied*, Order No. 822-A, 156 FERC ¶

change. To the extent that FERC, NERC, or individual ISO/RTOs have examined such risks, that examination has been piecemeal, and has at no point taken into account downscaled climate projections[11] for the coming years and decades.

This paper argues that such an approach is inadequate to ensure the long-term resilience of the BPS to climate change. That inadequacy is legal as well as practical. The Federal Power Act (FPA) requires FERC to ensure the BPS operates in a manner that yields reliable electricity services at rates that are just, reasonable, and not unduly discriminatory or preferential.[12] To meet that requirement, FERC relies on market mechanisms, reasoning that they "provide correct incentives for [participants] to . . . make efficient investments in facilities and equipment."[13] However, FERC has recognized that, for markets to provide "correct" investment incentives, they must account for differences in the risk profiles of BPS facilities.[14] At present, because neither FERC nor the ISO/RTOs have conducted a comprehensive assessment of climate risks to BPS facilities, it is unclear whether those risks are duly unaccounted for.

While various facility owners have identified climate change as a source of material physical risk to their operations,[15] no one has sought to map such risks systematically at the ISO/RTO level. This paper argues that such mapping is an essential first step toward ensuring that, as the climate changes, the BPS continues to deliver reliable electricity services at just and reasonable rates. The rest of the paper proceeds in three sections. Section 2 briefly describes key

61,052 (2016); Revised Critical Infrastructure Protection Reliability Standards, Order No. 829, 156 FERC ¶ 61,050 (2016); Cyber Systems in Control Centers, Notice of Inquiry, FERC Stats. & Regs. ¶ 35,557 (2016); Revised Critical Infrastructure Protection Reliability Standards CIP-003-7 – Cyber Security – Security Management Controls, Notice of Proposed Rulemaking, 161 FERC ¶ 61,047 (2017); Reliability Standard for Transmission System Planned Performance for Geomagnetic Disturbance Events, Order No. 830, 156 FERC ¶ 61,215 (2016).

[11] Downscaled projections identify likely future changes in climate-driven extreme weather and other phenomenon at local scales.

[12] 16 U.S.C. §§ 824d(a)-(b) & 824o.

[13] Price Formation in Energy and Ancillary Services Markets Operated by Regional Transmission Organizations and Independent System Operators; Notice Inviting Post-Technical Workshop Comments, 80 Fed. Reg. 3,580 (Jan. 23, 2015).

[14] *See generally* P.J.M Interconnection, L.L.C., 151 FERC ¶ 61,208 (2015), *order on reh'g*, 155 FERC ¶ 61,157 (2016).

[15] *See e.g.*, NextEra Energy, Inc., Florida Power & Light Co., Annual Report (Form 10-K) 26 (Feb. 23, 2017); Consolidated Edison Company of New York, Inc., Annual Report (Form 10-K) 32 (Dec. 31, 2016); American Electric Power Company, Inc., Annual Report (Form 10-K) 41–42 (Dec. 31, 2016).

risks climate change poses for the BPS. Section 3 identifies processes and resources that can be employed to assess the BPS's vulnerability to climate change and plan for climate resilience. Section 4 contains recommendations for conducting vulnerability assessments and developing resilience plans.

2. CLIMATE CHANGE AND THE BULK POWER SYSTEM

Since the start of the 19th century, annual average temperatures in the contiguous U.S. have increased by up to 1.8°F (1.0°C), with two-thirds of this increase occurring in the last two decades.[16] Those decades also saw a marked rise in the frequency and intensity of heat waves[17] and other extremes, including droughts, floods, and storms,[18] as well as climate-related environmental changes such as sea level rise.[19] Conditions are expected to worsen in coming years as temperatures continue to increase, leading to significant and widespread adverse impacts, including on the BPS and the systems, communities, and individuals that rely on it.

Numerous sources—including reports of national laboratories,[20] federal agencies,[21] state agencies,[22] privately-sponsored researchers,[23] and international organizations,[24] corporate filings

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[16] R.S. Vose et al., *Temperature Changes in the United States*, *in* CLIMATE SCIENCE SPECIAL REPORT: FOURTH NATIONAL CLIMATE ASSESSMENT 185, 186 (D.J. Wuebbles et al. eds., 2017), https://perma.cc/TD85-T3H8.

[17] *Id*. at 191-192.

[18] M.F. Wehner et al., *Droughts, Floods, and Wildfires, in* CLIMATE SCIENCE SPECIAL REPORT: FOURTH NATIONAL CLIMATE ASSESSMENT 231, 231 (D.J. Wuebbles et al. eds., 2017), https://perma.cc/TD85-T3H8.

[19] W.V. Sweet et al., *Sea Level Rise*, *in* CLIMATE SCIENCE SPECIAL REPORT: FOURTH NATIONAL CLIMATE ASSESSMENT 333, 333 (D.J. Wuebbles et al. eds., 2017), https://perma.cc/TD85-T3H8.

[20] *See e.g.*, BENJAMIN L. PRESTON ET AL., RESILIENCE OF THE U.S. ELECTRICITY SYSTEM: A MULTI-HAZARD PERSPECTIVE (2016), https://perma.cc/9G93-P824.

[21] *See e.g.*, U.S. DEPT. OF ENERGY, CLIMATE CHANGE & THE ELECTRICITY SECTOR: GUIDE FOR CLIMATE CHANGE RESILIENCE PLANNING (2016), https://perma.cc/4WHR-EDFJ [hereinafter 2016 DOE Report]; U.S. DEPT. OF ENERGY, U.S. ENERGY SECTOR VULNERABILITIES TO CLIMATE CHANGE & EXTREME WEATHER (2013), https://perma.cc/9N8H-VM6S [hereinafter 2013 DOE Report]; ELECTRIC POWER RESEARCH INSTITUTE, POTENTIAL IMPACT OF CLIMATE CHANGE ON NATURAL RESOURCES IN THE TENNESSEE VALLEY AUTHORITY REGION (Nov. 2009), https://perma.cc/6YXR-QPBG.

[22] *See e.g.*, JAYANT SATHAYE ET AL., ESTIMATING RISK TO CALIFORNIA ENERGY INFRASTRUCTURE FROM PROJECTED CLIMATE CHANGE (2012), https://perma.cc/2ANF-S8ZV.

[23] *See e.g.*, EDWARD VINE, PUBLIC POLICY INSTITUTE OF CALIFORNIA, ADAPTATION OF CALIFORNIA'S ELECTRICITY SECTOR TO CLIMATE CHANGE (2008), https://perma.cc/5N2N-667Q.

[24] *See e.g.*, INTERNATIONAL ENERGY AGENCY, MAKING THE ENERGY SECTOR MORE RESILIENT TO CLIMATE CHANGE (2015), https://perma.cc/5WSM-J45P.

with the U.S. Securities and Exchange Commission,[25] and utilities' climate change vulnerability assessments and adaptation plans,[26] have identified the effects of climate change as sources of material physical risk for the generation and transmission segments of the BPS. The nature and extent of risks to generation and transmission will vary across regions because, though the global climate is generally growing warmer and stormier, regional climates will experience these and other phenomenon to varying degrees,[27] and also because different regions rely on different types of generation and differently situated transmission facilities. However, according to a 2015 Department of Energy (DOE) report, which mapped climate impacts on different parts of the U.S. energy sector, no region will go unscathed (see Figure 1).[28] Thus, ISO/RTOs in all regions should be planning for the effects of higher temperatures, heat waves, and more intense storms, which will be felt nationwide, as well as for regional effects, such as sea level rise along the coasts, wildfires in the West, drought in the Southwest and California, and more frequent and intense precipitation in the Northeast.[29]

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[25] *See e.g.*, the 10-Ks listed *supra*, in note 15.
[26] TENNESSEE VALLEY AUTHORITY, CLIMATE CHANGE ADAPTATION PLAN—2016 UPDATE (June 2016), https://perma.cc/AQ82-M736; CRYSTAL RAYMOND, SEATTLE CITY LIGHT CLIMATE CHANGE VULNERABILITY ASSESSMENT AND ADAPTATION PLAN (2015), https://perma.cc/GBT2-2UV8.
[27] *See generally* CLIMATE CHANGE IMPACTS IN THE UNITED STATES: THE THIRD NATIONAL CLIMATE ASSESSMENT 370–618 (J.M. Melillo et al., eds., U.S. Global Change Research Program 2014) [hereinafter 3rd NCA].
[28] U.S. DEP'T OF ENERGY, CLIMATE CHANGE AND THE U.S. ENERGY SECTOR: REGIONAL VULNERABILITIES AND RESILIENCE SOLUTIONS (2015), https://perma.cc/3WQC-5JYV.
[29] These effects are described thoroughly in chapters 16 to 25 of the 3rd NCA, *supra* note 27.

Figure 1: DOE Map of Climate Impacts on the U.S. Energy Sector [30]

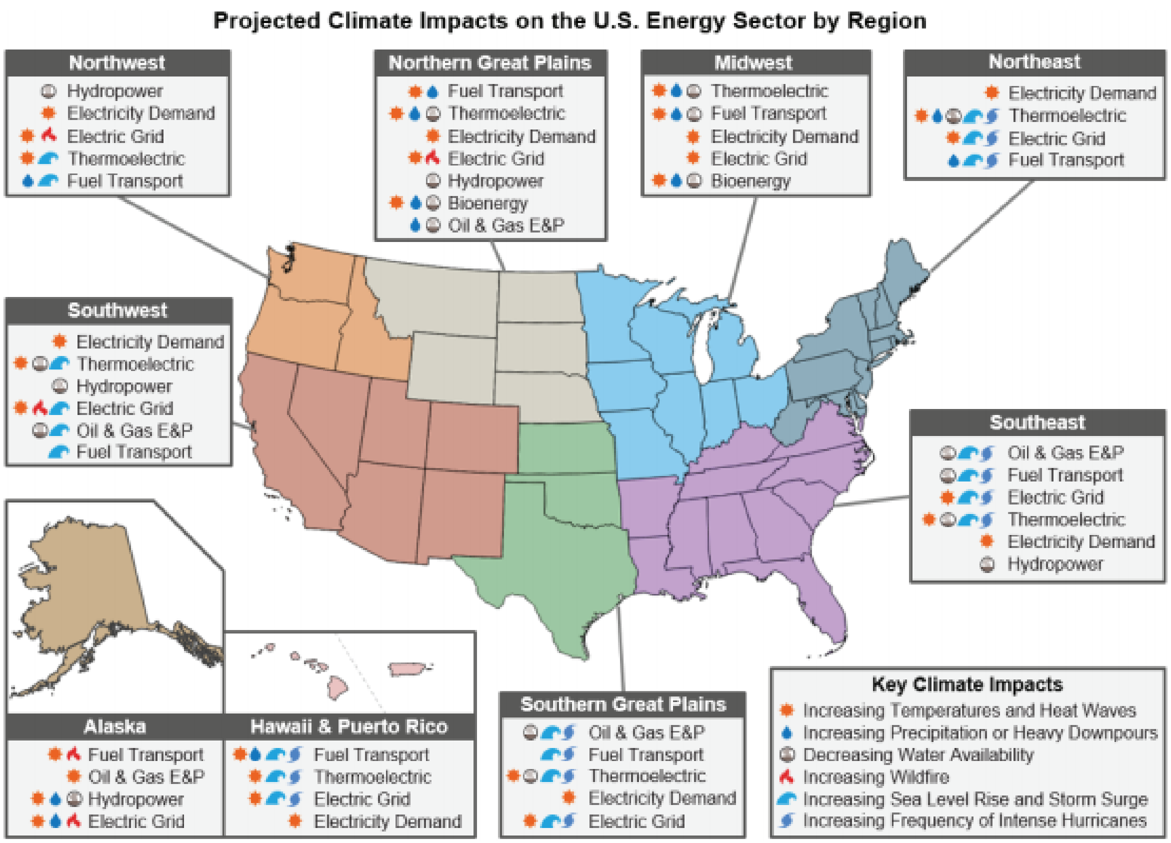

Figure ES-1. Potential climate change impacts on the U.S. energy infrastructure vary by region. Energy subsectors considered most vulnerable to projected climate impacts are listed first for each region.[1]

[1] "Thermoelectric" generally refers to power plants that use a steam turbine to generate electricity. Examples of thermoelectric power plant fuel sources include coal, natural gas, oil, nuclear, biomass, geothermal, and concentrated solar power. "Oil & Gas E&P" refers to upstream oil and gas operations, primarily exploration and production (E&P). "Fuel Transport" refers to movements of energy resources by rail, truck, marine vessel, and pipeline, and it includes associated facilities such as ports, pumping stations, terminals, and storage facilities. Hurricane impacts in Hawaii refer to a projected increase in the frequency of all hurricanes striking the islands, not just intense hurricanes; see Chapter 10 for specific projections. The order of subsector vulnerabilities shown in the figure is based on judgments by the report authors as well as experts from government agencies, national laboratories, and private sector energy companies.

A table summarizing the likely effects of various climatic changes on electricity generation and transmission facilities in each ISO/RTO region is included as Appendix A to this paper. Additional information regarding the effects is provided in this section. While the section discusses each climatic change separately, many will occur in parallel, and thus have compounding effects. Parts of the northeastern U.S., for instance, will simultaneously experience higher temperatures and sea level rise, both of which will adversely affect generation. Similarly, in the West, transmission will be simultaneously affected by higher temperatures and more extreme wildfires. In both areas, interdependencies between generation and transmission facilities and, more

[30] U.S. Dep't of Energy, *supra* note 28, at i.

generally, between the bulk and retail electricity systems may lead to further compounding of effects.[31]

2.1 Climate Change Impacts on Generating Facilities

Climate change will have profound impacts on electricity generation in the U.S., disrupting operations at many facilities, and forcing some to curtail output or entirely shutdown. The likely extent of these and other impacts, under various climate change scenarios, has been explored in a number of studies, the key findings of which are summarized below.

Increasing air temperatures: The Fourth National Climate Assessment, published in November 2017, forecasts that annual average temperatures in the contiguous U.S. will rise by at least 2.5°F (1.4°C) between 2021 and 2050.[32] Rising temperatures lower the efficiency of thermoelectric generating facilities, including nuclear and fossil fuel plants equipped with steam turbines, for at least three reasons. At higher temperatures:

1. the air mass of the turbine for a given volume intake is lower (i.e., as warmer air is less dense) ;
2. the pressure ratio within the turbine is lower, which reduces mass flow; and
3. the specific volume of air is higher, resulting in more power being consumed by the turbine during compression.[33]

The degree of efficiency reductions will depend on, among other things, the design of the generating facility and the fuel used. As an example, most natural gas facilities are designed to operate at 59°F (15°C), and may experience efficiency reductions of up to 1% for each 1.8°F (1°C) increase in temperatures above that level.[34] While this may sound small, when extended regionally, the impact on generator efficiency would be significant, particularly during heat waves. Research

[31] *See supra* subpart 2.3.
[32] Vose et al., *supra* note 16, at 195.
[33] Sathaye et al., *supra* note 22, at 12.
[34] *Id*. at 13 (citing previous studies finding that, for each 1.0oC increase in temperatures above 15°C, the capacity of combined-cycle gas power plants may fall by 0.3-0.5% (if equipped with wet cooling) or up to 0.7% (if equipped with dry cooling) and indicating that, as "simple-cycle gas units . . . have been shown to be more sensitive to ambient temperature relative to combined-cycle units," the capacity of those units is assumed to "decrease by 1.0 percent per degree Celsius above 15°C"). *See also* 2013 DOE Report, *supra* note 21, at 10 (noting that "the power output of natural gas-fired combustion turbines . . . is estimated to decrease by approximately 0.6%-0.7% for a 1.8°F (1°C) increase in air temperature," while "[f]or combined cycle plants, output can decrease by approximately 0.3%-0.5%").

undertaken by the Lawrence Berkeley National Laboratory (LBNL), focusing on gas-fired generation in California, indicates that electricity losses on hot days could reach 10.3 gigawatts (GW) by 2100 or 23.4% of total current gas-fired capacity.[35] Electricity load on hot days is also projected to increase,[36] and with it the height of peak load, leading to an expected shortfall in peak generating capacity of over 35%.[37]

Increasing water temperatures: Generation shortfalls can also occur due to high water temperatures. Thermoelectric power plants generally require low-temperature water for cooling, using it to condense steam that has passed over the turbine, and thereby create a vacuum to draw more steam in.[38] Increased water temperatures reduce the effectiveness of this process, leading to turbine backpressure which lowers plant output.[39] Some nuclear plants, for example, could see declines in electricity output of 0.5% for each 1.8°F (1°C) increase in water temperatures.[40] In cases where water temperatures exceed technical specifications, plants may be forced to curtail output by larger amounts or entirely shutdown. This occurred in Connecticut in 2012, when the Millstone nuclear plant shut down after a heat wave caused cooling water temperatures to rise above the maximum allowed under its permit from the Nuclear Regulatory Commission.[41] Also in 2012, a heat wave in Illinois affected operations at several nuclear and coal plants, causing them to exceed

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[35] Sathaye et al., *supra* note 22, at 18. This represents a 6.2 percent increase in the maximum peak capacity loss compared to the period from 1961 to 1990. *Id*.

[36] *Id*. at 35 (indicating that, in California, "per-capita peak loads are projected to increase between 10 percent and 20 percent at the end of the century due to the effects of climate change on summer weekday afternoon temperatures").

[37] *Id*. at 38.

[38] Some thermoelectric generating plants are equipped with "dry cooling" systems which use ambient air to cool the steam and condense it back to water. *See* STEVE FLEISCHLI & BECKY HAYAT, POWER PLANT COOLING AND ASSOCIATED IMPACTS: THE NEED TO MODERNIZE U.S. POWER PLANTS & PROTECT OUR WATER RESOURCES & AQUATIC ECOSYSTEMS 3 (2014), https://perma.cc/DUF4-4H9Z.

[39] 2013 DOE Report, *supra* note 21, at 10 (indicating that "[i]ncreases in . . . cooling water temperatures will increase steam condensate temperatures and turbine backpressure, reducing power generation efficiency").

[40] Ahmet Durmayaz & Oguz Salim Sogut, *Influence of Cooling Water Temperature on the Efficiency of a Pressurized-Water Reactor Nuclear Power Plant*, 30 INTL. J. OF ENERGY RESEARCH 799 (2006).

[41] Matthew L. Wald, *Heat Shuts Down a Coastal Reactor*, N.Y. TIMES (Aug. 13, 2012), https://perma.cc/XE3C-8AH7 (reporting that the shutdown occurred after water temperatures in Long Island Sound reached 76.7°F. Under Millstone nuclear plant's operating permit, the cooling water it extracts can be no warmer than 75°F).

thermal limits[42] for cooling water discharges.[43]

Declining water availability: Many thermoelectric and other generating facilities, particularly in the West and South, will also be affected by droughts, which may become more frequent and severe due to climate change.[44] This will reduce the availability of cooling water for thermoelectric generating facilities, potentially forcing them to curtail or shut down operations. According to a recent DOE study, under extreme drought conditions on par with those experienced during the U.S. "dust bowl" of the 1930s, thermoelectric generation in the Southwest could decline by up to 20%.[45] The study also predicted declines of almost 60% in the region's hydroelectric generation under extreme drought conditions.[46] California has already experienced double-digit reductions in hydroelectric generating capacity, for example, in 2014, when persistent drought caused it to fall to just 58% of the ten-year average.[47]

Changing precipitation patterns: Hydroelectric and some thermal generating facilities will also be affected by other changes in precipitation, including shifts to more precipitation falling as rain rather than snow.[48] This will increase runoff during winter months, overloading hydroelectric reservoir capacity, and leading to the loss of energy normally available later in the year.[49] Similar losses may also occur as a result of earlier and more rapid thawing of the snowpack due to higher temperatures.[50] In both cases, stream flows throughout the year will be lower, reducing the

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[42] Thermal limits have been established for cooling water discharged back into the environment (i.e., following use) to protect aquatic ecosystems. *See* R. SKAGGS ET AL., CLIMATE AND ENERGY-WATER-LAND SYSTEM INTERACTIONS 2.14-2.15 (2012), https://perma.cc/969B-RAUS.

[43] Matthew L. Wald, *So, How Hot Was It?* N.Y. TIMES (Jul. 17. 2012), https://perma.cc/TNK3-CMAP.

[44] D.J. Wuebbles et al., *Executive Summary, in* CLIMATE SCIENCE SPECIAL REPORT: FOURTH NATIONAL CLIMATE ASSESSMENT 10, 11 (D.J. Wuebbles et al. eds., 2017), https://perma.cc/TD85-T3H8.

[45] ARGONNE NATIONAL LABORATORY, IMPACTS OF LONG-TERM DROUGHT ON POWER SYSTEMS IN SOUTH WEST 10, 37 (2012), https://perma.cc/7EKU-2Z3C (defining the "southwest" region to encompass Arizona, California, Colorado, New Mexico, Nevada, Texas, and Utah).

[46] *Id*.

[47] Preston et al., *supra* note 20, at 13.

[48] Wuebbles et al., *supra* note 44, at 22 (projecting "shifts to more precipitation falling as rain than snow in the cold season in many parts of the central and eastern United States").

[49] Preston et al., *supra* note 20, at 13.

[50] *Id*. *See also* Wuebbles et al., *supra* note 44, at 21 (indicating that "[t]here has been a trend toward earlier snowmelt" and noting that this trend is expected to continue).

efficiency of hydroelectric generating facilities by reducing the pressure that drives their turbines.[51] Intense deluges, like the one that accompanied Hurricane Harvey in 2017, have also saturated coal piles, preventing their use as an energy source.[52]

Storms and flooding: All electricity generating facilities, regardless of type or location, will be impacted by future storms which are expected to become more intense due to climate change.[53] More intense rainstorms will contribute to inland flooding which can prevent the operation of generating facilities, as seen in Nebraska in mid-2011, when floodwaters surrounded the Fort Calhoun nuclear plant and prevented it returning to service after an earlier routine shutdown.[54] Similar issues have also occurred at coastal facilities due to hurricanes and associated storm surge—e.g., in New York during Hurricane Sandy[55]—with this situation expected to worsen in the future due to rising sea levels. Research by the National Laboratories suggests that, by 2050, sea level rise could increase the number of generating facilities exposed to inundation from storm surge during a weak (category 1) hurricane by 40%.[56] Many facilities could also be inundated by sunny-day or "nuisance" flooding caused solely by sea level rise—a recent DOE study of just four coastal cities (Houston, Los Angeles, New York, and Miami) identified up to 315 energy facilities that could be affected by 2100.[57]

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[51] 2013 DOE Report, *supra* note 21, at 26. *See also* U.S. Dept. of Energy & U.S. Dept. of Homeland Security, Dams & Energy Sectors Interdependency Study 24 (2011), https://perma.cc/9PB7-QFHR (indicating that "[f]or every foot of elevation lost in Lake Mead, Hoover Dam produces 5.7 MW less power").
[52] *Harvey's rain caused coal-to-gas switching: NRG Energy*, PLATTS, Sept. 27, 2017.
[53] *See e.g.*, Wuebbles et al., *supra* note 44, at 21 (noting that "[t]he frequency and intensity of heavy precipitation events in the United States are projected to continue to increase over the 21st century").
[54] The Fort Calhoun plant was shut-down prior to the flooding for refueling. The plant's return to service was delayed for several months due to persistent flood waters. *See* A.G. Sulzberger & Matthew L. Wald, *Flooding Brings Worries Over Two Nuclear Plants*, N.Y. TIMES, Jun. 20, 2011, http://www.nytimes.com/2011/06/21/us/21flood.html.
[55] Steven Mufson, *3 Nuclear Power Reactors Shut Down During Hurricane Sandy*, WASH. POST, Oct. 30, 2012, https://perma.cc/BTX9-FDLF (noting that "[t]hree nuclear power reactors were shut down because of electricity issues during Hurricane Sandy, while a fourth plant, Oyster Creek in New Jersey, remains in "alert" mode because of high water levels in its water intake structure").
[56] JAMES BRADBURY ET AL., CLIMATE CHANGE & ENERGY INFRASTRUCTURE EXPOSURE TO STORM SURGE & SEA-LEVEL RISE 11 (2015), https://perma.cc/3WKY-CVY9.
[57] U.S. DEPT. OF ENERGY, EFFECT OF SEA LEVEL RISE ON ENERGY INFRASTRUCTURE IN FOUR MAJOR METROPOLITAN AREAS 13 (2014), https://perma.cc/D23E-768D (predicting that, in Houston, 16 energy facilities could be inundated by 2050 and 67 by 2100. In Los Angeles, 11 facilities could be inundated by 2050

2.2 Climate Change Impacts on Transmission Facilities

Climate change will also have impacts on electricity transmission facilities and operations, though uncertainty remains as to the precise nature and extent of those impacts. The current state of knowledge, based on research to date, is summarized below.[58]

Increasing air temperatures: Higher ambient air temperatures, particularly when accompanied by higher humidity, increase transmission line resistance, which lowers the line's carrying capacity and increases the fraction of electricity lost rather than transmitted.[59] The impacts are likely to be particularly severe during future summer heat waves, when already high temperatures rise by large amounts over short periods.[60] NREL estimates that the 9°F (5°C) increase in summer temperatures expected in parts of California by 2100 could reduce transmission capacity by 7% to 8%.[61] Increasing temperatures will also reduce the useful life of some transmission equipment,[62] and cause lines to expand and sag, potentially resulting in them coming into more frequent contact with trees.[63] Furthermore, higher night-time temperatures (which have risen faster than day-time temperatures) will reduce or eliminate opportunities for transmission lines and equipment to cool.[64]

More frequent wildfires: Transmission facilities are also affected by wildfires which, due to

and 29 by 2100. In Miami, one facility could be inundated by 2050, and 49 by 2100. In New York, 17 facilities could be inundated by 2050 and 170 by 2100.)

[58] The authors are aware of conferences led by the Electric Power Research Institute (EPRI) and of EPRI-authored research focused on this subject area. *See, e.g.*, EPRI, How the Transmission Resiliency Research Fits Together (Dec. 2015); EPRI, Proceedings of EPRI/NATF 2014 Resiliency Summit (Dec. 2014); EPRI, Proceedings of the Industry Summit on Transmission System Resiliency to Severe Natural Events (June 2013). However, the results of such efforts sit behind very high paywalls and so are not publicly available. They also seem not to have prompted the sort of assessments we call for in this paper, nor to have put to rest the need for such assessments.

[59] Sathaye et al., *supra* note 22, at 25. See also Preston et al., *supra* note [20], at 16.

[60] Studies suggest that the impact of smaller temperature increases, occurring gradually over time, are likely to prove easier to manage. *See e.g.*, EDWARD VINE, ADAPTATION OF CALIFORNIA'S ELECTRICITY SECTOR TO CLIMATE CHANGE 10 (2008), https://perma.cc/JV3M-LMJF.

[61] Sathaye et al., *supra* note 22, at 27.

[62] 2016 DOE Report, *supra* note 21, at 10.

[63] 2013 DOE Report, *supra* note 21, at 13.

[64] *Id.* at 12.

higher temperatures and drought conditions, are expected to become more frequent and intense.[65] Wildfires can damage or destroy wooden transmission poles, and the associated soot and smoke can affect the operation of lines, causing leakage currents[66] and arcing.[67] Grid operation can also be affected by certain firefighting practices, including the use of fire retardants that foul lines.[68] While grid operators have traditionally been able to manage these impacts due to the redundancy built into the transmission system, management is likely to become increasingly difficult as more frequent, longer, and more severe wildfires threaten more facilities.[69] This will be a particular problem in California, where almost all transmission facilities are expected to face increased wildfire risk by 2100, in some cases by 45% annually.[70]

Storms and flooding: Storm-related transmission disruptions could also increase in the future as extreme weather events become more frequent and severe due to climate change.[71] Transmission facilities in some areas—e.g., the Midwest and Northeast—could be affected by more intense winter storms that cause ice to accumulate on lines and equipment, and thereby cause mechanical problems.[72] Transmission lines may also be damaged by trees felled by accumulated ice or uprooted during hurricanes.[73] Hurricane-related flooding is another problem, as seen in Texas in 2017, when floodwaters from Hurricane Harvey inundated a number of transmission substations, leading to outages.[74] In total, Harvey-related flooding and winds caused widespread high-voltage

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[65] Wehner et al., *supra* note 18, at 249 (finding that "[t]he incidence of large forest fires in the western United States and Alaska has increased since the early 1980s . . . and is projected to further increase in those regions").

[66] Leakage currents may occur where particulate matter in soot accumulates on insulators. *See* Sathaye et al., *supra* note 22, at 40 (noting that "the insulators that attach the lines to the towers can accumulate soot, creating a conductive path and causing leakage currents").

[67] Arcing may occur where ionized air in smoke acts as a conductor. *See Id*. (finding that "[i]onized air in smoke can act as a conductor, causing arcing; either between lines, or between lines and the ground").

[68] *Id*.

[69] *Id*.

[70] *Id*. at 42 –45.

[71] J.P. Kossin et al., *Extreme Storms, in* CLIMATE SCIENCE SPECIAL REPORT: FOURTH NATIONAL CLIMATE ASSESSMENT 257, 257 (D.J. Wuebbles et al. eds., 2017), https://perma.cc/TD85-T3H8.

[72] Hyde M. Merrill & James W. Feltes, *Transmission Icing: A Physical Risk with a Physical Hedge*, POWER ENGINEERING SOCIETY GENERAL MEETING 1 (2006). *See also* Preston et al., *supra* note [20], at 16.

[73] *Id*. at 10 & 16.

[74] Kenny Mercado, CenterPoint Energy's Response to Hurricane Harvey, Presentation to ERCOT Board of Directors (Oct. 17, 2017), https://perma.cc/5KCJ-V2VK.

transmission outages, including on six 345 kilovolt (kV) lines and more than 200 69 to 138 kV lines.[75]

2.3 Interrelated Impacts on Facilities and Load

The sections above identify various ways in which higher temperatures and other climatic changes could disrupt the operation of generation and transmission facilities. These disruptions would occur alongside higher peaks in electricity load—potentially high enough to strain transmission and generation facilities' capacities.[76] PJM experienced an instance of this in 1999, when a heat wave caused load to exceed projections by 10% and several transmission problems followed, including transformer failures and—as a result of an increase in imported energy—a depression in voltage.[77]

These strains create a pincer effect: higher load peaks amid higher temperatures increase the likelihood of bumping into technical and operational limits on the supply side, at the same time as higher temperatures also tighten those limits by reducing the efficiency and capacities of transmission and generation facilities.[78] Therefore, to usefully capture the full range of scenarios that BPS facilities can expect to face, ISO/RTOs must consider potentially synergistic combinations of coincident changes in operationally important factors. The California Energy Commission,[79] for one, seeks to do this by identifying what it calls "climate parameters" and incorporating those parameters into relevant design specifications and planning criteria.[80]

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[75] U.S. Energy Information Administration, *Hurricane Harvey Caused Electric System Outages & Affected Wind Generation in Texas*, TODAY IN ENERGY (Sep. 13, 2017), https://perma.cc/P7T3-QXMN.
[76] EPRI, Temperature Impacts on Electricity Demand for Cooling in New York State; 2017 Technical Update 3-2 l – 3-5 (Sept. 2017); Matthew Bartos et al., *Impacts of rising air temperatures on electric transmission ampacity and peak electricity load in the United States*, 11 ENVTL. RES. LETTERS 114008, 1 (Nov. 2016).
[77] EPRI, JOINT TECHNICAL SUMMIT ON RELIABILITY IMPACTS OF EXTREME WEATHER AND CLIMATE CHANGE 3-1 – 3-5 (2008), https://perma.cc/6FNY-8WYN.
[78] JAMES MCCALL ET AL., NAT'L RENEWABLE ENERGY LAB'Y, WATER-RELATED POWER PLANT CURTAILMENTS: AN OVERVIEW OF INCIDENTS AND CONTRIBUTING FACTORS (2016), https://perma.cc/9TXQ-VH9G (reporting 43 curtailments due to higher water temperatures).
[79] The California Energy Commission, formerly the Energy Resources Conservation and Development Commission, is the state's energy policy and planning agency, not to be confused with the California Public Utility Commission.
[80] Guido Franco, Cal. Energy Comm'n, Climate Parameters for the Energy System, 2017 IEPR Joint Agency Workshop: Climate Adaptation and Resilience for the Energy System, Sacramento, Aug. 29, 2017, https://perma.cc/JNK8-JQKB.

3. PLANNING FOR THE IMPACTS OF CLIMATE CHANGE

Given the potential for higher temperatures, more intense storms, and other climate-driven phenomenon to disrupt operation of the BPS, FERC and ISO/RTOs' resilience planning efforts must recognize and account for the present and foreseeable future effects of climate change. Ignoring rather than assessing those effects would invite a circumstance in which the BPS may be unable to deliver reliable electricity services at just and reasonable rates as required by the FPA. To explain, under the FPA, FERC must ensure that rates for the interstate[81] transmission and wholesale sale[82] of electricity are just and reasonable and not unduly discriminatory or preferential, and that the BPS operates reliably.[83] To that end, ISO/RTOs under FERC's jurisdiction operate markets, which are intended to encourage the development of plentiful electricity supplies at low prices.[84] Both ISO/RTOs and FERC have recognized that, to achieve these goals, markets must be designed so as to incentivize investment in new facilities capable of reliably delivering electricity.

This was the motivation behind recent reforms to the capacity market operated by PJM Interconnection, L.L.C. (PJM).[85] PJM argued, and FERC accepted, that its pre-existing capacity market design failed to ensure the delivery of electricity during extreme weather and other emergencies.[86] To address this issue, PJM proposed market changes, which would have the effect of increasing the compensation paid to facilities that reliably delivered electricity during emergencies.[87] In approving the proposal, FERC emphasized that it would "incentivize existing reliable resources to stay in the market, while facilitating the entry of new reliable resources to displace less reliable ones."[88]

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[81] For the purposes of the FPA, the transmission and sale of electricity is "interstate" whenever electric energy moves from the buyer to the seller via an interstate transmission grid, such as the eastern or western interconnect. *See* Fed. Power Comm'n v. Florida Power & Light Co. 404 U.S. 452 (1972).

[82] Under the FPA, "sales at wholesale are defined to mean sales to any person for resale. *See* 16 U.S.C. § 824(d).

[83] 16 U.S.C. §§ 824d(a)-(b) & 824o.

[84] FERC, *Electricity Markets: National Overview* (last updated Apr. 13, 2017), https://perma.cc/PJX9-2A8X . *See also* FERC v. Electric Power Supply Association 136 S. Ct. 760 (2015).

[85] PJM operates the BPS in Delaware, Maryland, New Jersey, Pennsylvania, Virginia, the District of Columbia, and parts of Illinois, Michigan, North Carolina, Ohio, Tennessee, and West Virginia

[86] P.J.M Interconnection, L.L.C., 151 FERC ¶ 61,208 (2015), *order on reh'g*, 155 FERC ¶ 61,157 (2016).

[87] *Id*.

[88] *Id*.

FERC's reasoning in the PJM case suggests that, to provide appropriate incentives for investment, markets must account for differences in the risk profiles of BPS facilities.[89] This can only occur if there is a thorough mapping of risks which, to our knowledge, has not yet occurred in the context of climate change. While a number of BPS facility owners have identified climate change as a source of material physical risk to their operations,[90] there has been no comprehensive assessment of such risks at the ISO/RTO level.[91] Rather, to the extent that any assessments have occurred, they have generally been partial and piecemeal.

A prime example is ISO-New England[92] (ISO-NE)'s 2017 Regional System Plan, which identifies resource and transmission facilities needed to maintain BPS reliability over the next ten years.[93] The plan assumes, for the purposes of projecting peak loads, that summer temperatures will increase as they have done in the recent past, but does *not* consider the implications of summer heat for transmission facility efficiency or lifespan.[94] Thus, even though ISO-NE is assuming that increasing levels of summer heat will drive load and load peaks higher, as the Department of Homeland Security observed in 2016, it "is not addressing climate change in its planning activities to determine the grid enhancement requirements necessary to meet future demand given projected temperature increases."[95] ISO-NE's planning is often based on historic trends which, given the existence of climate change, are not a good proxy for future conditions. In particular, ISO-NE's annual Capacity, Energy, Loads and Transmission Report, which forecasts key details like expected transmission and large transformer losses and peak loads, looks to "historical demand" and "weather data," among other factors, but not climate projections.[96]

155 FERC ¶ 61,157 (2016).

[90] See 10-Ks listed in note 15, *supra*.

[91] *See* note 58, *supra*.

[92] ISO-NE operates the BPS in Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont.

[93] ISO-NE, 2017 REGIONAL SYSTEM PLAN (2017), https://perma.cc/4YSP-UWW5.

[94] *Id*. at 19 & 41.

[95] U.S. DEP'T OF HOMELAND SECURITY (DHS), CASCO BAY REGIONAL CLIMATE CHANGE RESILIENCY ASSESSMENT 40 (2016), https://perma.cc/8JL9-RWXJ.

[96] The "2017-2026 Forecast Report of Capacity, Energy, Loads, and Transmission" is a source of assumptions for use in electric planning and operations reliability studies. *See* ISO-NE, 2017 CELT REPORT: 2017-2026 FORECAST REPORT OF CAPACITY, ENERGY, LOADS AND TRANSMISSION (2017), https://perma.cc/Y3LV-F8D8. Its "energy and peak load forecasts integrate state historical demand, economic and weather data, and the

We do not mean to single out ISO-NE here. It is by no means alone in its failure to comprehensively assess the impacts of climate change on the BPS using downscaled climate projections. ISO/RTOs typically leave such considerations to the states in which they operate or the owners of facilities they oversee. By and large, however, those entities have not considered or addressed the likely effects of future climate change on the BPS or its component parts. To illustrate what this might mean, consider an example from the distribution segment of the grid: testimony given before the New York Public Service Commission during the post-Sandy rate case in 2013 revealed that Consolidated Edison[97] had specified design parameters for its equipment that would be incompatible with the summer temperatures expected to occur during the useful life of that equipment.[98] Climate vulnerability assessments of existing or planned segments of the BPS could detect this sort of incompatibility—and failure to conduct such assessments is likely to leave them present, but obscured from the analysis of risks to and constraints on BPS performance.

3.1 Approach to Planning

As discussed in section 2 above, the impacts of climate change on the BPS will vary by region, as will the solutions available to ensure the system is climate resilient. Given this regional variation, there can be no "one-size fits-all" approach to planning, though a number of general principles have been identified to guide the process. DOE, for example, has outlined eight key steps for climate change resilience planning in the electricity sector (see Figure 2).[99] Most of the steps relate to the conduct of a vulnerability assessment which aims to identify where and under what conditions facilities may be affected by rising temperatures, more intense storms, and other

impacts of utility-sponsored conservation and peak-load management programs." *See* ISO-NE, *CELT Reports*, https://perma.cc/3PRT-RQJH (accessed Feb. 1, 2018).

[97] Consolidated Edison is a distribution utility operating in New York City and Westchester County in New York.

[98] Report of Klaus H. Jacob on behalf of the New York State Office of the Attorney General, In re Con Edison Major Rate Proceedings, Case Nos. 13-E-0030 et al., 10 tbl.2 (May 31, 2013) (listing expected departure from 1971-2000 baseline in 2020s, 2050s, and 2080s for, inter alia, ambient temperature); *see also* Consolidated Edison Company of New York, Inc., Storm Hardening and Resiliency Collaborative Report 81 tbl.12 (Dec. 2013) (listing design standards under review for likely revision, including "temperature variable" and "heat waves").

[99] 2016 DOE Report, *supra* note 21.

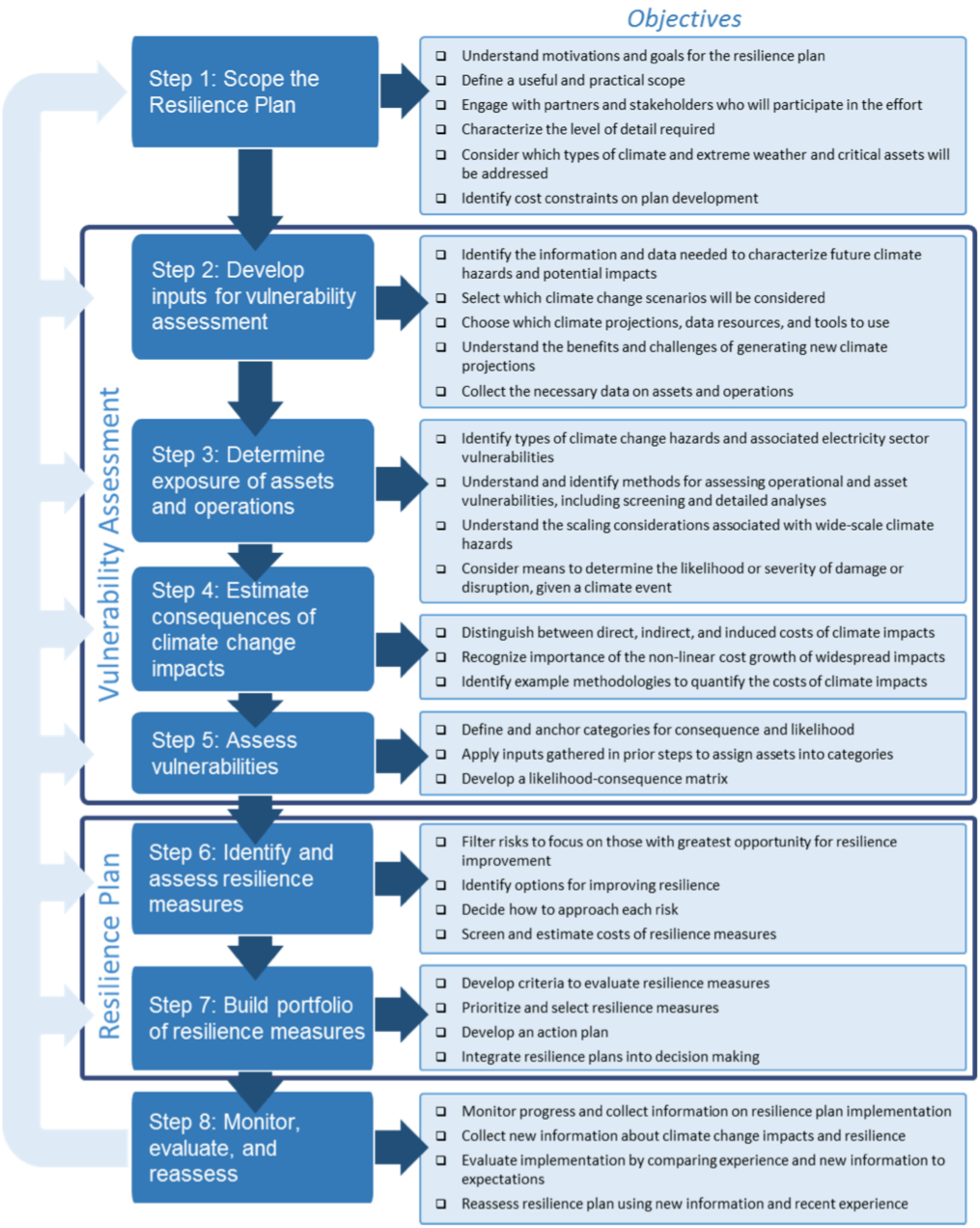
climate-driven weather changes.[100] Based on the results of the vulnerability assessment, a resilience plan can be developed, identifying actions that should be taken to mitigate critical vulnerabilities, either by reducing the probability of damage or disruption to facilities (e.g., through relocation or hardening) or the consequences of any damage or disruption (e.g., by enhancing recoverability).

It is important that any planning effort take a long-term view and consider climate-related risks over the expected useful life of transmission and generation facilities. Currently however, stakeholders in the BPS planning process tend to employ ten to fifteen-year time horizons when evaluating risks to reliability (and resilience),[101] whereas generation and transmission facilities tend to have useful lives of twenty-five to forty years or more.[102] Thus, as DOE's Quadrennial Energy Review notes, "[p]lanning for decarbonization and climate resilience reaches beyond typical planning horizons for grid operators."[103]

While taking a longer view is essential to adequately assess how the impacts of climate change could constrain and disrupt BPS operations, simply expanding planning horizons would add complexity and uncertainty to the plans developed by ISO/RTOs[104]—to a potentially unworkable degree. Changes in technology, regulation, consumer demand, and other important factors cannot be foreseen several decades in advance, yet the likelihood of such changes also cannot be ignored because they could significantly affect the grounds for ISO/RTOs' initial

[100] *Id*. at iii.
[101] *See e.g.*, PJM, 2017 PJM Baseline Reliability Assessment for the 2017–2032 Period (Jan. 2018) (using 15-year planning horizon).
[102] *See e.g.*, NERC, *Reliability Assessments*, https://perma.cc/XFC8-F6LP (accessed Feb. 5, 2018) ("Long-Term Reliability Assessments annually assess the adequacy of the Bulk Electric System in the United States and Canada over a 10-year period. The reports project electricity supply and demand, evaluate transmission system adequacy, and discuss key issues and trends that could affect reliability."); U.S. Energy Information Administration, *Nuclear Regulatory Commission resumes license renewals for nuclear power plants*, TODAY IN ENERGY (Oct. 29, 2014), https://perma.cc/D7HG-V2Q9 (reporting approvals of 20-year extensions on 40-year operating licenses for 74 nuclear reactors); Edison Electric Institute, Transmission Projects: At A Glance (Dec. 2016), https://perma.cc/433Q-WQL7 (". . . transmission assets are built to be in use for several decades . . . ."); Electric Power Research Institute, Plant Support Engineering: Common Medium-Voltage Cable Specification for Nuclear Power Plants, at vi (Oct. 2009) ("The existing fleet's medium-voltage cable population has an average age of roughly 30 years.").
[103] Quadrennial Energy Review (Second Installment): Transforming the Nation's Electricity System 4-7 (Jan. 2017).
[104] 2016 DOE Report, *supra* note 21, at 86.

Figure 2: DOE's Recommended Approach to Resilience Planning in the Electricity Sector[105]



[105] *Id*. at 3.

planning decisions. And, of course, they could also alter aspects of the BPS's vulnerability to climate change and the options available to enhance its climate resilience. What to do? The approach taken by California's Pacific Gas and Electric (PG&E),[106] a distribution utility, to assessing climate-related risk and resilience is instructive here.[107] As part of its periodic Risk Assessment Mitigation Phase (RAMP) effort PG&E has identified climate-driven hazards, potential impacts of those hazards, and resilience measures that can mitigate or avoid them. But unlike other types of risk which it assesses in just one timeframe, PG&E considers two time frames—2022 and 2050—when assessing risks arising from climate-driven hazards.[108] This approach serves to highlight looming risks and likely constraints without forcing PG&E to speculate unduly about the future. Furthermore, because PG&E's RAMP efforts are periodic, it will revisit its assessment of vulnerabilities and resilience options, updating them as appropriate.[109]

3.2 Existing Tools and Resources

As the foregoing discussion makes clear, significant information will be required to conduct vulnerability assessments and prepare resilience plans, including localized climate change projections. Such projections may be found in existing publicly available tools, datasets, and reports developed by governmental, academic, and other independent bodies.[110] Examples include:

- NASA downscaled datasets;[111]
- U.S. Geological Survey (USGS) National Climate Change and Wildlife Science Center downscaled datasets;[112]

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[106] PG&E provides retail electricity services in the northern two-thirds of California, from Bakersfield to almost the Oregon border.

[107] PG&E, 2017 RISK ASSESSMENT AND MITIGATION PHASE 22-i – 22-20 (2017); PG&E, CLIMATE CHANGE VULNERABILITY ASSESSMENT AND RESILIENCE STRATEGIES (2016), https://perma.cc/5LXQ-83U7.

[108] *Id.* at 22-3.

[109] 2016 DOE Report, *supra* note 21, at 86–89 (calling for adaptive approach involving periodic review and update).

[110] Among the hundreds of datasets accessible via Data.gov, dozens capture information on climate-related topics like precipitation, solar radiation, and temperature. *See* Data.gov, https://www.data.gov/climate/ (accessed Feb. 16, 2018). For a collection and description of tools and data useful for this and related purposes, see JESSICA WENTZ, ASSESSING THE IMPACTS OF CLIMATE CHANGE ON THE BUILT ENVIRONMENT UNDER NEPA AND STATE EIA LAWS: A SURVEY OF CURRENT PRACTICES AND RECOMMENDATIONS FOR MODEL PROTOCOLS 15–26 (2015), https://perma.cc/M6MQ-S2UB.

[111] National Aeronautics and Space Administration, NASA Earth Exchange (NEX) Downscaled Climate Projections (NEX-DCP30).

- ClimateNA (short for North America) dataset.[113]
- New York City Panel on Climate Change data and reports;[114] and
- Cal-Adapt's data, tools, and other resources;[115]

These resources draw on the climate models used by the Intergovernmental Panel on Climate Change, an international body which periodically assesses global climate trends,[116] and the U.S. Global Change Research Program, which prepares national climate assessments.[117] ISO/RTOs may find it useful to review those bodies' reports, which provide the most authoritative projections of national and regional climate change trends.

Given uncertainty regarding the pace and magnitude of climate change—which will depend on future emissions levels and any mitigation action taken—ISO/RTOs planning should take into account multiple projections covering a range of scenarios (e.g., "high emissions," "medium emissions," and "low emissions").[118] Plans should not be based solely on historic data, particularly records of past storms and other extreme events, which are unlikely to reflect the intensity of future events.

This encouragement to consult climate projections would be incomplete if it did not also warn against reliance on data that are incomplete and/or ignore the future. The Flood Insurance

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112 U.S. Geological Survey, New Statistically Downscaled Climate Data Available for the Conterminous U.S., http://bit.ly/2abfdNu (accessed Feb. 8, 2018); *see also* Adrienne Wootten et al., U.S. Geological Survey, Downscaled Climate Projections for the Southeast United States: Evaluation and Use for Ecological Applications, Open-File Report 2014–1190 (2014), https://perma.cc/7UYP-AF9R.

113 Tongli Wang et al., *Locally Downscaled and Spatially Customizable Climate Data for Historical and Future Periods for North America*, PLoS ONE (June 2016) (describing ClimateNA software package, useful for deriving downscaled climate data for North American locations).

114 *Building the Knowledge Base for Climate Resiliency: New York City Panel on Climate Change 2015 Report*, 1336 Ann. N.Y. Acad. Scis. 1–150 (2015).

115 *See* http://cal-adapt.org/ (accessed Feb. 8, 2018), Cal-Adapt is the product of a collaboration among state agencies, universities, and private companies based in California. Susan Wilhelm, Cal. Energy Comm'n, Unveiling Cal-Adapt 2.0: Facilitating Energy Sector Resilience and Providing Foundational Scenarios for California's Fourth Climate Change Assessment, IEPR Workshop on Adaptation and Resilience for the Energy System, Sacramento, California, Aug. 29, 2017, https://perma.cc/27TJ-H2J7.

116 *See* Intergovernmental Panel on Climate Change, https://perma.cc/Y2S6-2GDA (accessed Feb. 9, 2018).

117 *See* U.S. Global Change Research Program, *Climate Science Special Report*, https://perma.cc/2XL4-SBDN (accessed Feb. 9, 2018).

118 Consistent with this recommendation, PG&E's Climate Resilience RAMP considers two emissions scenarios. PG&E, *supra* note 107, at 22-3.

Rate Maps (FIRMs) developed by the Federal Emergency Management Authority (FEMA) for use in the National Flood Insurance Program (NFIP) usefully illustrate this danger. To begin, FIRMs are strictly backward looking, even though the risks they purport to depict are highly sensitive to several climate-driven impacts. FIRMs also suffer from several other problematic limitations, resulting from their design parameters and the funding and administration of mapping efforts.[119] Currently, for instance, the maps do not reflect flood risks arising from the rapid accumulation of precipitation, such as occurred in Houston during Hurricane Harvey. The Technical Mapping Advisory Council (TMAC), established to review and suggest improvements to the maps, has issued a host of recommendations to FEMA,[120] most of which have gone largely unheeded.[121] A 2017 Inspector General's report highlighted several programmatic deficiencies as well, such as the slow rate of updating and poor application of quality control measures.[122] Thus BPS planning decisions should not rely exclusively on FEMA flood maps to determine flood risk in the near or long-term.

4. RECOMMENDATIONS

To ensure that the BPS continues to deliver reliable electricity services at just and reasonable rates, FERC and ISO/RTOs must plan for the impacts of climate change. Recommendations to guide the planning process are set out below.

- A detailed climate change vulnerability assessment should be undertaken to determine how the components and operations of each ISO/RTO's system will be affected by increasing

[119] For an overview of the key issues, see Michael Keller et al., *Outdated and Unreliable: FEMA's Faulty Flood Maps Put Homeowners at Risk*, Bloomberg, Oct. 6, 2017, https://perma.cc/QWN8-PNRL. Notably, mapping efforts were an incidental feature of the NFIP until 2012, when new legislation incorporated them into the independently authorized and funded National Flood Mapping Program. *See* Biggert-Waters Flood Insurance Reform Act of 2012, Pub. L. No. 112-132, 126 Stat. 365 (May 31, 2012), *codified at* 42 U.S.C. § 4101b.
[120] *See* TMAC, National Flood Mapping Program Review (June 2016), http://bit.ly/2sclUaH; TMAC, Future Conditions Risk Assessment and Modeling (Dec. 2015), http://bit.ly/2fJY7Vq.
[121] *See* Comment letter from Sabin Center for Climate Change Law to FEMA, re National Flood Insurance Program Draft Nationwide Programmatic, June 1, 2017, at 7–10, https://perma.cc/3AGQ-Q7SF.
[122] DHS OFFICE OF THE INSPECTOR GENERAL, FEMA NEEDS TO IMPROVE MANAGEMENT OF ITS FLOOD MAPPING PROGRAMS (2017), http://bit.ly/2nNoLkV.

temperatures, changing precipitation patterns, more intense storms, droughts, and other climate-driven weather extremes expected in their respective regions.

- Vulnerability assessments should be based on downscaled projections of future climate change in their respective operating regions. Many projections are available in existing datasets, including those developed by NASA and the USGS.
- Where even downscaled projections fail to provide data for key variables (e.g., humidity (wet-bulb temperature) or temperatures at particular times of day) the entity conducting the assessment should, at minimum, acknowledge the lack of complete information, and, if possible, seek to supplement available data sets.
- Multiple projections reflecting a range of possible climate change scenarios, including a "worst case" (i.e., assuming continued high greenhouse gas emissions lead to large temperature increases and rapid rates of sea level rise), should be considered in the vulnerability assessment.
- The timeframe for the vulnerability assessment should reflect the anticipated useful life of existing facilities or facilities scheduled for construction in the relevant ISO/RTO's region.
- The vulnerability assessment should be periodically reviewed and updated as new information becomes available.

- Based on the vulnerability assessment, a resilience plan should be developed, outlining measures that can be taken to prevent or manage system disruptions.

5. CONCLUSION

FERC and NERC's ongoing efforts to address risks to electric reliability aim to, among other things, "identif[y] long-term emerging issues and trends that do not necessarily pose an immediate threat to reliability but will influence future [BPS] planning, development and system analysis."[123] The resilience of the BPS to climate-driven impacts—and to other impacts amid climate-related constraints—falls cleanly within this mandate. The implications of climate change for the BPS should inform efforts by ISO/RTOs, FERC, and NERC to ensure its resilience to all manner of disruptions.

[123] NERC, *Reliability Assessment and Performance Analysis*, https://perma.cc/TMZ9-BXCL (accessed Feb. 1, 2018).

APPENDIX A

Potential Impacts of Climate Change on the Generation and Transmission Segments of the BPS

<table>
<tr><th colspan="2" rowspan="2">Climate Change Phenomenon</th><th colspan="2">Potential BPS Impacts</th><th rowspan="2">ISO/RTO Regions Impacted</th></tr>
<tr><th>Generation</th><th>Transmission</th></tr>
<tr><td rowspan="3">Temperature</td><td>Rising air temperatures</td><td rowspan="2">↑ electricity load and the height of peak load
↓ thermoelectric and solar photovoltaic generating efficiency and capacity
Shifts in timing of hydroelectric generation (e.g., due to earlier snow melt)</td><td rowspan="2">↓ transmission line carrying capacity
↑ transmission line losses
↑ transmission outages (e.g., due to sagging lines contacting trees)</td><td rowspan="2">All</td></tr>
<tr><td>More frequent and severe heat waves</td></tr>
<tr><td>Higher water temperatures</td><td>↓ thermoelectric generating efficiency and capacity
↑ thermoelectric generating facility curtailment and shutdown (e.g., due to temperature of cooling water exceeding technical specifications)</td><td>N/A</td><td>All</td></tr>
<tr><td rowspan="2">Precipitation</td><td>Lower annual precipitation</td><td rowspan="2">↓ thermoelectric and hydroelectric generating capacity
↑ thermoelectric generating facility curtailment and shutdown (e.g., due to water levels falling below water intake structures)
↑ hydroelectric generating facility curtailment and shutdown (e.g., due to insufficient water flows)
Shifts in timing of hydroelectric generation (e.g., from summer to winter)</td><td rowspan="2">N/A</td><td rowspan="2">California ISO, Mid-continent-ISO, Southwest Power Pool (SPP)</td></tr>
<tr><td>More frequent and severe droughts</td></tr>
</table>

Climate Change Phenomenon		Potential BPS Impacts: Generation	Potential BPS Impacts: Transmission	ISO/RTO Regions Impacted
	Shift from snow- to rain-fall	↓ hydroelectric generating capacity (e.g., due to lower annual water storage) ↑ hydroelectric generating facility curtailment and shutdown (e.g., due to insufficient water flows) Shifts in timing of hydroelectric generation (e.g., from summer to winter)	N/A	All
	More heavy rainfall events	↑ generation facility curtailment and shutdown (e.g., due to flooding)	↑ transmission outages (e.g., due to trees falling on lines)	All
Storms	More frequent and severe storms	↑ thermoelectric generating facility shutdown (e.g., due to flooding) ↑ hydroelectric facility shutdown (e.g., due to dam damage)	↑ transmission outages (e.g., due to trees falling on lines)	All
Coastal impacts	Sea level rise Increased storm surge	↑ generating facility shutdown (e.g., due to flooding)	↑ transmission outages (e.g., due to flooding)	All except SPP
Wildfire	Increased wildfire risk	↑ generating facility shutdown (e.g., due to fire damage)	↑ transmission outages (e.g., due to destruction or fouling of lines)	California ISO