PNNL-34304

Emerging Best Practices for Electric Utility Planning with Climate Variability

A Resource for Utilities and Regulators

May 2023

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Prepared for the U.S. Department of Energy
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Summary

Climate change impacts are becoming increasingly apparent in the United States and around the world. The National Oceanic and Atmospheric Administration (NOAA) reports that over a 143-year record, the last nine years (2014 to 2022) are the warmest years on record (NOAA 2023). Utility system operations and planning are based on historical trends, so deviations from trends can have severe impacts on utility system services. Table ES.1 shows a sampling of the ways climate change can impact electric utilities.

This report is intended to support electric utilities and regulators as they work together to increase the climate resilience of the power system in the United States. It focuses on best practice methods and examples of conducting utility forecasting with climate change (Section 2) as well as three overlapping types of electric utility planning for climate change: resource planning (Section 3), asset planning (Section 4), and contingency planning (Section 5). This report also addresses data development and access (Section 6), emerging pathways for planning including decision-making under deep uncertainty and storylines approaches (Section 7), regulatory considerations (Section 8), and coordination and innovative funding and cost sharing approaches to planning for climate variability (Section 9).

Table ES.1. Examples of Ways Electric Utilities are Impacted by Climate Change

Climate Change Factor	Potential Impacts to Utility Assets
Extreme heat	Reduced equipment efficiency and a need to derate or update equipment
	Increased forced outage rates for thermal generators
	Need for modified or increased active cooling equipment
	Need to increase generation and the capacity of transmission and distribution assets to account for end-use load increases
	Worker safety issues and the need to change protocols to protect workers
Extreme cold	Need for increased vegetation management
	Need to weatherize electric system equipment and fuel supply chains
	Need to harden conductors to withstand increased ice loads
	Potential need to establish or support warming centers
Wildfires	Need for enhanced vegetation management
	Need to replace, modify, or underground equipment to prevent fires
	Need for enhanced equipment inspection and accelerated maintenance and repair programs to prevent utility equipment from causing wildfires
	Need for higher levels of situational awareness through equipment to measure weather and moisture conditions, and improved weather forecasting abilities
	Need for proactive power shutoffs and backup generators and battery storage systems for impacted communities

Climate Change Factor	Potential Impacts to Utility Assets
Extreme storms and sea level rise	Need for flood protection for low lying equipment or relocating assets out of floodplains
	Need to increase vegetation maintenance and harden infrastructure to protect it from wind and debris damage
Drought	Reduced water supply for hydropower or thermoelectric cooling
	Increased energy loads due to water pumping and irrigation
	Changes in other loads caused by drought impacts on agriculture and industry
	Increased probability of wildfire
Population migration	Locational shifts in energy demand and need to replace, rebuild, relocate and/or harden infrastructure to handle in-migration
	Loss of tax base and load due to out-migration

Forecasting with Climate Change

Utilities traditionally use historic trends to project future conditions. However, with climate change, the weather of the past is not necessarily representative of the conditions of the future. Utilities are taking different approaches to the challenge of forecasting with climate change:

- Some utilities are **using adapted, or downscaled, results from global climate models**, called general circulation models (GCMs) as the basis for forecasts and risk assessments
- Other **utilities are using more simple forecasting approaches**, including weighting recent years (~15 years) more heavily in load and weather forecasts, applying trends in the number and magnitude of heating-degree and cooling-degree days, and evaluating trends in the availability of generation resources resulting from changes to water availability, wind and solar variations, and changes to forced outage rates resulting from extreme temperatures.

Resource Planning with Climate Change

Historical averages may no longer be sufficient for resource planning with climate change. A combination of factors contributes to the potential for significant resource gaps and/or cost exposure that may be mitigated through robust resource planning. Some best practices for resource planning in the face of climate change include the following:

1. **Use the latest downscaled climate data** to forecast temperatures (and associated impacts to loads and forced outage rates), water availability (for hydropower and thermoelectric cooling), and solar and wind resources (for renewable energy generation). There are different downscaling approaches with associated pros and cons. Utilities should take care to select datasets that are appropriate for their needs.
2. **Consider multiple scenarios** based on downscaled climate models and observed trends, including those outside traditional history-based scenario analysis, to identify risks, opportunities, and least-regret investment approaches.
3. **Identify signposts or thresholds that signal needs for adaptive management decisions**. Track climate science and extreme weather events and trends and adapt planning criteria and operations accordingly.
4. **Consider interregional impacts** of climate change on the grid, electricity markets, and resource adequacy.

5. **Adjust resource adequacy approaches** to account for weather and resource uncertainty.

Asset Planning with Climate Change

Asset planning in the face of climate variability is an approach to identify where and under what conditions utility assets are at risk from the impacts of climate change and then developing plans to reduce risks. Asset planning is an important part of planning for climate variability to ensure existing and future assets can function as needed during future conditions.

Many utility assets are predicated on specific temperature maximums and minimums as well as load ranges. Temperatures above or below the specified maximum or minimum and equipment overloading can lead to derating, damage, and failure, which impacts system reliability. Periods of extremely high and low temperatures, when utility asset performance may be degraded, often correspond to times with higher-than-normal loads. **Under climate change, utilities need to evaluate design standards and temperature ranges for equipment. Utilities can also work with equipment vendors need to adapt equipment ratings and specifications.**

Asset planning can also include relocating equipment out of flood areas and undergrounding or adapting equipment due to fire risks.

A systematic approach to asset planning with climate change includes evaluating the following:

1. The **exposure** of critical assets or operations to an adverse climate event
2. The **probability of damage** to assets or disruption to operations as a result of exposure to those climate threats (risks posed by threat)
3. The **likely consequences** if the event were to occur (severity of impacts)
4. **Mitigation measures** that can reduce the risk to vulnerable assets and take into consideration impacts to disadvantaged communities.

Contingency Planning with Climate Change

In this report, contingency planning is an umbrella concept that includes all utility planning for the nontraditional, unexpected, and potentially destructive impacts of climate change. Utilities and regulators are advancing two general approaches for contingency planning related to climate change. The first is **planning in response to specific environmental changes** and the risks associated with utility system operations (i.e., wildfire mitigation plans or storm protection plans). The second is a **comprehensive approach**, in which utilities conduct **complete climate vulnerability assessments and resilience plans** to mitigate climate impacts.

California and New York regulators require utilities to perform comprehensive climate change planning. Utilities such as Con Edison and Seattle City Light conducted wide-ranging climate vulnerability assessments absent specific regulatory requirements. Some best practice utility and regulatory examples of climate change contingency planning are described in this report and summarized below.

- Seattle City Light's plan **evaluates the impacts of eight different aspects of climate change identified as likely to impact its system** (sea level rise, warmer temperatures, extreme weather, landslides, changes to snowpack and runoff, flooding, and lower summer streamflows) **on five aspects of utility operations and infrastructure** (shoreline infrastructure, electricity demand, transmission and distribution, hydroelectric operations, and fish habitat restoration) to develop **thirteen impact pathways** through which the utility could experience risks to its mission. Seattle City Light then identifies **seventeen specific potential adaptation actions.**

- Con Edison's Climate Vulnerability Assessment **characterizes historical and projected climate changes across its service territory**, identifying sea level rise, storm surge, increased temperature and heat waves, and extreme weather as critical climate risks. Con Edison identifies **specific potential impacts** to loads, equipment ratings, reliability planning, asset management, cooling equipment, emergency response activations, and worker safety. Con Edison proposes a **flexible adaptive approach** and **identifies monitoring indicators or thresholds**, called signposts, that can inform adaptive management decisions. Signposts were established in relation to observed climate phenomena, updated climate projections, climate impacts, and policy, societal, and economic conditions.
- **The California Public Utility Commission (CPUC) issued guidance** (Phase 1 Topics 1 and 2; Phase 1 Topics 4 and 5) **for California utilities filing Climate Adaptation Vulnerability Assessments**. Utilities were directed to use the same three climate scenarios and projections from the most recent California Statewide Climate Change Assessment, the data for which is available on a **state-sponsored web platform called** Cal-Adapt. California utilities were also directed to map disadvantaged vulnerable communities (DVCs) based on a definition provided by the CPUC and actively engage DVCs in planning, as spelled out in a **Community Engagement Plan** that utilities must file with the CPUC one year prior to filing the vulnerability assessment.

Data Development and Access

In planning for climate change, data is critical but downscaling global climate models can be a time-consuming and expensive process, and different models can provide different results and different downscaling approaches have different pros and cons. As utilities embark on planning for climate change, it is important to define climate-related decisions that need to be made and then work with climate science experts to select datasets that are appropriate for their needs. Some utilities have developed climate datasets in partnership with government and academic organizations and projections are updated over time in response to new science and observed events. In California, state organizations have led detailed statewide assessments and made granular (6 kilometer by 6 kilometer) climate change data available for use by utilities, municipalities, and other entities through a web portal called Cal-Adapt.

Although not as granular as Cal-Adapt, other regional and national-level datasets and resources exist that can be informative for electric utilities. Descriptions of and links to many different data and information sources are provided in this report, including the U.S. Climate Resilience Toolkit, Climate Mapping for Resilience and Adaptation, the Pacific Northwest National Laboratory (PNNL) Climate Research Portal, and the Climate Risk & Resilience Portal (ClimRR) developed by Argonne National Laboratory and others.

Climate translators may be needed to help utilities and regulators navigate the uncertainty and myriad of climate and weather data and information available. In particular, utilities could use information that connects extreme events experienced by power infrastructure to the weather events that caused them so future projected weather events can be used to project future extreme events and potential infrastructure impacts (Tipton and Seitter 2022).

Dealing with Uncertainty

Because climate models are not a perfect representation of the Earth's climate and major limitations exist in climate-model-based projections for utility planning, alternative approaches, such as decision-making under deep uncertainty (DMDU), are growing in utilization. Deep uncertainty occurs when parties to a decision do not know or do not agree on the likelihood of alternative futures or how actions are related to consequences (Lempert et al. 2013). DMDU methods seek to build confidence in a decision rather than a model. DMDU recognizes the principle of non-stationarity, which means that future conditions cannot be predicted based on the past, even if elements of those futures vary stochastically. DMDU approaches are also based on a "monitor and adapt" paradigm rather than a "predict then act" paradigm. The adaptive pathways approach used by Con Edison is an example of a monitor and adapt strategy, because utility actions shift as more information about climate change and external conditions is learned over time.

While DMDU approaches can support robust and adaptable decisions, the uptake of DMDU in practice is relatively limited and DMDU implementation can be a challenge for utilities.

Regulatory Considerations

Regulatory commissions can help utilities prioritize climate change investments that balance cost and risk. By establishing clear goals, expectations, and metrics, regulatory commissions can support prudent utility investments and help reduce utility concerns about cost recovery. Table ES.2 lists states with climate-planning related requirements and states in which resilience activities of different kinds are tied to favorable cost recovery.

Table ES.2. States Requirements and Resilience Actions Tied to Cost Recovery

Climate-Related Process	California	Connecticut	D.C.	Florida	Hawaii	Louisiana	Maryland	Massachusetts	Michigan	Nevada	New Hampshire	New York	New Jersey	North Carolina	Oklahoma	Oregon	Pennsylvania	Rhode Island	Texas	Utah	Washington
State-level planning requirements																					
Requirement for climate vulnerability assessment and adaptation plans	●											●									
Requirement for storm management plans				●																	
Requirement for wildfire mitigation plan[1]	●									●						●				●	○
Requirement to consider climate change in distribution system planning									○												
Settlement agreement requires climate vulnerability assessment														●							

Climate-Related Process	California	Connecticut	D.C.	Florida	Hawaii	Louisiana	Maryland	Massachusetts	Michigan	Nevada	New Hampshire	New York	New Jersey	North Carolina	Oklahoma	Oregon	Pennsylvania	Rhode Island	Texas	Utah	Washington
Resilience actions tied to cost recovery																					
Grid hardening or storm management actions tied to cost recovery surcharge		●	●		●	●	●	●			●		●	○	●		●	●	●		

● is used to indicate the statutory or legislative requirement exists, or utilities voluntarily developed the plans indicated.

○ is used to indicate that dockets are open in which the objective would apply.

[1] States apply several names, e.g., resource protection plans, but wildfire mitigation is a major part of such alternative plans.

Regulators can support utilities' planning through investigations and convening stakeholders to discuss what utilities should do to prepare the electric system for a changing climate. In prudence reviews of utility investments, regulators can consider the extent to which utilities use widely available climate projections. If regulatory bodies set clear goals and expectations, but utility investments are not vetted through a climate adaptation process, those investments could be at risk in a future prudence review.

Coordination and Cost Sharing

As states and utilities face unprecedented risks due to climate change, new questions are being asked of utilities and regulators, as well as state and local policymakers. There is an important role for elected legislative and administrative officials in addressing the challenges of climate change. Coordination between electric utilities and other private and government organizations can lead to more comprehensive, equitable, and cost-effective solutions. Some states have passed laws or amended previous legislation to mandate the inclusion of climate adaptation and resilience in planning and zoning activities.

Examples of innovative collaborations between utilities and other organizations to realize climate resilience include the following:

- **Pacific Gas & Electric (PG&E) SAFER Bay Project** was co-developed by PG&E, the city of Menlo Park, and Meta (formerly Facebook). The project applied for a $50 million grant from Federal Emergency Management Agency's (FEMA's) Building Resilient Infrastructure and Communities (BRIC) funding to protect a PG&E substation at risk due to sea level rise, provide more general flood protection, and safeguard ponds at a wildlife refuge (SCE 2022a; Bradshaw 2021).
- **The New Jersey Energy Resilience Bank Program** was established in 2014 following Superstorm Sandy with $200 million of Community Development Block Grant – Disaster Recovery funds allocated to New Jersey by the U.S. Department of Housing and Urban Development (HUD). The program paid for resilient energy investments (combined heat and power and microgrids) at critical facilities (water, wastewater, hospitals). Projects were prioritized that served low- and moderate-income communities (NY NJ TAP 2019).

Small utilities may not be as well-equipped to plan for and adapt to the challenges of climate change. **Government organizations, professional associations, and larger and better-**

resourced electric utilities can partner with smaller and rural utilities to share resources, best practice approaches, and lessons learned. This information sharing can occur in gatherings convened by regional or federal bodies, including DOE. New and innovative collaborations are needed to support electric system planning for resilience in the face of climate variability and change.

Acknowledgments

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Acronyms and Abbreviations

API	Application Programming Interface
BRIC	Building Resilient Infrastructure and Communities
CAISO	California Independent System Operator
CMRA	Climate Mapping for Resilience and Adaptation
CPUC	California Public Utility Commission
CREAT	Climate Resilience Evaluation and Awareness Tool
DDOT	District Department of Transportation
DERs	Distributed Energy Resources
DMDU	Decision-making under deep uncertainty
DOE	Department of Energy
DSCADA	Distribution system supervisory control and data acquisition
ECMWF	European Centre for Medium-Range Weather Forecasts
EEA	European Environmental Agency
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FLISR	Fault location, isolation and service restoration
FPL	Florida Power & Light
FPSC	Florida Public Service Commission
GCM	General circulation model
GHG	Greenhouse gas
GIS	Geographic information systems
HUD	Housing and Urban Development
IEA	International Energy Agency
IOU	investor-owned utility
IRP	Integrated Resource Plan
MW	Megawatts
NASA	National Aeronautics and Space Administration
NCEI	National Centers for Environmental Information
NERC	North American Electric Reliability Corporation
NESC	National Electric Safety Code
NOAA	National Oceanic and Atmospheric Administration
NPCC	New York City Panel on Climate Change
NREL	National Renewable Energy Lab
NYPSC	New York’s Public Service Commission
NYSERDA	New York State Energy Research and Development Authority
OECD	Organization for Economic Cooperation and Development

OEIS	Office of Energy Infrastructure Safety
OMS	Outage Management Systems
PG&E	Pacific Gas & Electric
PNNL	Pacific Northwest National Laboratory
PSPS	Public safety power shutoff
RMJOC	River Management Joint Operating Committee
SCE	Southern California Edison
SCL	Seattle City Light
SGIP	Self-Generation Incentive Program
SPP	Storm protection plans
TEC	Tampa Electric Company
TV	Temperature variable
TVA	Tennessee Valley Authority
VVO	Volt-var optimization
WCRP	World Climate Research Program
WIND	Wind Integration National Dataset

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1.0 Introduction

As the climate changes, the United States will experience more frequent, dramatic shifts away from historic weather[1] patterns. Climate and weather have been and will remain an important facet of electric system planning, dictating how utilities design and operate their systems to meet customer needs. Weather inputs in utility planning processes and underlying engineering assumptions have long relied on historically observed weather—data that is no longer reliable due to climate change. As the climate changes, investment decisions may prove particularly challenging because of the unpredictable nature of future regional climate trends and weather events.

As climate change has already caused greater variability in operating conditions, some utilities and regulators have responded by developing new or adapting existing planning and operational practices to integrate climate variability. **This paper, intended for electric utilities and utility regulators, reviews planning activities in the United States to prepare electric power systems for the impacts of climate change.**

The review focuses on the following topics in the context of planning for climate variability:

- Forecasting key design and planning variables
- Resource planning
- Asset planning
- Contingency planning[2]
- Data development and access
- Emerging approaches, including decision-making under uncertainty and storyline approaches
- Regulatory considerations
- Cost sharing approaches.

Illustrative examples of best practices in climate resilience planning are provided. This report is intended to support electric utilities and regulators as they work together to increase the climate resilience of the power system in the United States.

1.1 New Challenges for Electric System Operations

In recent years, climate change impacts have become increasingly apparent in the United States. According to the Fourth U.S. National Climate Assessment (NCA4), the average temperature in the United States increased 1.8°F between 1901 and 2016 (USGCRP 2017). The National Oceanic and Atmospheric Administration (NOAA) reports that, globally, 2022 was the sixth warmest year and the ten warmest years in the 143-year record have all occurred since 2010, with the last nine (2014 to 2022) being the warmest years on record (NOAA 2023).

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[1] Weather in this report is taken to mean short-term conditions, while climate is taken to mean weather averaged over a long period in a specific area.

[2] In this report, contingency planning is an umbrella concept that includes all utility planning for the nontraditional, unexpected, and potentially destructive impacts of climate change.

Figure 1.1 shows the global average surface temperatures relative to the 1901–2000 average temperature in °C.

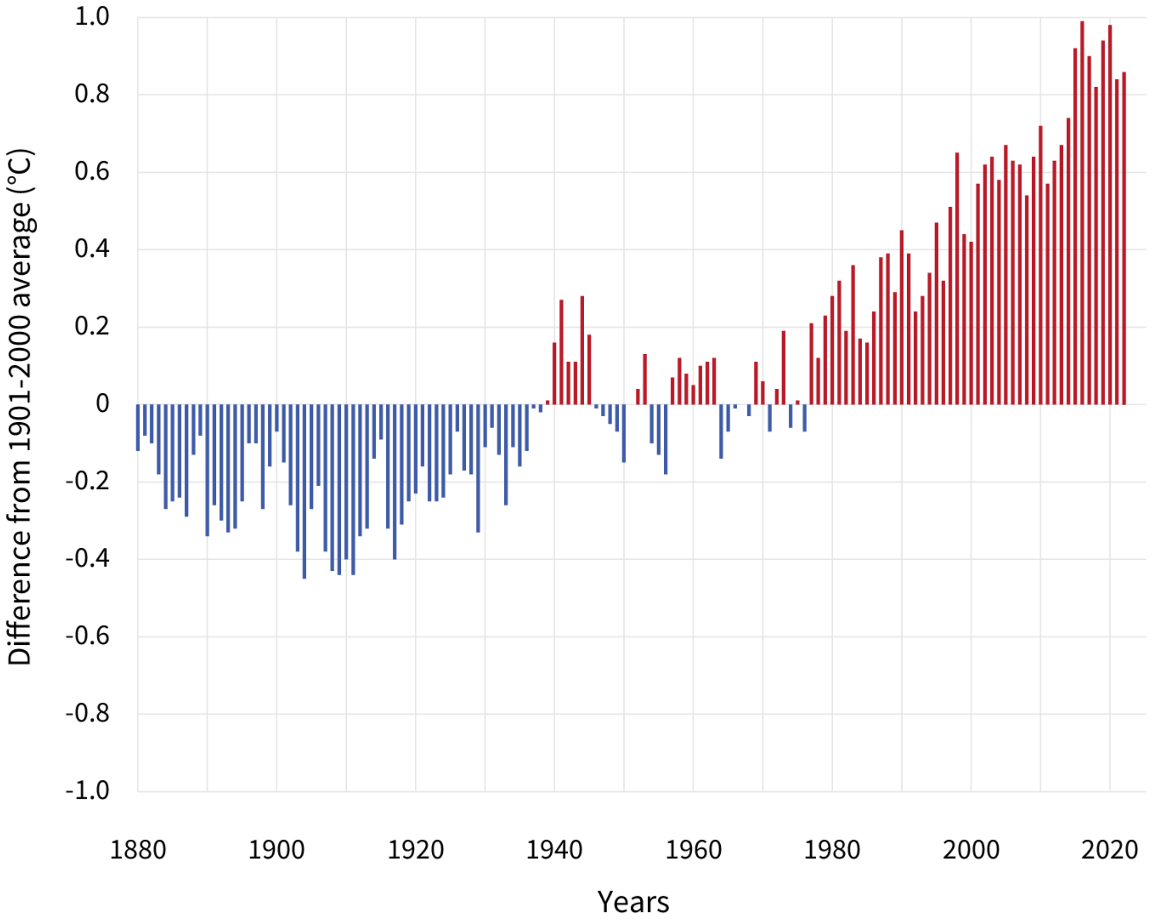

Figure 1.1. Global Average Surface Temperature (NOAA 2023)

NCA4 reports other changes affecting the United States or disrupting historic patterns in U.S. weather as the following:

- Global sea levels have risen by 7–8 inches since 1901
- Rainfall is increasing in intensity and frequency
- Incidence of large wildfires is increasing
- Reduced snowpack and earlier melting are affecting water resources in the western U.S. states
- Chronic, long-duration drought is increasingly possible (USGCRP 2017).

In addition, high-impact, low-frequency events, such as those described in Figure 1.2, are becoming more intense and frequent due to climate change. The projected impacts of a shifting climate vary greatly by region, and there is significant uncertainty associated with the degree to which impacts may occur. According to the National Centers for Environmental Information (NCEI), from 1980 through 2021 the United States experienced 323 weather and climate events in which the overall cost of the event reached or exceeded $1 billion, with nine additional events through July 11, 2022. The total costs of events through July 11, 2022, adjusted to $2022, exceeds $2.275 trillion (NCEI 2022). The number of billion dollar events per year is increasing, as shown in Figure 1.2.

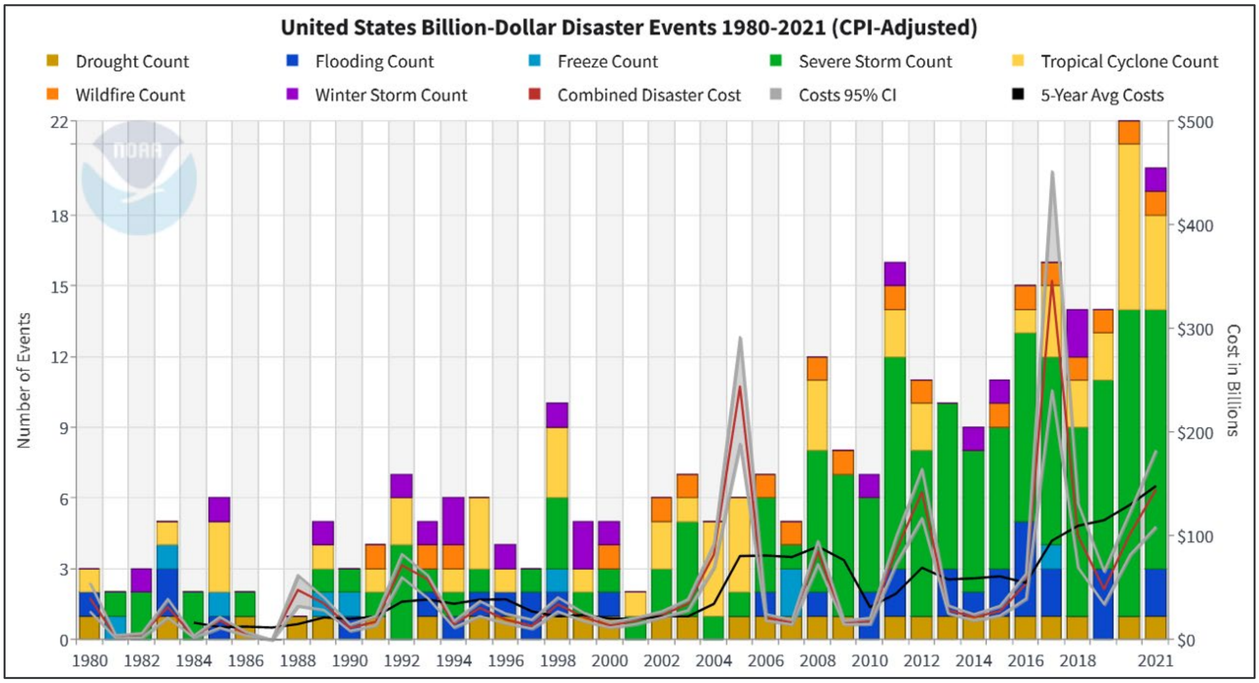

Figure 1.2. U.S. Billion Dollar Weather/Climate Disasters, by Type of Disaster, by Year with Annual Costs and 5-Year Average Costs (NOAA 2022a)

Table 1.1 contains potential climate change impacts to electric utility assets from extreme heat, extreme cold, uncontrolled wildfires, extreme storms and sea level rise, drought, and climate migration.

Table 1.1. Potential Climate Change Impacts on Electric Utility Assets

Climate Change Factor	Potential Impacts to Utility Assets
Extreme heat	Reduced equipment efficiency and a need to derate or update equipment
	Increased forced outage rates for thermal generators
	Need for modified or increased active cooling equipment
	Need to increase generation and the capacity of transmission and distribution assets to account for end-use load increases
	Worker safety issues and the need to change protocols to protect workers
Extreme cold	Need for increased vegetation management
	Need to weatherize electric system equipment and fuel supply chains
	Need to harden conductors to withstand increased ice loads
	Potential need to establish or support warming centers

Climate Change Factor	Potential Impacts to Utility Assets
Wildfires	Need for enhanced vegetation management
	Need to replace, modify, or underground equipment to prevent fires
	Need for enhanced equipment inspection and accelerated maintenance and repair programs to prevent utility equipment from causing wildfires
	Need for higher levels of situational awareness through equipment to measure weather and moisture conditions, and improved weather forecasting abilities
	Need for proactive power shutoffs and backup generators and battery storage systems for impacted communities
Extreme storms and sea level rise	Need for flood protection for low lying equipment or relocating assets out of floodplains
	Need to increase vegetation maintenance and harden infrastructure to protect it from wind and debris damage
Drought	Reduced water supply for hydropower or thermoelectric cooling
	Increased energy loads due to water pumping and irrigation
	Changes in other loads caused by drought impacts on agriculture and industry
	Increased probability of wildfire
Population migration	Locational shifts in energy demand and need to replace, rebuild, relocate and/or harden infrastructure to handle in-migration
	Loss of tax base and load due to out-migration

2.0 Forecasting with Climate Change

Traditional electric supply and demand forecasting approaches that are solely based on historical system characteristics (or modeled on temperature and weather norms) can no longer account for an increasingly uncertain future climate. Increasingly, utilities are recognizing that they need to plan for the **weather of the future, not just the conditions of the past.** Some utilities are taking different approaches to the challenge of projecting climate change consequences on the regional and local scales relevant to their service territories, with decision-making tools ranging from simple statistical analyses of recent climatic trends to more complex downscaling techniques of global climate simulations.

Two types of approaches for forecasting utility planning parameters are described in this section. The first is forecasting based on the recent past or trends in historical data and the second is downscaling global climate simulations. Other emerging approaches of decision-making under deep uncertainty and storyline approaches are described later in Section 7.0 of this report.

2.1 Forecasting Based on Recent Historical Data or Trends

Utilities have typically used historical data to forecast loads, generation availability, and weather- and water-based determinants of load, generation, and system performance. However, the unpredictability and uncertainty of climate change make this data a poor choice for the foundations of future investment planning. Alternatives to traditional approaches of using historical averages of peak weather events include the following:

1. **Weighting recent years (~ last 15 years) more heavily** in load and weather forecasts to account for recent changes due to climate change. Some utilities, such as Puget Sound Energy, explored forecasting options with customers that based future projections on data from the more recent past (i.e., the last 15 years), rather than the full 30 years typically used for forecasting demand (PSE 2021).
2. **Applying trends in the number and magnitude of heating-degree and cooling-degree days** to future year forecasts rather than using historical averages. This approach is being used by integrated resource plans by Vectren (Vectren 2020), Portland General Electric (PGE 2019), Entergy Mississippi (Entergy 2021), and Vermont Gas (Vermont Gas 2021).
3. **Evaluating modeling scenarios that reflect trends in the availability of generating resources, water availability, wind and solar variations, or temperature.** This option entails considering observed trends that impact generating resources and including climate change scenarios that address the continuance or expansion of those trends. An example of this approach is in the Tennessee Valley Authority (TVA) 2019 Integrated Resource Plan (IRP), which studied water temperature cooling capacity issues at thermal plants. TVA identified possible summer capacity derating of coal and nuclear facilities in response to hotter, drier summers, and ultimately outlined changes in the resource portfolio (more solar, earlier installation of combustion turbines) to compensate for the reduced capacity (TVA 2019).

2.2 Using Downscaled General Circulation Models

Downscaling of climate models is a technique that is used to translate large-scale general circulation models (GCMs) into more localized results. Downscaling allows scientists to understand how climate change will impact local and regional climates. Some utilities are starting to use adapted, or downscaled, results from GCMs as the basis for forecasts and risk assessments. GCMs are complex models of the Earth's climate that consider the main components (land, oceans, atmosphere, and sea ice) and their interactions. GCMs represent the Earth using a grid, as pictured in Figure 2.1. In GCMs, the spatial resolution of the grids is typically between 100 to 600 square kilometers. GCMs generate large numbers of variables averaged across hourly, daily, and monthly time periods. By modeling various representative concentration pathways (RCP) cases, climate scientists estimate the impact of efforts to curb greenhouse gas (GHG) emissions on climate. RCPs predict different climate futures based on emission trajectories and human behavior. The following are two common RCPs that are used in climate modeling:[3]

- RCP 4.5 – a scenario that assumes moderate efforts to curb emissions, thereby potentially avoiding some of the most dire consequences of climate change.
- RCP 8.5 – a scenario that assumes low efforts to curb emissions and high increases in negative climate change impacts. RCP 8.5 is often referred to as a high-risk or worst-case scenario RCP.[4]

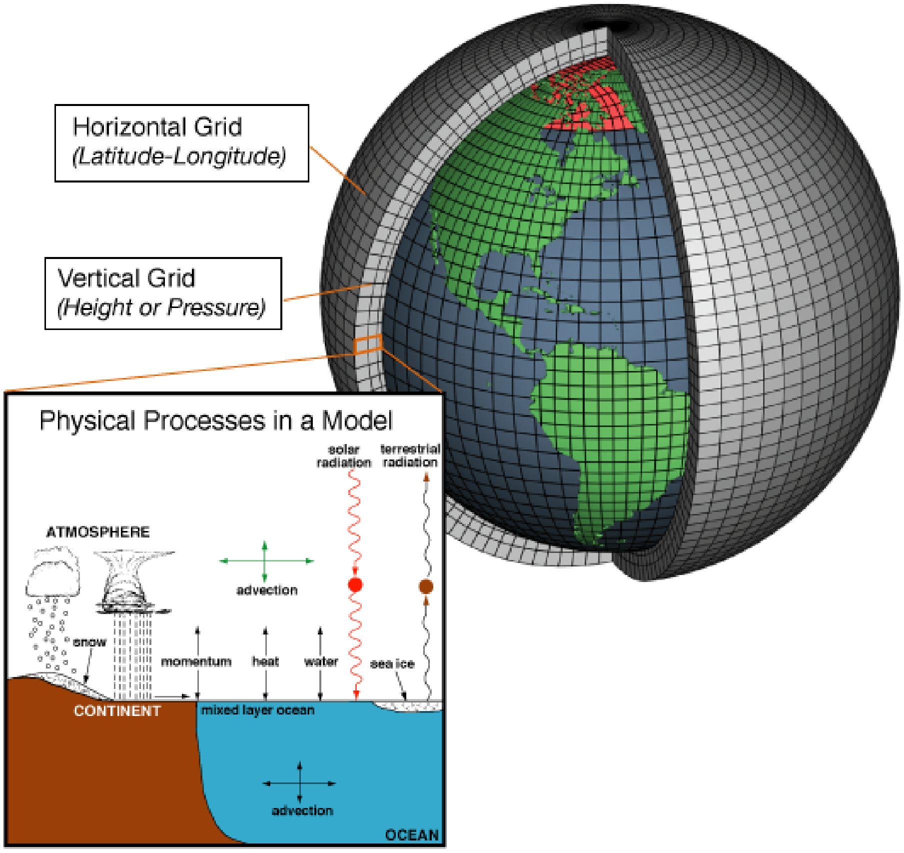

Figure 2.1. NOAA Representation of Global Climate Models (NOAA 2018)

Shared Socioeconomic Pathways, or SSPs are scenarios of different socioeconomic pathways and changes through the year 2100. SSPs are the basis of different greenhouse gas emissions

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[3] RCPs 4.5 and 8.5 refer to the concentrations of carbon that deliver global warming at an average of 4.5 and 8.5 watts per square meter, respectively, across the planet.

[4] It is also frequently referred to as a business-as-usual case although it is not intended as such.

scenarios used in global climate modeling activities, including those that are part of the Coupled Model Intercomparison Project (CMIP). CMIP is a global coordinated modeling initiative designed to better understand climate change from various sources. SSPs have replaced RCPs in the latest round of CMIP models used to consider different potential climate futures, but RCPs are still widely used.

To utilize GCM results, a utility with a service territory located in one (or more) state(s) must **downscale** the global models to their specific service territory and to the geographic areas that impact their service territory. Downscaling allows utilities or jurisdictions to translate broad GCM results down to more specific weather impacts at the scale of the utility territory.

There are two main types of downscaling techniques typically employed in GCMs: dynamical downscaling and statistical downscaling. **Dynamical downscaling** uses highly granular regional climate models, which, unlike GCMs, only cover a portion of the world (e.g., continental United States) and can subsequently be run with higher resolution, allowing for better simulation of regional processes and features. Dynamical downscaling results in physical consistency across variables (e.g., temperature, precipitation, humidity, wind speed). The downside of dynamical downscaling is that it is computationally expensive, making comprehensive regional studies difficult. **Statistical downscaling** uses different statistics-based mathematical relationships between the output from global climate simulations and observed local climate responses to project future conditions. Statistical downscaling is particularly effective at capturing local climate changes that are strongly tied to large-scale climatic shifts. Statistical downscaling is less computationally intensive and expensive than dynamical downscaling, but it is not as physically and scientifically rigorous and it does not produce results that are consistent across different climate change variables.

GCMs contain uncertainties in the simulation of various feedback mechanisms in models concerning water vapor and warming or ocean circulation and snow reflectivity. For example. GCMs are not only constrained by the complexity of the climate system itself, but also by the limitations of computing power. A report by the American Meteorological Society points out the limitations that currently exist in the ability of climate models to generate results sufficient for long-term utility planning (Tipton and Seitter 2022).

> *"Projections for how climate change will affect river basin runoff, wind and solar generating capacity in specific geographic regions, and weather extremes that impact generating infrastructure and distribution networks are still not sufficiently robust to allow confidence in long-term planning."*

Regardless of the limitations of GCMs, the use of downscaled GCMs is considered a best practice for electric utility climate resilience planning. However, downscaling GCMs can be time consuming and expensive. For this reason, utilities often team up with regional organizations and university partners to perform downscaling or otherwise apply GCM data to their service territory.

A good example of downscaled climate model data development and sharing is represented in the combination of the California Climate Change Assessments and the Cal-Adapt open-source web platform. The California Climate Change Assessments are funded by the California Energy Commission and the most recent released assessment is California's Fourth Climate Change Assessment, which is made of 44 technical reports and seven external contributions and is accessible at https://climateassessment.ca.gov/ (CA Climate Assessment 2023). The Fifth Assessment is expected around 2026 but preliminary data is now available on Cal-Adapt (Cal-

Adapt 2023). Cal-Adapt contains useful information from the assessments. Cal-Adapt was funded by the California Energy Commission and the California Strategic Growth Council. Cal-Adapt provides peer-reviewed data that shows how climate change may affect California at both the local and state level; this data is available to all.

More information on Cal-Adapt and downscaled data availability are contained in Section 6.2 of this report.

3.0 Resource Planning with Climate Variability

Electric utility resource planning processes address the question of whether there are enough supply- and demand-side resources to meet customer demand. In many states across the United States, IRP are used to develop a utility's long-term energy resource strategy. IRPs forecast energy demand and identify the resource mix that ensures reliable service to customers in the most cost-effective way, while accounting for traditional risks. In many cases, IRPs or similar processes present an opportunity to integrate climate variability in planning through the integration of forward-looking forecasts, including the use of downscaled global climate models, as described in Section 2.0.

While many utilities have taken strides to integrate climate change risk factors into resource planning processes, some lessons learned highlight the need to embrace proactive long-term climate planning. For example, a conventional objective in integrated resource planning is ensuring reliability through resource adequacy—the ability of supply-side and demand-side resources to meet the aggregate electrical demand. Determining resource adequacy is increasingly complex and challenging due to the following:

- **Increases in retirement of fossil fuel plants and greater deployment of renewable resources** as well as the accompanying uncertainty in the amount of generation available during peak demand periods
- **Changes to electric loads due to the electrification** of transportation and, to a lesser extent, buildings, and industrial processes
- **Changes to forced outage rates of thermal generators due to weather changes** and potential transmission circuit outages due to wildfire
- **Changes in timing and amount of water availability** for thermoelectric cooling and hydropower production
- **Changes in temperatures and increases in extreme weather events** leading to changes in demand profiles and potential use of demand-side resources
- Impacts of changing weather, extreme events, and resource mix on **interregional impacts to resource adequacy and market prices.**

Utility resource planning can be adapted to account for uncertainties and risks due to climate change, but planners should be cognizant of the fact that more uncertainties may exist than planning processes currently reflect. For example, IRPs generally consider some factors as certainties that may be uncertain, such as the existence of sufficient cooling water to operate thermal resources at levels they were designed to operate. The increasingly complex and changing energy landscape makes it vital for utilities to implement the following:

1. **Consider multiple scenarios**, including those outside traditional business-as-usual scenario analysis, to identify risks and opportunities for charting a sound resource investment approach with climate variability.
2. **Track climate science *and* extreme weather events** and trends and adapt planning criteria and operations accordingly.
3. **Coordinate strategies with other sector service providers** (i.e., water, fuel, telecommunications, transportation) including utilities and planners/operators in neighboring regions, and federal/state/local emergency planning organizations.

4. **Communicate with customers** about potential risks (e.g., public safety power shutoffs) and mitigations (e.g., demand response options to support resilience during heat waves).

3.1 Climate Change Impacts to Electricity Demand

Electricity demand is a function of many things—the primary among them is the presence of electric heating and cooling equipment and temperatures. With climate change, changing temperatures can lead to changes in loads and the availability and performance of demand-side resources. Rather than using historic averages to forecast future temperatures and loads, the methods described in Section 2.0 can be used for more forward-looking forecasts.

The importance of accurate temperature forecasts together with appropriate resource adequacy planning requirements is demonstrated in the *Final Root Cause Analysis Report* from the August 2020 California power outages (CAISO 2021). A climate-change-induced extreme heat storm across the western United States in August 2020 resulted in demand for electricity exceeding the existing electricity resource planning targets, forcing California Independent System Operator (CAISO) to order electric utilities in the state of California to initiate temporary rolling service cuts due to a shortage of electricity supplies. Figure 3.1 shows the CAISO daily average composite temperatures from 1985 and 2020, including the August 2020 peaks. A root cause analysis of the incident by CAISO determined that, among other factors, **existing resource planning processes do not adequately account for climate change impacts** (CAISO 2021).

In California, prior to this event, electricity demand forecasts used to develop resource adequacy requirements were based on average historical peak demand plus a 15% planning reserve margin. However, this forecasting approach was insufficient to account for the impact of the 2020 heat waves. **This suggests that utilities need to consider tightening the feedback loops between resource planning and climate change planning considerations to minimize the risk of supply shortages and associated outages.**

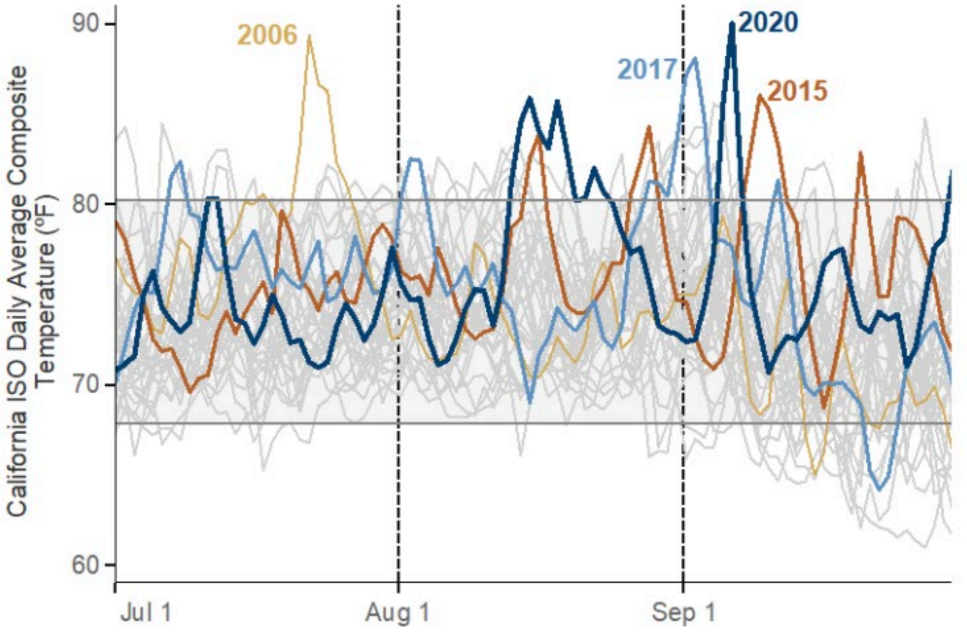

Figure 3.1. California July, August, and September Temperatures 1985-2020. Source: CAISO Final Root Cause Analysis – Mid-August 2020 Extreme Heat Wave (CAISO 2021).

3.2 Climate Change Impacts to Hydropower and Other Renewable Resources

Changes to water availability caused by climate change can affect thermal generation and hydropower production. Climate change can ultimately affect the timing, temperature, and volume of water available for thermoelectric and hydropower operations, which poses a threat to grid reliability and adequate power supply to end-users. Thermoelectric and hydropower facilities have already had documented challenges associated with water availability, including a shortage of cooling water, incoming cooling water that exceeds temperature thresholds for optimal operation, and water discharge temperatures exceeding permit limits (Cooke et al. 2021). S&P Global Market Intelligence reported that, for the year of 2030, nearly 100 GW of coal capacity will face water stress challenges that could exacerbate the frequency and duration of operational constraints (Kuykendall and Whieldon 2020).

An October 2021 report by Pacific Northwest National Laboratory (PNNL) (Cooke et al. 2021) reviewed thirty different IRPs from across the country to summarize best practices for analyzing and reporting on potential water-based and climate change risks within the integrated resource planning process. Figure 3.2 shows the IRPs reviewed.

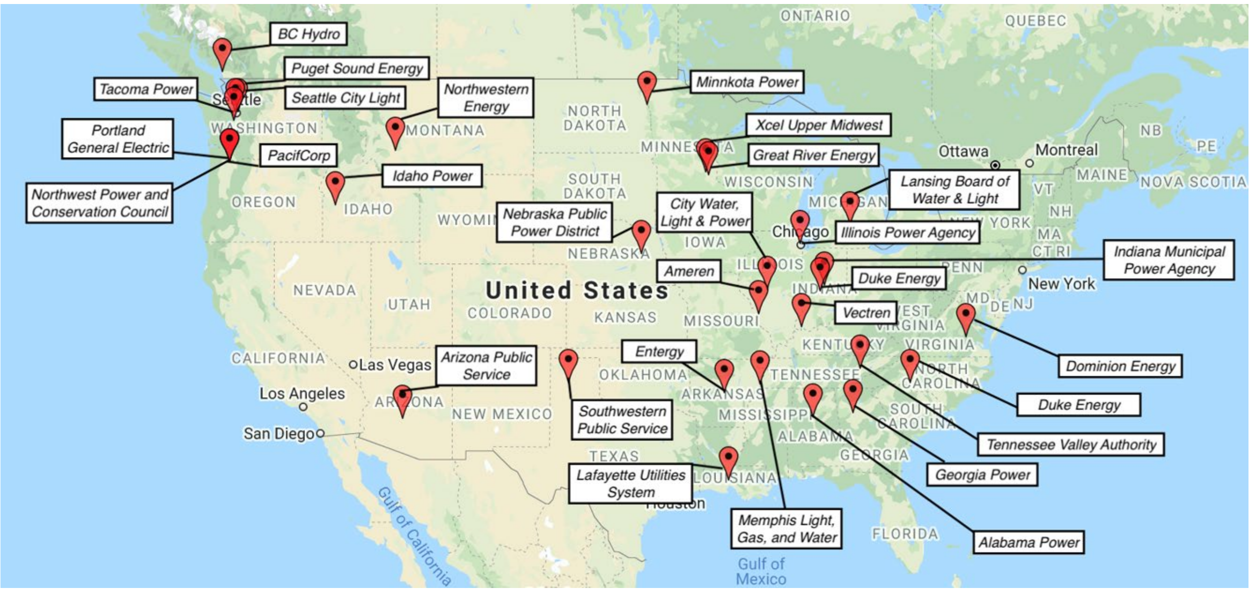

Figure 3.2. IRPs Reviewed in Cooke et al. (2021) for Water and Climate Change Analysis

Some best practices related to addressing water availability in resource planning include the following:

- Developing and presenting a resource plan that includes an examination of water availability for thermoelectric cooling and hydropower (e.g., APS 2020)
- Evaluating the impact of climate change on snowpack and timing and quantity of water available for hydropower production (e.g., NWPCC 2021, Tacoma Power 2020, SCL 2016, TVA 2019, BC Hydro 2012)
- Including water-constrained scenarios in the scenario analysis conducted for the IRP (e.g., SPS 2018, Tacoma Power 2020)
- Using water consumption as a metric for selecting future resources (e.g., APS 2020, TVA 2019, and MLGW 2020)
- Adjusting plant capacity values (and forced outage rates) to account for potential water temperature or supply constraints (e.g., Xcel 2019 and Vectren 2020)
- Considering potential impacts of water temperature on thermoelectric cooling and potential impacts to additional cooling capacity costs or potential deration of thermal plants (e.g., TVA 2019)
- Commissioning a consultant to study the potential impacts of water resource variations on electricity supply (e.g., AECOM 2018).

Climate change can also impact the availability of bioenergy, wind, and solar resources. Gernaat et al. (2021) showed that globally, climate change will notably change the availability of bioenergy, hydropower, and wind energy, while global impacts on solar power will be minor. A presentation by PNNL to the Western Electricity Coordination Council summarized the impacts of extreme heat and cold to wind and solar generation in the West based on an analysis of data from 1980 to 2019. Balancing areas in the Pacific Northwest show notable suppression of wind during extreme heat waves, whereas other balancing areas in the west experience more typical wind generation during heatwaves. During cold snaps, some balancing areas in the WECC see lower than normal wind, where others see increases in wind production. Peak solar production is largely the same before, during, and after heat waves in the West, but there's a slight tendency for lower peak solar production in days after heat waves in some balancing authorities. In general, solar generation tends to be lower before and after cold snaps in the west but solar production is high on the coldest days (Burleyson et al. 2022). To support reliability and resilience with increasing wind and solar resources, accurate modeling of wind and solar with climate change, including the correlations or anticorrelations of these resources, are needed. Resources are in development that will support such assessments, including the Wind Integration National Dataset (WIND) toolkit, but additional resources are needed (Tipton and Seitter 2022).

3.3 Climate Change Impacts to Forced Outage Rates

Climate change can also lead to an increase in forced outage rates for thermal generators. In the Southern California Edison (SCE) 2022 Climate Adaptation Vulnerability Assessment, the utility looked at extreme temperature exposure for all thermal resources located in SCE's service territory. Based on operating design thresholds for one of SCE's thermal generators, they identified 115°F as the threshold, above which generators would be at risk for increased unplanned forced outages. SCE forecasted a 600% increase in possible forced outages for all thermal resources in their service territory due to extreme heat by 2030; this risk grows to a 1,000% increase by 2050 (SCE 2022a). Figure 3.3 shows the thermal resource outage risk due to extreme heat, expressed as megawatt-days of risk and percent increase over baseline (SCE 2022a).

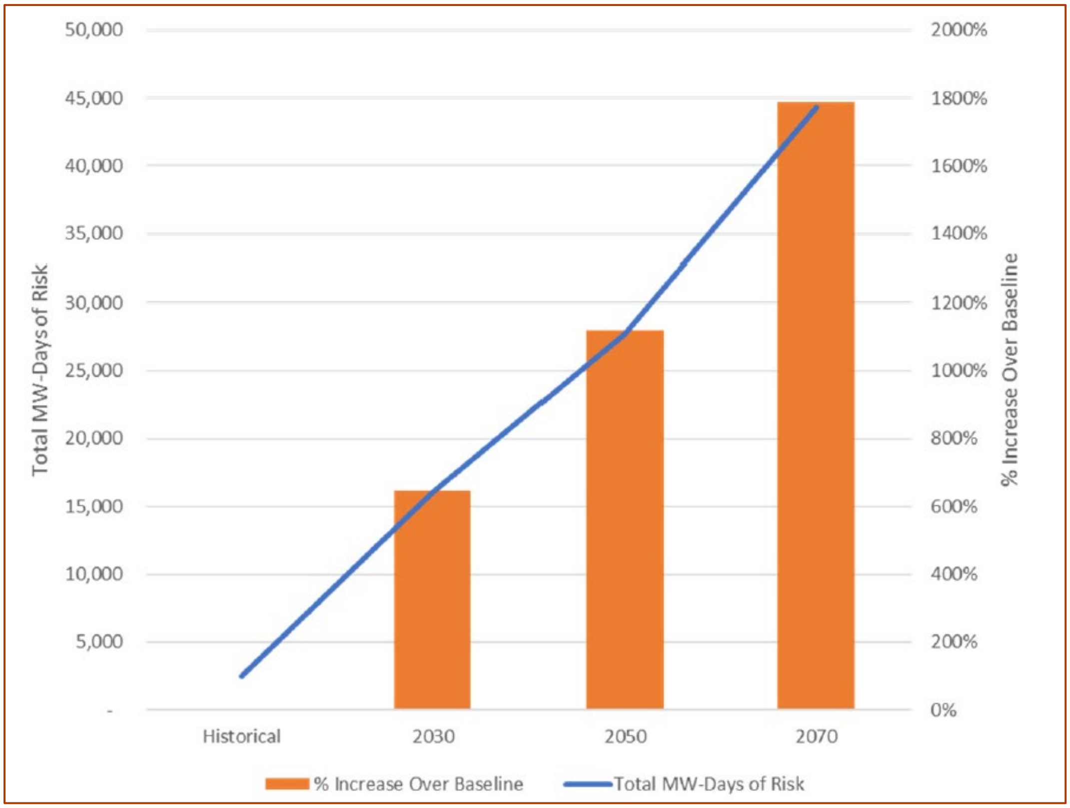

Figure 3.3. SCE Forecasted Increase in Thermal Resource Unplanned Outages Due to Extreme Heat (SCE 2022a)

3.4 Interregional Climate Change Impacts

Some states are undertaking intensive efforts to deal with climate change, through retiring fossil fuel generation, promoting distributed generation at battery storage, and electrifying transportation and other end uses. These changes in generation and loads can impact regional resource adequacy and wholesale market power prices.

A study conducted by PNNL, the National Renewable Energy Lab (NREL), and the University of Washington in 2020 evaluated the impact of climate change on water availability and its propagation through the western U.S. power grid, finding that changes in water availability in one region trigger a response in other regions and that regional dependencies are critical to evaluating climate change impacts. Voisin et al. (2020) point out that climate change impacts on water availability in the Northwest result in changes in power generation in other regions and overall regional power flows. Generation from the desert Southwest plays a critical role in compensating for variations in water availability and generation in other areas throughout the West. The importance of regional forces is noted, beyond a single utilities' generation footprint or service area, in shaping grid and market conditions under drought and climate change. These forces and conditions can impact resource adequacy and risk as well as a utility's preferred resource portfolio in resource planning scenario analysis. Therefore, utilities should consider potential interregional impacts in resource planning, including changes to market conditions and power availability.

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The combination of changes in the timing of the water flows and hydropower generation, changes to forced outage rates due to extreme heat, increases in extreme and high and low temperatures in some areas and associated cooling and heating loads, emerging electrification loads, and interregional impacts to resource adequacy and wholesale power market point to the potential for non-trivial resource gaps and/or cost exposure that can be mitigated through robust resource planning.

4.0 Asset Planning

Asset planning is the process by which utilities manage supply infrastructure and the physical delivery system. Elements of traditional asset planning include tracking age, usage, performance, maintenance history, and other variables. Considering climate change, asset planning can be enhanced through adjusting temperature ranges for equipment design standards, relocating equipment out of flood areas, and undergrounding or adapting equipment due to fire risks. Asset planning is an important part of planning for climate variability to ensure existing and future assets can function as needed during future conditions.

A 2016 U.S. Department of Energy report titled "Climate Change and the Electricity Sector: Guide for Climate Change and Resilience Planning" identified the electric system assets listed in Table 4.1 as potentially vulnerable to climate change. Table 4.2 summarizes different types of asset planning actions and investments that can be used to address climate change.

Table 4.1. Types of Potentially Vulnerable Electric System Assets (Adapted from DOE 2016)

Electric Power Sector Category	Asset Types
Generation	• Generator units • Generator cooling water intake systems • Water filtration and handling equipment • Substations • Backup power supply sources • Fuel handling and storage systems • Distributed energy resources (DERs)
Transmission	• Transmission wires and towers • Station control buildings • Substation assets: - Circuit breakers - Grounding structure - Transformers and cooling system - Bus bars - Underground cables - Protection/control equipment
Distribution	• Transformers • Feeder circuits • Switches • Primary circuits • Electric poles
General	• HQ and operations centers • Fleet storage and service centers • Roads, access routes

Table 4.2. Asset Planning Actions and Investments for Climate Change (Adapted from Kallay et al. 2021a)

		Investments	Description
Asset Planning Actions and Investments	**Traditional**	Undergrounding and relocation	Undergrounding and relocating assets (such as out of flood zones or to avoid sea level rise) to prevent jeopardizing critical equipment.
		Grid hardening and updating equipment	Upgrading or replacing critical equipment, such as poles, conductors, transformers, and substation equipment to higher design standards such as broader temperature ratings.
		Physical security	Fencing, locks, enclosures, platforms, building extensions, monitoring systems, and alarms to protect transmission and distribution system assets.
		Replacement parts and mutual aid agreements	Local store of replacement parts that are in high demand and/or difficult to procure on short notice; mutual aid agreements where utilities agree to help each other with personnel, equipment and materials in times of need.
		Cyber protection system controls and communications networks	Communications between control centers, system security management and controls, electronic security perimeters, configuration change management, and information protection. Communication networks and data management systems.
		Transmission and distribution grid automation and controls	Geographic information systems (GIS), distribution system supervisory control and data acquisition (DSCADA), fault location, isolation and service restoration systems (FLISR), volt-var optimization (VVO), voltage stabilization (e.g., SVC STATCOM), outage management system, and network monitoring devices.
		Meters and metering controls	Customer electric meters that provide outage and restoration notification and/or on-demand data.
		Emergency trainings	Trainings to promote effective response to emergency situations and hazard conditions, including drills and emergency preparedness education.
		Damage assessment and outage management system	Platforms to monitor and respond to outages caused by severe weather conditions and emergency incidents, as well as perform damage assessments.
		Vegetation management	Control the growth of vegetation around utility infrastructure through trimming, removal and replacement.
	Nontraditional	Renewable energy plus energy storage	Renewable energy paired with storage that provide a secondary or alternate source of power during a resilience event.
		Microgrids and DERs	A group of interconnected electricity generators and users operating as part of the larger grid normally, but able to operate in islanded mode during resilience events. DERs include distributed generation, and distributed storage that serve the critical load.
		Energy efficiency and DSM	Includes energy efficiency and demand response mechanisms to reduce utility resources required to restore load immediately after a resilience event.
		Grid modernization	Includes advanced distribution management systems, advanced meter infrastructure, synchrophasors, and distributed energy resource management systems.
		Environmental solutions	Practices that enhance the natural environment's ability to withstand extreme weather events and buffer utility assets.
		Supplemental heating and hot water systems	Electric, solar, or biomass fueled supplemental water and heating systems that provide a secondary or alternate source of water and/or space heating during a resilience event.

A systematic approach that some utilities are using, as part of comprehensive vulnerability assessments (described more in Section 5.0), includes evaluating the following:

1. The **exposure** of critical assets or operations to an adverse climate event
2. The **probability of damage** to assets or disruption to operations as a result of exposure to those climate threats (risks posed by threat)
3. The **likely consequences** if the event were to occur (severity of impacts)
4. **Mitigation measures** that can reduce the risk to vulnerable assets and take into consideration impacts to disadvantaged communities.

4.1 Updating Design Standards, Specifications, and Ratings

Per Con Edison's 2019 Climate Change Vulnerability Assessment (Con Edison 2019), addressing and updating design standards, specifications, and ratings are important parts of asset planning under climate variability.

Many utility assets are predicated on specific temperature maximums and minimums as well as load ranges. Many design requirements come from standards, which typically vary based on region. Ambient temperatures above or below the specified maximum or minimum can lead to equipment derating, damage, and failure. Existing equipment, including transformers and conductors, may not be designed for the temperatures being experienced. This can have reliability implications to the utility, as extremely high and low temperatures can correspond to times with higher-than-normal loads.

In other cases, due to changes to precipitation patterns and floodplain designations, pieces of equipment may now be in a flood plain when they previously were not due to changes to floodplain designations. In these cases, equipment may need to be relocated out of flood zones or redesigned to withstand submersion.

In asset planning with climate variability, **layers of utility assumptions need to be reevaluated.** Utilities have traditionally used internal guidelines, rules of thumb, and industry standards. Utility assumptions and industry standards may need to be reconsidered. Utilities can assess and potentially adjust their assumptions and can work with equipment vendors to adapt equipment ratings and specifications. **Regulators can encourage or require utilities to revisit assumptions and internal design standards and ask for regular updates.**

4.2 Examples of Asset Planning for Climate Variability

This section provides specific examples of utility asset planning for climate variability.

4.2.1 Con Edison after Superstorm Sandy

After Superstorm Sandy in 2012, Con Edison spent $1 billion and four years to elevate adjustable relay panels and control houses, ensure new equipment in flood zones could perform if submerged, strengthen overhead lines, and add islanding capabilities to the grid in order to reduce the number of customers affected by damage to one grid section (Brody, Rogers, and Siccardo 2019).

4.2.2 Florida Power & Light after Hurricane Wilma

In response to Hurricane Wilma in 2005, Florida Power & Light spent more than $5 billion on flood protection, distribution feeder reinforcement, and replacing wood poles with steel or concrete structures, among other grid hardening initiatives (NextEra Energy nd).

4.2.3 California Energy Commission Study for Los Angeles County

A report titled *Climate Change in Los Angeles County: Grid Vulnerability to Extreme Heat*, paid for by the California Energy Commission, described actions SCE and Los Angeles County took to address their vulnerability to extreme heat. As part of the study, they identified future climate trends via downscaled climate data, with a focus on future heat events. They also estimated future loads. They identified the capacity ratings of electrical assets in Los Angeles County, including the temperatures that equipment is rated for. They then identified the impacts on capacity if temperature ratings are exceeded. They found that peak hour demand was projected to increase between 0.2 and 6.5 gigawatt hours (GWh) by 2060 depending on population growth scenarios, building efficiency, specific location, and warming case, among other factors. They determined that all grid components were expected to lose 2–20% of capacity by 2060 with future heat events (Burillo et al. 2018).

4.3 Non-Wires Alternatives as Part of Asset Planning for Climate Change

Some utilities are exploring nontraditional, non-wires investments, such as decentralized generation, as part of asset planning for climate change. Decentralized solutions and distributed energy resources can reduce vulnerability and reliance on long transmission lines that are vulnerable to storm damage. Non-wires solutions include battery storage systems, which can mitigate outages caused by extreme weather events; microgrids or resilience hubs that can function apart from the centralized grid (and thus reduce the number of customers affected); and enhanced environmental management, which can provide protection against extreme weather. Many utilities have already begun pursuing such non-wires options as climate change mitigation and adaptation strategies. Some examples are listed below:

- **Duke Energy** announced plans in 2017 to invest $30 million to install what was at the time North Carolina’s two largest battery-energy storage systems to provide backup power and improve grid reliability (Gupta 2017).
- **Entergy and other Gulf Coast companies** have started pilot programs exploring the efficacy of environmental management, namely restoration of coastal wetlands in Louisiana, to provide storm protection.
- **California** has implemented a program to provide no-cost battery storage systems to vulnerable, low-income households located in high fire-threat districts and public safety power shutoff zones (CPUC 2022).
- **The Minnesota Public Utilities Commission** approved an **Xcel Energy** proposal for the development of resilience hubs (with solar, storage, controls, and hardened distribution system infrastructure) in partnership with racially diverse communities in Minneapolis as part of the Resilient Minneapolis Project (Xcel Energy 2021).

5.0 Contingency Planning with Climate Variability

This report observes two general approaches for contingency planning related to climate change. The first contingency planning approach described here is planning in response to specific environmental changes and the risks associated with utility system operations (i.e., wildfire mitigation plans or storm protection plans). The second is a comprehensive approach, in which utilities conduct complete climate vulnerability assessments and resilience plans to mitigate climate impacts.

5.1 Risk-Specific Plans

Planning for climate change in some jurisdictions has taken the form of responding to specific risks, such as wildfires and hurricanes, made worse by climate variability. Plans developed in response to specific risks may not look at climate change impacts holistically in terms of different types of threats or cascading impacts. They also may not consider the way that observed and known risks may evolve or substantively change due to previously unseen climate change effects that are not apparent if the models being used are based on history. Examples of two types of risk-specific plans, wildfire mitigation plans and storm protection plans, are described in this paper below.

5.1.1 Wildfire Mitigation Plans

Wildfire mitigation planning has grown in prevalence over the past five years among utilities in Washington, Oregon, and California along with system operators like the Bonneville Power Administration.[5] These plans are focused on responding to risks created by the electric power system in certain conditions and are an attempt to reduce the risk of transmission or distribution infrastructure igniting wildfires. The development of these plans has focused on two areas. The first focuses on identifying the risks by completing system vulnerability assessments in response to conditions. The second is detailing a mitigation strategy to reduce the risks identified in the assessment. In some instances, these plans include strategies to de-energize powerlines in identified conditions to reduce the risk of a utility-caused ignition. This strategy is sometimes called a public safety power shutoff (PSPS).

In California, the guidelines for wildfire mitigation plans come from the California Office of Energy Infrastructure Safety Wildfire, which is a new state office that was established in July 2021. Before July 2021, the role was carried out by the CPUC Wildfire Safety Division. Plans are scoped to narrowly assess wildfire risks and to meet specific requirements placed on the utilities by state agencies. An example of these requirements is contained in the California

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[5] California and Oregon require utilities to file wildfire mitigation plans. Washington has a utilities and transportation commission (WUTC) proceeding underway and has required utilities to file wildfire preparedness plans into docket U-210254, most recently by a notice issued October 5, 2022, and requiring submittal by October 25, 2022. The Washington regulatory commission has not issued a set of requirements as detailed as the California requirements. Nevada requires utilities to submit Natural Disaster Protection Plans. Utah requires utilities to submit Wildlands Fire Protection Plans. As of this writing, the authors are unaware of other states that require submission of plans but note that plans have been submitted to regulatory agencies as evidence of need for cost recovery in Idaho and Colorado. Additionally, there have been articles in newspapers and trade press (see T&D World, Aug. 8, 2022, for example) about litigation filed against PNM Resources in New Mexico alleging that the utility's "poorly maintained electric wires" ignited fires in that state, so it is realistic to believe other western states will follow suit and require wildfire mitigation plans or something very similar.

Office of Energy Infrastructure Safety (OEIS) Final 2022 Wildfire Mitigation Plan Update Guidelines (California OEIS 2021).

California utilities' wildfire mitigation plans address ten categories of potential mitigations, including the following (SCE 2022b):

- Grid design and system hardening
- Asset management and inspections
- Vegetation management and inspections
- Situational awareness and weather forecasting
- Grid operations and protocols
- Emergency planning and preparedness (workforce preparedness)
- Stakeholder cooperation and community engagement
- Risk assessment and mapping
- Resource allocation methodology
- Data governance.

Examples of specific actions utilities identify and track in wildfire mitigation plans, include the following (SCE 2022b):

- Covering conductors
- Undergrounding
- High fire risk inspections and remediations
- Vegetation management
- Public safety power shut offs
- Weather stations
- High-definition cameras
- Sectionalizing devices
- Fast acting fuses
- Backup resiliency programs (e.g., batteries to customers with medical needs).

PG&E plans to bury 10,000 miles of power lines to reduce the risk of fires in areas subject to drought and high winds at a cost of between $15 and $30 billion (Associated Press 2021).

In SCE's 2022 wildfire mitigation plan, most SCE analyses are based on historical weather data. Some of the key and required elements of the wildfire mitigation plans include analyses of ways in which climate change is altering the risks of wildfire ignition. Additionally, one of SCE's near-term and long-term risk assessment and mapping goals is to incorporate weather to account for forward-looking climate scenarios (SCE 2022b). Other wildfire mitigation plans submitted by Pacific Gas & Electric (PG&E 2022), San Diego Gas & Electric (SDGE 2022), and PacifiCorp (PacifiCorp 2022) include analyses of the climate-change-driven risks of ignition, and PG&E includes a research proposal to investigate the increased use of downscaled climate data.

5.1.2 Storm Protection Plans

Storm protection plans are another example of a planning process intended to mitigate significant environmental risks. Storm protection plans differ from wildfire mitigation plans in that rather than trying to mitigate the utility system being the cause of widespread damage, they respond to environmental conditions that could cause a long-term outage or widespread damage to the system.

In Florida, for instance, utilities develop and implement storm protection plans (SPPs) to enhance the ability of the electric grid to withstand and recover from tropical storms and hurricanes. The Florida Public Service Commission (FPSC) requirements date back to 2006 when the FPSC ordered SPPs, including inspections of wooden poles every eight years to ensure weakened poles were replaced, plus ten preparedness specifications (FPSC 2018):

1. Three-year vegetation management cycles for all distribution circuits
2. Audit of joint pole use agreements
3. Six-year inspection program for transmission structures
4. Hardening existing transmission structures
5. Development of a Geographic Information System covering transmission and distribution systems
6. Collection of post-storm data and forensic analyses to determine how the systems fared in the storms
7. Collection of outage data distinguishing between overhead and underground systems
8. Increased coordination with local governments
9. Collaborative research on effects of hurricane winds and storm surge
10. Development of natural disaster preparedness and recovery program plans.

Reviewing the Florida Power & Light (FPL) SPP from 2020, the plan includes a number of ongoing projects as well as one new project. FPL included the following:

- Distribution pole inspections
- Transmission systems inspections
- Feeder hardening to meet National Electric Safety Code (NESC) extreme wind loading criteria
- Lateral hardening (undergrounding) targeting laterals that were impacted by recent storms and have histories of vegetation related outages and other reliability issues
- Completion of replacement of wood transmission structures with steel or concrete structures
- Substation storm surge/flood protection (new) to protect transmission and distribution substations prone to flooding either from storm surge or extreme weather events
- Vegetation management with distribution systems on a three-year cycle and transmission vegetation management to conform with North American Electric Reliability Corporation (NERC) standards.

The high-level components of the FPL SPP include significant levels of details, including expected costs and benefits, start and completion dates, criteria used to select and prioritize programs, and FPL's expectations with respect to the possible number of system components that will need to be replaced as a result of inspections, miles of lines to be undergrounded, and number of substations that are considered flood-prone (FPL 2020). The state's other investor-owned utilities, as well as some of the larger consumer-owned utilities, prepare SPPs. The coverage of individual components varies depending on the specific utility's situation, but overall, the SPPs are similar. Some SPPs include detailed modeling and technical analyses of wind events, storm surge, and flood events based on historical weather data. As structured currently in Florida, these plans do not require integrating climate change variability. For example, the Tampa Electric Company indicated the World Meteorological Organization commented evidence was inconclusive as to whether climate change will increase the frequency of major storms, so they used historical data for storm probability and declined to include data beyond historical averages (TEC 2022).

Plans that respond to specific risks are growing in prevalence because they allow utilities and system operators to examine how specific parts of the system might respond in defined conditions, such as high winds. They are limited because they examine a defined risk condition, (i.e., where the system is most vulnerable to downed power lines or other ignition threats during high wind, low humidity days). They require utility staff to examine existing practices, such as vegetation management, and create new operating procedures for those practices in response to the specific risk.

5.2 Comprehensive Climate Vulnerability Assessments

In 2016, the U.S. Department of Energy developed comprehensive guidelines for climate resilience planning. DOE's guidelines detail an eight-step process (Figure 5.1)for conducting a climate vulnerability assessment and resilience plan, starting with scoping the plan and ending with monitoring, evaluating, and reassessing (DOE 2016). Many utility plans follow a similar process to the DOE guidelines. Examples from utilities in Washington State, New York, and California are provided below.

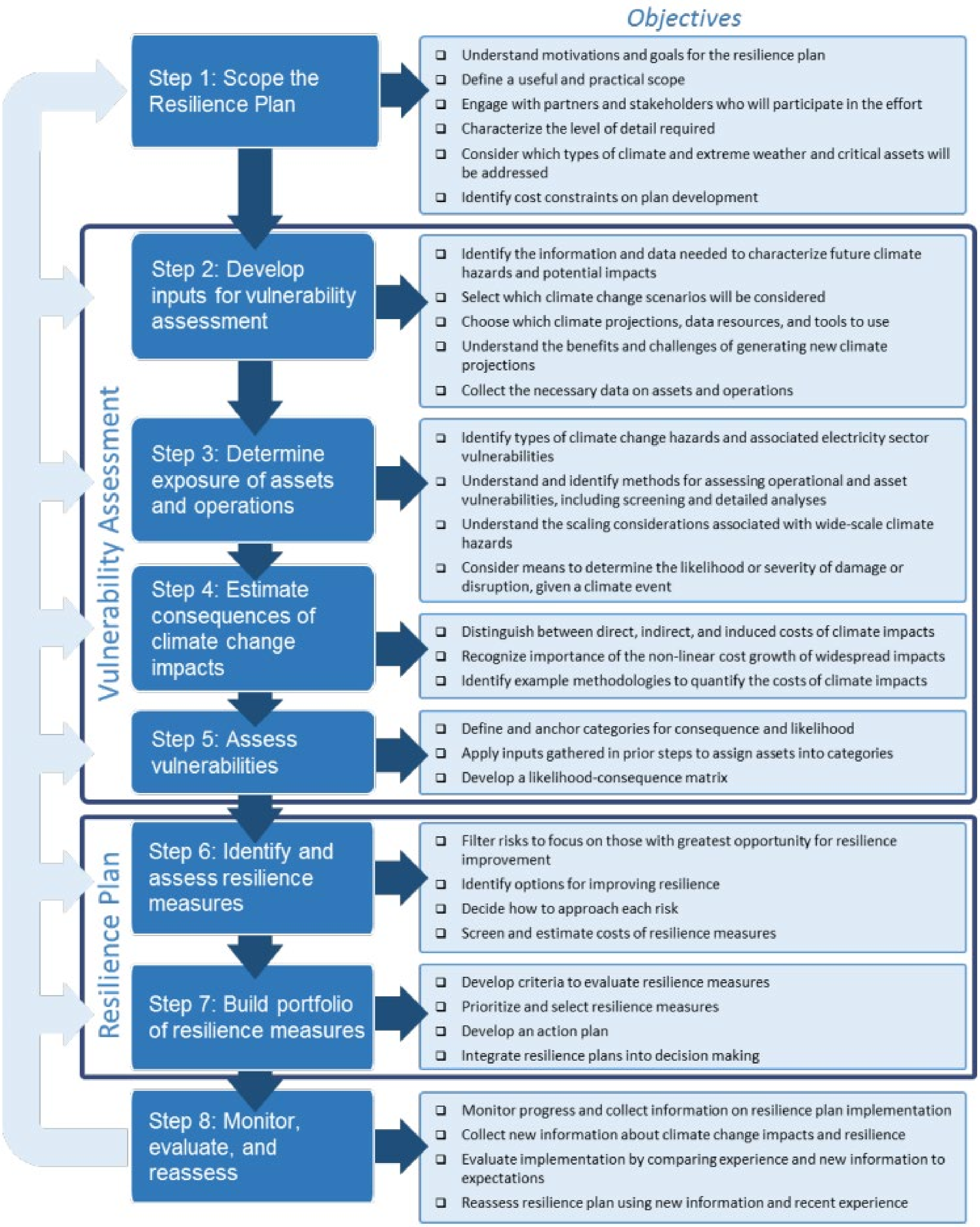


Figure 5.1. DOE Approach for Conducting a Vulnerability Assessment and Developing a Resilience Plan (DOE 2016)

5.2.1 Seattle City Light

Seattle City Light (SCL) completed its Climate Change Vulnerability Assessment and Adaptation Plan in 2015. The objectives of the plan were to 1) research the impacts of climate change on SCL, and 2) develop a plan with strategic actions to minimize the impacts (SCL 2015). The plan evaluates the impacts of eight different aspects of climate change on five aspects of utility operations and infrastructure to come up with thirteen impact pathways through which the utility could experience risks to its mission (Figure 5.2).

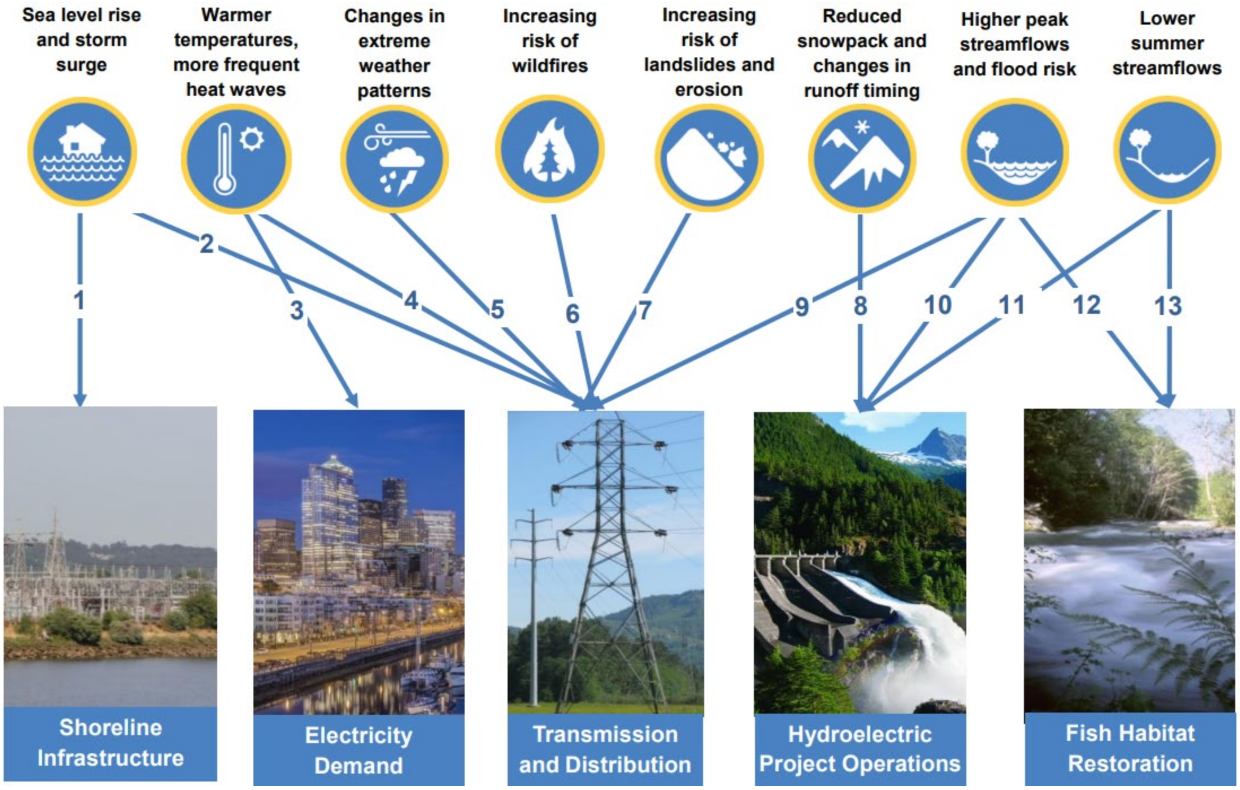
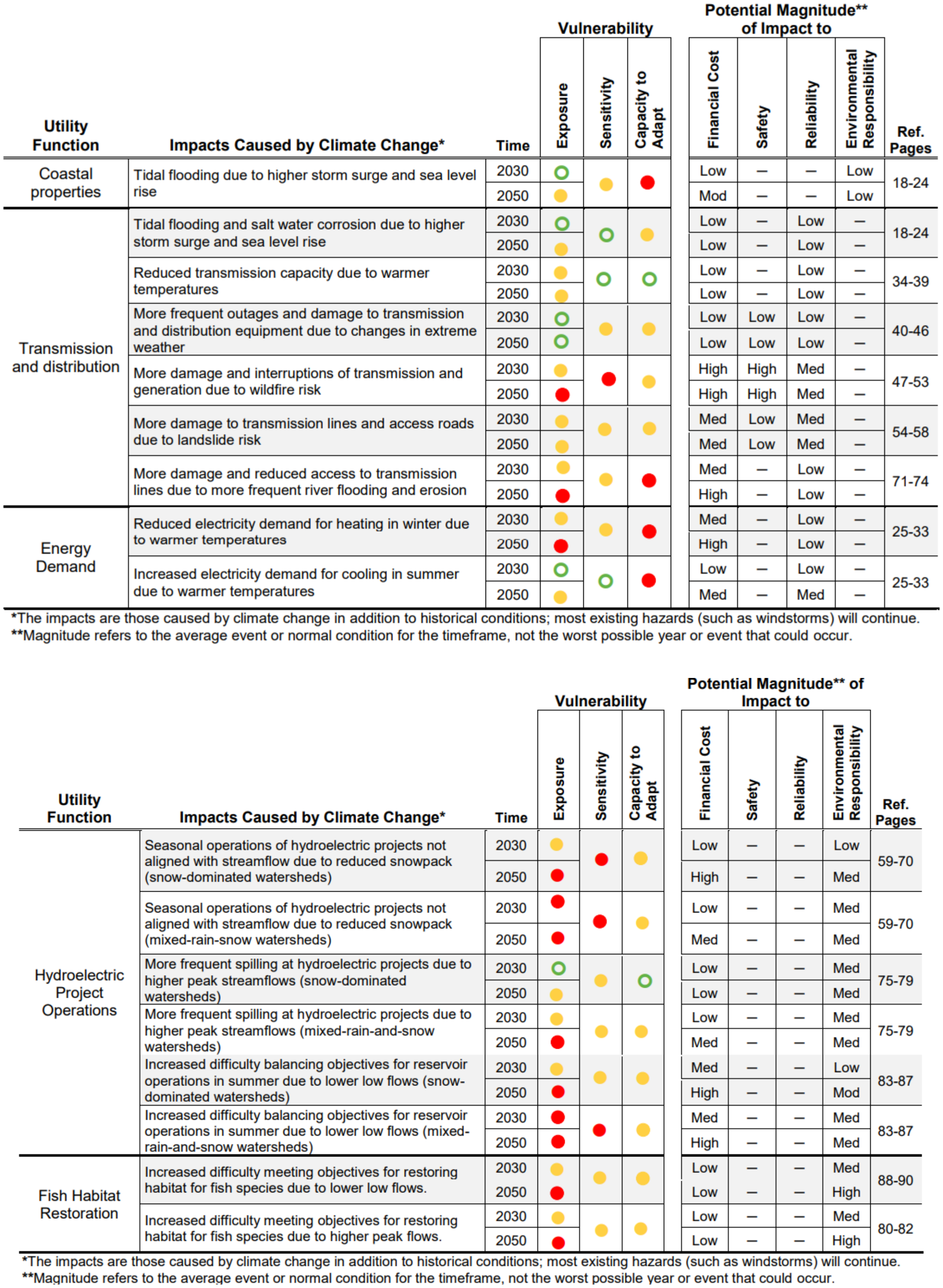


Figure 5.2. Seattle City Light Climate Change Impact Pathways with the Potential to Impact Utility Operations

For each of the thirteen impact pathways, SCL describes the following:

1. Exposure to expected changes in the climate
2. Inherent system sensitivity to the changes
3. Existing policies and operations that increase the utility's capacity to adapt to a changing climate.

The results of the vulnerability assessment are illustrated in a summary table (Figure 5.3). In the exposure column, red and yellow circles represent impacts with higher exposure. As exposure can increase as climate change intensifies over time, exposure is shown both for the near future (2030s) and far future (2050s). For sensitivity and capacity to adapt, red and yellow circles show impacts where SCL can reduce sensitivity or enhance the organization's capacity to prepare for impacts. As per SCL, "the goal of implementing adaptation actions is to shift sensitivity and adaptive capacity from yellow or red to green" (SCL 2015).



Utility Function	Impacts Caused by Climate Change*	Time	Vulnerability: Exposure	Vulnerability: Sensitivity	Vulnerability: Capacity to Adapt	Potential Magnitude** of Impact to: Financial Cost	Safety	Reliability	Environmental Responsibility	Ref. Pages
Coastal properties	Tidal flooding due to higher storm surge and sea level rise	2030	○	🟡	🔴	Low	–	–	Low	18-24
		2050	🟡			Mod	–	–	Low	
Transmission and distribution	Tidal flooding and salt water corrosion due to higher storm surge and sea level rise	2030	○	○	🟡	Low	–	Low	–	18-24
		2050	🟡			Low	–	Low	–	
	Reduced transmission capacity due to warmer temperatures	2030	🟡	○	○	Low	–	Low	–	34-39
		2050	🟡			Low	–	Low	–	
	More frequent outages and damage to transmission and distribution equipment due to changes in extreme weather	2030	○	🟡	🟡	Low	Low	Low	–	40-46
		2050	○			Low	Low	Low	–	
	More damage and interruptions of transmission and generation due to wildfire risk	2030	🟡	🔴	🟡	High	High	Med	–	47-53
		2050	🔴			High	High	Med	–	
	More damage to transmission lines and access roads due to landslide risk	2030	🟡	🟡	🟡	Med	Low	Med	–	54-58
		2050	🟡			Med	Low	Med	–	
	More damage and reduced access to transmission lines due to more frequent river flooding and erosion	2030	🟡	🟡	🔴	Med	–	Low	–	71-74
		2050	🔴			High	–	Low	–	
Energy Demand	Reduced electricity demand for heating in winter due to warmer temperatures	2030	🟡	🟡	🔴	Med	–	Low	–	25-33
		2050	🔴			High	–	Low	–	
	Increased electricity demand for cooling in summer due to warmer temperatures	2030	○	○	🔴	Low	–	Low	–	25-33
		2050	🟡			Med	–	Med	–	

*The impacts are those caused by climate change in addition to historical conditions; most existing hazards (such as windstorms) will continue.
**Magnitude refers to the average event or normal condition for the timeframe, not the worst possible year or event that could occur.

Utility Function	Impacts Caused by Climate Change*	Time	Vulnerability: Exposure	Vulnerability: Sensitivity	Vulnerability: Capacity to Adapt	Potential Magnitude** of Impact to: Financial Cost	Safety	Reliability	Environmental Responsibility	Ref. Pages
Hydroelectric Project Operations	Seasonal operations of hydroelectric projects not aligned with streamflow due to reduced snowpack (snow-dominated watersheds)	2030	🟡	🔴	🟡	Low	–	–	Low	59-70
		2050	🔴			High	–	–	Med	
	Seasonal operations of hydroelectric projects not aligned with streamflow due to reduced snowpack (mixed-rain-snow watersheds)	2030	🔴	🔴	🟡	Low	–	–	Med	59-70
		2050	🔴			Med	–	–	Med	
	More frequent spilling at hydroelectric projects due to higher peak streamflows (snow-dominated watersheds)	2030	○	🟡	○	Low	–	–	Med	75-79
		2050	🟡			Low	–	–	Med	
	More frequent spilling at hydroelectric projects due to higher peak streamflows (mixed-rain-and-snow watersheds)	2030	🟡	🟡	🟡	Low	–	–	Med	75-79
		2050	🔴			Med	–	–	Med	
	Increased difficulty balancing objectives for reservoir operations in summer due to lower low flows (snow-dominated watersheds)	2030	🟡	🟡	🟡	Med	–	–	Low	83-87
		2050	🔴			High	–	–	Mod	
	Increased difficulty balancing objectives for reservoir operations in summer due to lower low flows (mixed-rain-and-snow watersheds)	2030	🔴	🔴	🟡	Med	–	–	Med	83-87
		2050	🔴			High	–	–	Med	
Fish Habitat Restoration	Increased difficulty meeting objectives for restoring habitat for fish species due to lower low flows.	2030	🟡	🟡	🟡	Low	–	–	Med	88-90
		2050	🔴			Low	–	–	High	
	Increased difficulty meeting objectives for restoring habitat for fish species due to higher peak flows.	2030	🟡	🟡	🟡	Low	–	–	Med	80-82
		2050	🔴			Low	–	–	High	

*The impacts are those caused by climate change in addition to historical conditions; most existing hazards (such as windstorms) will continue.
**Magnitude refers to the average event or normal condition for the timeframe, not the worst possible year or event that could occur.

Figure 5.3. Summary Table of Seattle City Light Vulnerability Assessment (SCL 2015)

SCL also identified 17 specific potential adaptation actions, organized by utility function, to address the 13 impact pathways identified in Figure 5.2. These adaptation actions are summarized in Table 5.1.

Table 5.1. Seattle City Light – Potential Adaptation Actions Categorized by Utility Function (SCL 2015)

	Potential Adaptation Actions
Shoreline Infrastructure	Make **sea level rise and storm surge spatial information** available to all divisions of the utility.
	Consider a utility policy to identify future impacts of tidal flooding to potentially impacted **capital improvements**.
Electricity Demand	**Expand analysis** of the relationship between warming temperatures, season base and peak load, and air conditioner use.
	Identify **co-benefits of energy efficiency** to reduce electricity demand for summer cooling.
	Address potential for **demand response** to reduce peak commercial loads for areas with constrained distribution systems.
Transmission and distribution	Monitor and consider replacing **equipment sensitive to corrosion** from salt water in areas subject to tidal flooding.
	Monitor failures and **damage to underground cables** due to drier soils and consider alternative fill materials.
	Expand the use of **Outage Management Systems (OMS)** to quantify trends in extreme weather on outages.
	Increase the **capacity of employees** to prepare for and respond to increasing wildfire risk.
	Collaborate with adjacent landowners to **reduce flammable vegetation** and wildfire hazards along transmission lines.
	Work with state agencies and academic institutions to **map landslide risk** along transmission lines.
	Where needed, **upgrade transmission infrastructur**e to be resilient to higher peak flows and flood hazards.
Hydroelectric operations	Update and expand **analyses on how to adjust operations** to account for reduced snowpack and changing seasonal flows.
	Collaborate with other city utilities on modified dam operations.
	Consider **diversifying power resources** by increasing non-hydro renewable energy sources with complementary generation profiles.
Fish Habitat Restoration	Consider changed water flows in prioritizing acquisitions of **habitat mitigation lands.**
	Focus objectives and **design of restoration projects** on ameliorating impacts of changed stream flows and temperatures.

5.2.2 Con Edison and New York's Approach

New York's Public Service Commission (NYPSC) required Con Edison to develop a plan in response to the significant damage to Con Edison facilities caused by Superstorm Sandy in 2012. In a 2013 rate case filing, Con Edison proposed significant costs be included for future storm hardening investments to better protect the system against future storms. NYPSC staff proposed that Con Edison convene a stakeholder collaborative to come to agreement on treatment of the flood maps and subsequently on other climate-related risks (NYPSC staff, 2013). In the 2014 NYPSC order accepting a Joint Proposal to settle the rate proceeding, NYPSC accepted numerous proposals coming out of the collaborative, one of which was a proposal that Con Edison perform a comprehensive climate vulnerability study (NYPSC 2014).

The resulting Con Edison plan is often referred to as the “gold standard” for such plans (Webb 2020).

Con Edison filed their Climate Change Vulnerability Assessment in 2019. Con Edison’s Climate Change Vulnerability Study methodology is shown in Figure 5.4. At the center of Con Edison’s Vulnerability Assessment Methodology are climate science and engaging with subject matter experts to best identify risks and potential mitigations. Bothclimate science and subject matter expert engagement are critically important.

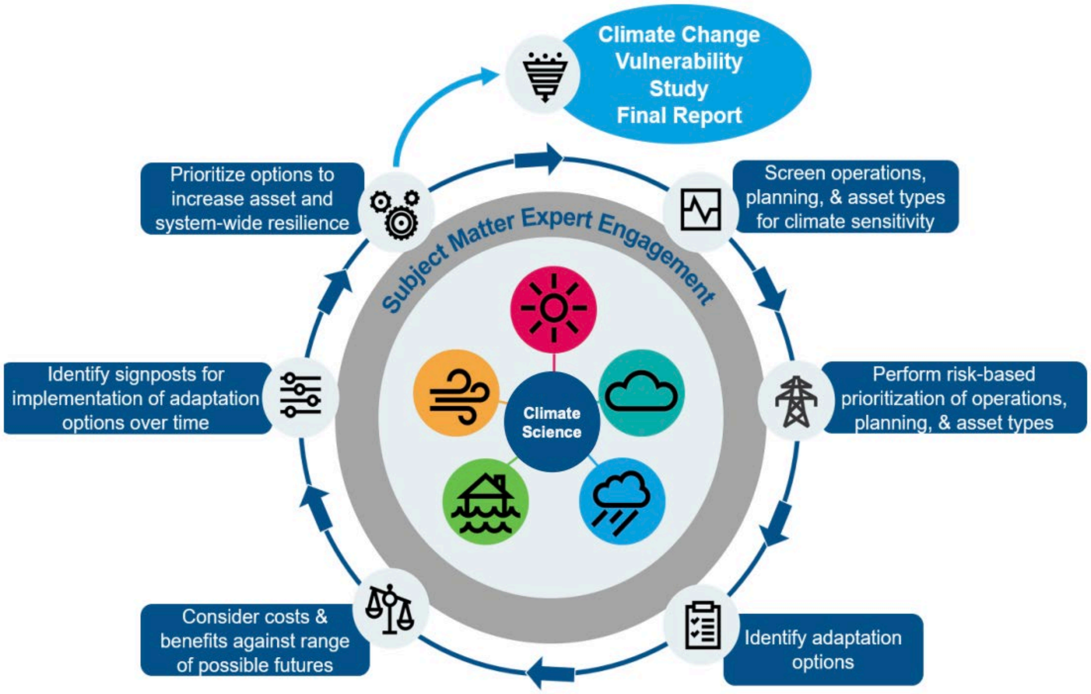


Figure 5.4. Con Edison Vulnerability Assessment Methodology (Con Edison 2019)

For the vulnerability study, Con Edison worked with ICF, Columbia University, and Jupiter Intelligence to characterize historical and projected (+2°C scenario and a +4°C scenario) climate changes across its service territory, identifying sea level rise, storm surge, increased temperature and heat waves, and extreme weather as critical climate-driven risks to electric, gas, and steam assets. To address impacts to assets and operations, the utility estimated an investment price tag of up to $5.2 billion by 2030, with investment priorities including hardening activities (e.g., selective undergrounding, stronger overhead poles), integration of climate projections into long-term peak load forecasting, expansion of monitoring capabilities, upgrading design guidelines around sea level rise concerns, and more.

Table 5.2 shows a summary of process updates and key findings in seven key areas of utility operations from Con Edison’s *Climate Change Resilience and Adaptation – Summary of 2020 Activities*.

Table 5.2. Con Edison Climate Change Resilience and Adaptation - Summary of Process Updates and Key Findings (Con Edison 2021)

Key Areas	Summary of Process Updates	Key Findings
Load Forecasting	• Climate information will be included in future load forecasts for all commodities beginning in 2020. • Con Edison will incorporate anticipated temperature variable (TV) increases into load forecasting, currently estimated at a 1-degree TV increase per decade beginning in 2030.	• The electric summer peak is expected to increase by 700 to 900 megawatts- (MW) due to increased TV by 2050.
Load Relief	• Beginning in 2021, Con Edison will incorporate projected climate-change-driven increases in load and reductions in power equipment ratings in the 10- and 20-year load relief plans.	• A relatively small impact on power transformers and network transformer ratings is expected due to ambient temperature rise between 2040 and 2050.
Reliability Planning	• Reliability modeling will use forward-looking climate-change-adjusted load forecasts and projected increases in TV. • In 2021. the Company will conduct a review of extreme event projections to determine whether additional model updates are warranted.	• Temperature increases and extended heat waves are expected to affect the reliability of distribution networks by 2030, absent adaptations.
Asset Management	• Con Edison processes will assess the extent to which expected future temperature changes impact ratings. • The Climate Change Planning and Design Guideline sets a flood design standard to account for increasing sea level rise, which applies to the electric, gas, and steam systems.	• The sea level projection exceeds the current design criterion of one foot of sea level rise by 2040.
Facility Energy Systems Planning	• Con Edison is updating designs to provide more flexibility for modifications during heating, ventilation, and air conditioning system replacement.	• Due to increases in temperature, the size of the cooling equipment in Con Edison's facilities may require an increase of up to 40% by 2040.

Key Areas	Summary of Process Updates	Key Findings
Emergency Response Activations	• Discussions are underway on how to incorporate heat, flooding, and precipitation projections into the weather and impact forecast model used to establish the Company's emergency response preparation to weather events. • The Company will plan for drills and exercises based on projected pathway criteria.	• Projected climate pathways could impact future weather and storm impact forecasts. • The Company will continue reviewing ways to incorporate climate change into a forward-looking model.
Worker Safety	• Con Edison will monitor climate change for impacts on worker safety. In 2022, the Company will consider whether additional heat stress protocols for climate change adaptation are warranted.	• An increase in temperature and heat index may exacerbate worker heat stress.

Con Edison's forward-looking vision comes at a cost to ratepayers. In January 2022, the utility filed an investment plan seeking new electric and gas rates in 2023 to fund clean energy investments and make infrastructure upgrades; the proposal seeks an additional $1.2 billion in revenue to upgrade and operate the company's distribution system, with a commensurate 11.2% electric bill hike for customers (which will vary by customer class).

While not originally required to do so, as a result of some 2021 legislation, New York's other electric utilities will be developing climate vulnerability assessments by or before September 22, 2023, as well as climate vulnerability and resilience plans to address the findings of the vulnerability assessments by or before November 21, 2023 (NY Legislature 2021). The legislation also includes a provision authorizing the use of a surcharge for collection of costs related to the climate vulnerability plans (NY Legislature 2021). To aid the utilities in framing their studies and plans and to ensure statewide consistency, the NYPSC initiated a proceeding to implement the legislation and address questions such as what climate variables (i.e., temperature, precipitation, etc.) to include, if any variables should be excluded, if utilities should use consistent approaches or be allowed to use different approaches, and what RCP scenarios should be used (NYPSC 2022).

While the legislation does not specifically state how utilities must develop their climate vulnerability assessments, it provides a list of items the assessment must discuss (i.e., infrastructure, design specification, procedures, and adaptation measures) (NY Legislature 2022).

The legislation also requires that climate resiliency plans identify the extent to which the plan will mitigate the effects of climate change; shorten restoration times and reduce restoration costs caused by future extreme weather events; address feasibility, cost effectiveness, equity, and rate impacts; account for operations and maintenance considerations, such as vegetation management; and address stakeholder participation and the establishment of a resiliency working group (NY Legislature 2022).

5.2.3 California PUC Requirements and Southern California Edison Vulnerability Assessment

In California, major utilities are required to develop and submit climate change vulnerability plans to the state regulatory commission—the California Public Utilities Commission (CPUC)—as spelled out in a CPUC rulemaking proceeding initiated in May 2018. CPUC gives utilities considerable guidance in Decision 19-10-054 (CPUC 2020). Specific direction given to utilities by the CPUC is summarized in Table 5.3, broken down by categories of data guidance, addressing disadvantaged vulnerable communities (DVCs), vulnerability assessment requirements, and miscellaneous.

Table 5.3. Excerpts from the CPUC Guidelines to California Electric Utilities for the Climate Adaptation and Vulnerability Assessments (CPUC 2019, 2020)

	Excerpts from the CPUC Guidelines
Data Guidance	Utilities shall **use the same three climate scenarios and projections** used in the most recent California Statewide Climate Change Assessment. If a new assessment becomes available, the utilities shall **align with the new scenarios** and projections. For any other climate variables or climate trend datasets, utilities shall **prioritize peer-reviewed methodologies** over those not peer-reviewed.
	Utilities shall **use Representative Concentration Pathway 8.5** for a business-as-usual case.
Addressing Disadvantaged Vulnerable Communities	A **definition**[6] of disadvantaged vulnerable communities (DVCs) was provided by the CPUC. Utilities shall **place maps on their websites** illustrating the locations of DVCs.
	A definition[7] of adaptive capacity was provided. Utilities shall **consult with DVCs** and consider their advice in determining **levels of adaptive capacity**. Vulnerability assessments must include an analysis of **how investor-owned utilities (IOUs) promote equity** in DVCs based on the communities' adaptive capacity.
	Utilities are required to **file Community Engagement Plans** every four years, and one year before the filing of the Vulnerability assessment. Utilities must meet with community-based organizations and DVCs in developing their plans.

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[6] DVC is defined as communities in the 25% highest scoring census tracts according to the California Communities Environmental Health Screening Tool (CalEnviroScreen), as well as all California tribal lands, census tracts with median household incomes less than 60% of state median income, and census tracts that score in the highest 5% of pollution burden within CalEnviroScreen, but do not receive an overall CalEnviroScreen score due to unreliable public health and socioeconomic data.

[7] Adaptive capacity is defined as the broad range of responses and adjustments to daily and extreme climate-change-related events available to communities. This includes the ability and resources communities have to moderate potential damages, take advantage of opportunities, and cope with consequences.

	Excerpts from the CPUC Guidelines
Vulnerability Assessment Requirements	Plans shall be submitted **every four years** and address the **next 20-30 years** primarily, but also address the 10-20 year and 30-50 year time frames.
	At a minimum, the assessment must **consider the following criteria**: • Temperature • Sea level • Variations in precipitation, including snowpack, extreme precipitation events, long-term precipitation trends, droughts, subsidence • Wildfire • Cascading impacts
	Utilities must use the Department of Water Resources' **two-step vulnerability assessment methodology** that 1) combines exposure and sensitivity to determine risk, and 2) combines risk and adaptive capacity to determine vulnerability.
	Consider and identify **climate risks to IOU operations and service** as well as to utility assets over which the IOUs have direct control. Assessment should also consider risks to facilities the utility contracts with.
	Plans should consider an **array of options** for dealing with vulnerabilities, ranging from easy fixes to more complicated, longer-term mitigations. Green and sustainable remedies should also be considered.
Misc.	Utilities shall designate **climate change teams** that report directly to an executive at a senior vice president level or above. • When signing new contracts for power, capacity or reliability the utilities shall seek an **acknowledgment in the contract** that the operator has considered long-term climate risk • Utilities shall create a **designated account to track direct costs** related to the vulnerability assessments and the community outreach and Community Engagement Plans.

Due to the timing of its next general rate case, SCE became the first utility to submit its plan, with other major utilities filing in future years (CPUC 2020). SCE's Climate Change Vulnerability Assessment was released in May 2022 (SCE 2022a). The SCE climate adaptation and vulnerability assessment followed the analytical framework outlined in Section 5.1.

SCE first identified the assets, operations, and services to consider in a vulnerability assessment (the Scoping step shown in Figure 5.5). In the Vulnerability Analysis step shown in Figure 5.5, for each climate change risk[8] SCE analyzed each asset, operation, and service to determine if it was exposed to the risk and its sensitivity to the climate risk. SCE combined the risk and sensitivity to develop an assessment of the vulnerability. In the At Risk Analysis step, SCE then identified the consequences of each vulnerability and whether SCE had the capacity to adapt and thereby mitigate or eliminate the consequences (e.g., responding to a flooded substation by routing power through an existing, neighboring substation). This became the basis for assessing the risk that SCE faces. In the Adaptation Development step, SCE used the Risk Analysis along with input concerning community resilience to prioritize risks and develop adaptation options.

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[8] Consistent with CPUC Decision 20-08-046 (CPUC 2020), SCE studied 5 types of climate hazards: temperature, sea level rise, variations in precipitation, wildfire, and cascading events. Cascading events included debris flows resulting from the combination of wildfire and heavy precipitation events, rain on snow events and dam safety, heatwave plus wildfire events, and drought.

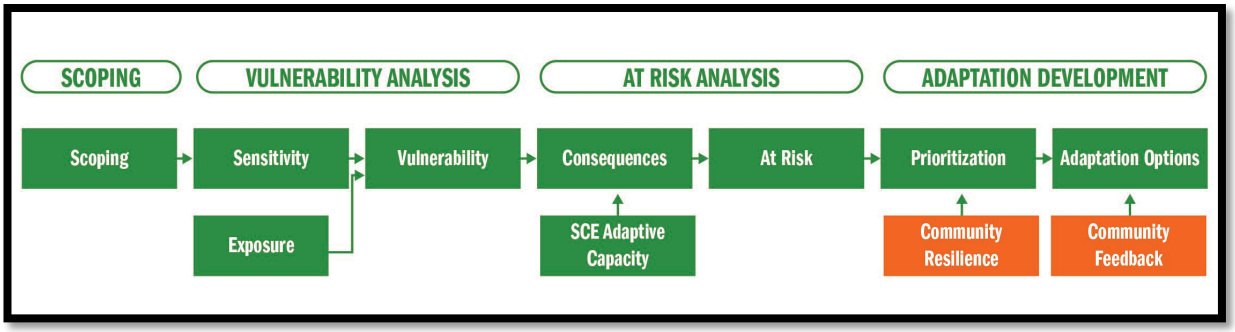

Figure 5.5. SCE Climate Change Vulnerability Assessment Analytical Framework (SCE 2022a)

California has demonstrated leadership in regulatory requirements for electric utilities to follow. In the following section, we describe another area in which California is leading by example—data developing and availability.

6.0 Data Development and Access

In planning for climate change, data is critical. A report from the American Meteorological Society (AMS) points out the following trusted and verified climate data sources can be difficult for utilities to locate and navigate (Tipton and Seitter 2022). As such, electric utilities may need support with accessing and translating the myriad climate forecasts available to them into actionable information. As utilities embark on planning for climate change, it is important to define climate-related decisions that need to be made and then work with climate science experts to select datasets that are appropriate for their needs.

This section describes data development partnership examples and examples of data repositories and sharing. Downscaling global climate models can be time consuming and expensive. Some utilities that are using downscaled climate data have developed the datasets in partnership with government and academic organizations. In other cases, state organizations have conducted detailed studies and made granular climate change data available for use by all utilities and municipalities. Smaller and rural utilities will likely also experience challenges from climate change although they may not have the time or resources to understand climate modeling and weather projections. They would benefit from support from government organizations and larger, more advanced utilities.

6.1 Data Development Partnerships

Developing a strong network of data partners across organizations is important and can alleviate some of the work that must be completed since data can be used for a variety of research purposes. The following are examples of utilities teaming up with state and federal organizations and universities to downscale GCMs for use in electricity planning.

- **Seattle City Light** – Supported by the University of Idaho to downscale 20 GCMs (SCL 2016) and the University of Washington who developed streamflow projections for watersheds that include hydroelectric generation.
- **Con Edison** – Built on approaches from the New York City Panel on Climate Change (NPCC) and worked in partnership with ICF, Columbia University’s Lamont-Doherty Earth Observatory, and Jupiter Intelligence (Con Edison 2019).
- **Puget Sound Energy and Tacoma Power** – Worked with the Northwest Power and Conservation Council and the River Management Joint Operating Committee, which includes the Bonneville Power Administration, the U.S. Army Corps of Engineers, and the Bureau of Reclamation, to develop downscaled GCM data for use in planning (PSE 2021).
- **Southern California Edison** – Used information developed and made available through Cal-Adapt funded by the California Energy Commission and the California Strategic Growth Council, developed with the support of UC San Diego, UC Berkeley, UCLA, UC Merced, and CU Boulder (SCE 2022a). Cal-Adapt includes data from the California Energy Commission Climate Change Assessments, the latest of which is the fourth assessment.

In June 2022, the New York Public Service Commission directed utilities to perform climate vulnerability assessments and compile an action plan (NYPSC 2022). However, guidance on harmonizing the use of data sources for climate-resilient planning is still underway as of 2022. In comments filed by the New York Joint Utilities,[9] it is indicated that numerous stakeholders—investor-owned utilities (IOUs), New York State Energy Research and Development Authority (NYSERDA), and the NYPSC—are collaborating on the compilation and usage of a consistent climate dataset for utility planning purposes. Columbia University will lead a baseline survey of observed and projected climate impacts in New York. Regional variations in those impacts were proposed by the New York Joint Utilities and received well by Columbia University and NYSERDA. The co-developed climate datasets and projections would serve as the foundation for a harmonized set of projections that utilities could integrate based on system and service territory characteristics rather "than having each utility undertake a [separate] climate projection [effort]" (NY Joint Utilities 2022). The New York Joint Utilities point to the following website where data will be housed: https://nysclimateimpacts.org/. Another cooperative effort in New York is the New York Climate Change Science Clearinghouse,[10] which aggregates an impressive collection of climate vulnerability and resilience plans compiled by cities, counties, and state agencies, as well as other entities in New York (NY CCSC nd). It also aggregates climate resources developed by others.

6.2 Data Sharing and Repositories

This section shares best practices and needs when it comes to data sharing. State- and national-level data sharing examples are provided as well as examples from Europe.

6.2.1 State-Specific Data Sets – Example Cal-Adapt

In California, the state has developed a resource with the latest climate data downscaled to a relatively fine level of granularity (6 kilometer by 6 kilometer) that electric utilities and others in California can use. This is a best practice example of developing and sharing climate data that is available all.

The California Energy Commission and the California Strategic Growth Council funded Cal-Adapt, which is a collaboration between state agencies, universities, and private sector researchers that provides a way to explore peer-reviewed data that shows how climate change may affect California at both the local and state level. Data is made available through downloads, visualizations, and a designated application programming interface, or API. **Cal-Adapt is a central repository for climate data, models, and projections for California that is available and accessible to multiple sectors and useful for utilities of all sizes.**

Cal-Adapt was developed by the state of California as a web-based climate adaptation tool that provides downscaled GCM data and data on a variety of climate-related topics. Along with data, the website provides interactive visualization tools, a community forum, climate stories, and education, as well as links to additional resources. All data is public, downloadable, and can be localized. California agencies maintain the database.

There are five categories of data included: temperature, precipitation, snowpack, sea level rise, and wildfire. Individual data sets include the following:

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[9] Joint Utilities of New York include Central Hudson Gas & Electric Corporation, Consolidated Edison Company of New York, Inc. (Con Edison), New York State Electric & Gas Corporation, Niagara Mohawk Power Corporation d/b/a National Grid, Orange and Rockland Utilities, Inc., and Rochester Gas and Electric Corporation.

[10] https://www.nyclimatescience.org/

- local climate change snapshot
- annual averages, sea level rise—coastal inundation scenarios
- extreme weather
- maps of projected change
- extreme precipitation events
- extreme heat days and warm nights
- snowpack
- wildfire
- cooling-degree days and heating-degree days
- streamflow
- extended drought scenarios
- hourly projections of sea level rise.

Figure 6.1, Figure 6.2, and Figure 6.3 contain example data visualizations from Cal-Adapt, including annual average temperature forecasts, maximum 1-day precipitation forecasts, and a sea level rise visualization.

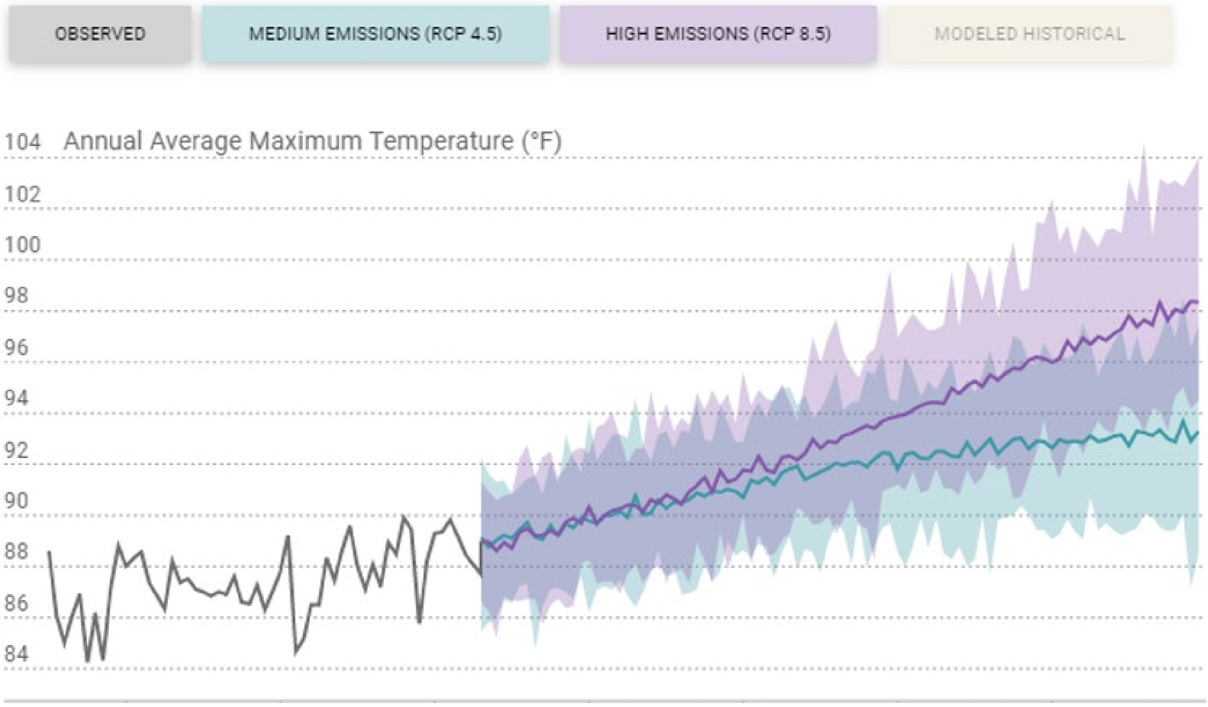


Figure 6.1. Example Annual Average Temperature Forecasts from Cal-Adapt

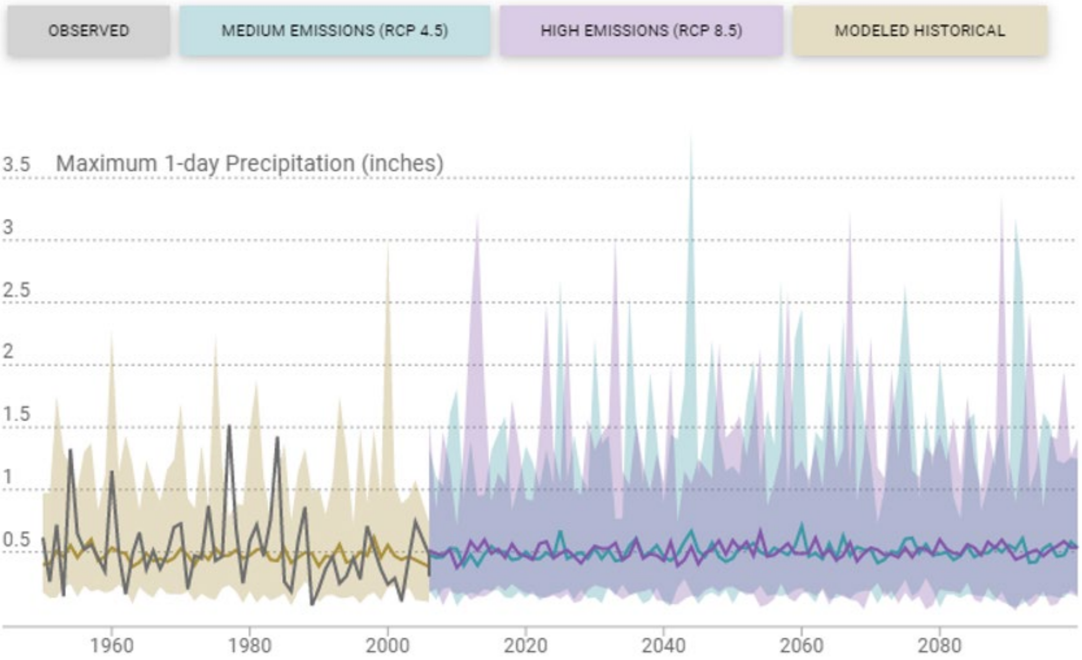
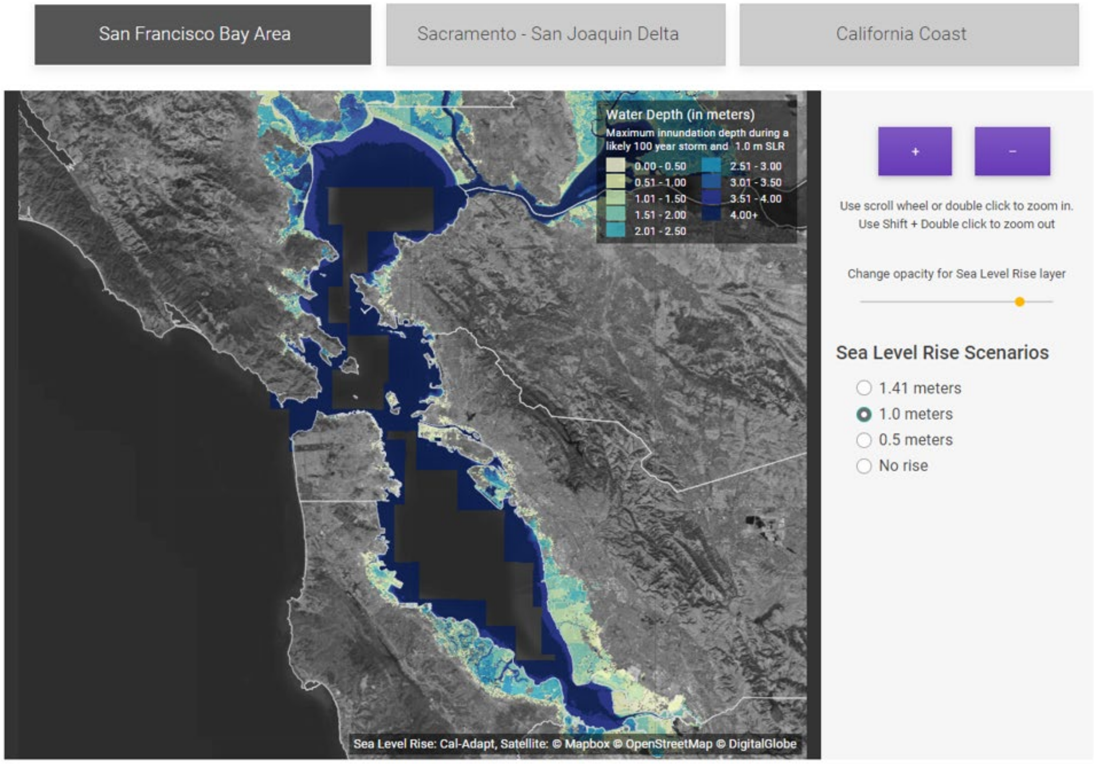


Figure 6.2. Example Maximum 1-Day Precipitation Forecasts from Cal-Adapt



Use scroll wheel or double click to zoom in.
Use Shift + Double click to zoom out

Sea Level Rise Scenarios

○ 1.41 meters
● 1.0 meters
○ 0.5 meters
○ No rise

Figure 6.3. Example Sea Level Rise Visualization from Cal-Adapt

Per a 2020 order, California utilities are required by the CPUC to use “the tools, scenarios, analyses, and data from the 2018 California Fourth Statewide Climate Change Assessment when analyzing climate impacts, climate risk, and climate vulnerability of utility infrastructure systems and operations" (CPUC 2020). CA utilities can use other third-party analyses and datasets, but they must be derived from or based on the same climate scenarios as the most recent California Statewide Climate Change Assessment.

The Fourth CA Statewide Climate Change Assessment uses 10 GCMs and two RCPs (RCP 4.5 and RCP 8.5) to simulate California's historical and projected future temperatures, precipitation, and other climate characteristics, such as humidity and soil moisture. The CPUC directs California utilities to update their assessments within six months if the forthcoming Fifth Assessment or future Assessment updates select different GCMs or RCPs. Where data is not available in one of the CA Assessments, utilities are directed to prioritize the use of peer-reviewed methodologies. Preliminary climate data for California's Fifth Climate Change Assessment, at a granularity of 3 kilometer by 3 kilometer are now available on Cal-Adapt (Cal-Adapt 2023).

6.2.2 National Climate Change Data Sets and Resources

Climate change data can be obtained from numerous sources and at a wide range of specificity. The sources listed in this section will not provide data in a form that can be directly useful in utility analyses (e.g., the hourly data needed for integrated resource planning models). The sources listed herein do provide a wealth of information on the various climate risks faced by utilities and, with creativity, may in some cases provide data sufficient for utility purposes. Many if not most of the following sites include tutorials and other material to help users navigate the tools offered by the site. Some of the datasets listed here were based on older models and downscaling methodologies. Utilities should seek support on the best datasets to used based on planned use of the data.

NOAA and the National Aeronautics and Space Administration (NASA) developed the U.S. Climate Resilience Toolkit,[11] (U.S. CRT nd). The toolkit also provides information on how to achieve resilience, case studies, trainings, and state-level climate summaries. The U.S. Climate Resilience Toolkit includes a climate projection tool, The Climate Explorer,￼[12] level. The Climate Explorer provides two climate projection scenarios based on lower and higher emissions. This may be helpful to utilities needing additional guidance in understanding which emissions projection scenario data is best to use for their energy system modeling to be most accurate in their planning and adaptation efforts. The Climate Explorer includes a discussion of the source of the climate data and references a website named Data.Gov.￼[13]The Data.Gov site aggregates a number of government sources of climate data that would be useful to someone with a base level of understanding and time to sort through the different resources (U.S. Data.gov nd). The visualization tools in The Climate Explorer are easier for a novice to simply start using.

The Climate Mapping for Resilience and Adaptation (CMRA)[14] resource presents data on climate-related hazards and includes the CMRA Assessment Tool[15] with projection capabilities to further identify resilience needs (CMRA nd). The CMRA site provides information related to the U.S. federal government efforts to foster climate resilience and information on climate-related hazards, including extreme heat, drought, wildfire, flooding, and coastal inundation. The

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[11] https://toolkit.climate.gov/

[12] https://crt-climate-explorer.nemac.org/

[13] https://data.gov/

[14] https://resilience.climate.gov/#top

[15] https://livingatlas.arcgis.com/assessment-tool/home/

visualization tool provides summaries of these hazards at a county level, including reference to the amount of change represented from historical averages (e.g., for annual days over 100°F, the tool shows an annual average of 1.5 days for the 2035–2064 time period, which represents an increase of 1.4 days since the historical 1976–2005 period for Tompkins County, NY).

The U.S. Environmental Protection Agency (EPA) provides the online Climate Change Adaptation Resource Center (ARC-X)[16] that includes numerous tools for climate change adaptation (EPA 2023). ARC-X is particularly focused on tools for water, wastewater, and storm water utilities but many of the tools from ARC-X would be useful for energy utilities as well. The ARC-X tools and frameworks are broken into five major categories, including air quality, water management, waste management and emergency response, public health, and adaptation planning. Among the tools, the EPA's Climate Resilience Evaluation and Awareness Tool (CREAT)[17] Climate Change Scenarios Projection Map provides state-level projections for temperature, precipitation, storms, extreme heat, and sea level (CREAT nd). Also, given that utilities in many parts of the country are incorporating concepts of environmental justice into their climate change planning and adaptation, the EPA's Environmental Justice Screening and Mapping Tool, or EJScreen,[18] can be utilized. EJScreen is provides a nationally consistent dataset and approach for combining environmental and demographic socioeconomic indicators (EJScreen 2023). In addition, there are multiple frameworks that are accessible, such as EPA's Smart Growth Fixes for Climate Adaptation and Resilience,[19] which highlights approaches to adapting to climate change that would be useful information for electric utilities (EPA 2022a). As part of this, EPA provides a sortable table that details policy options for Smart Growth Fixes for Climate Adaptation and Resilience (EPA 2022b).[20]

PNNL developed and will regularly be updating the PNNL Climate Research Portal. Datasets available on this portal include U.S. power grid balancing authority projections of hourly meteorology under climate change for four climate change scenarios; results from scenarios where past extreme events are replayed under four scenarios of future global warming conditions to show potential increases in extreme event intensity, scope and duration; and county-level meteorology (temperature, specific humidity, shortwave radiation, longwave radiation, and wind speed) under four different climate change scenarios (PNNL nd).

Battelle and NASA developed the NASA Earth Observations for Electric Utility Applications.[21] This site combines significant information about U.S. electric utility infrastructure and climate-related hazards (sea level change, temperature, surface water and flooding, and others) (NASA 2021).

Argonne National Laboratory teamed with FEMA and AT&T to develop a Climate Risk & Resilience Portal (ClimRR) that is designed for individuals, governments, and organizations to access simulated future climate conditions at mid- and end-of-century for different climate

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[16] https://www.epa.gov/arc-x/tools-climate-change-adaptation

[17] https://epa.maps.arcgis.com/apps/MapSeries/index.html?appid=3805293158d54846a29f750d63c6890e

[18] https://www.epa.gov/ejscreen

[19] https://www.epa.gov/smartgrowth/smart-growth-fixes-climate-adaptation-and-resilience

[20] https://www.epa.gov/smartgrowth/table-policy-options-smart-growth-fixes-climate-adaptation-and-resilience

[21] https://itcanbedone.maps.arcgis.com/apps/MapSeries/index.html?appid=f3f5aa31bd5f4eb7b3abe033a403ab4f

risks.[22] Information is provided at a granularity of twelve square kilometers for average annual maximum and minimum temperatures, average seasonal maximum and minimum temperatures, total annual precipitation, consecutive days with no precipitation, number of heating and cooling degree days, and average annual wind speeds. One goal of ClimRR is to provide free and equitable access to the latest vetted datasets to support decision-making. ClimRR is designed to be useful to technical and non-technical audiences (ClimRR nd).

6.2.3 Europe Example

Europe provides an example of making climate forecasts available for use in infrastructure planning. One way for European electric utilities to access climate data is through Climate-ADAPT,[23] which was created through a partnership between the European Environmental Agency (EEA) (Climate-ADAPT nd). EEA is an agency of the European Union and the European Commission and launched in 2012 (Hocquet 2020). Climate-ADAPT is similar to Cal-Adapt,[24] described previously.

Climate-ADAPT is maintained by the EEA and supported by the European Topic Centre on Climate Change Impacts, Vulnerability and Adaptation (ETC/CCA). The objective of Climate-ADAPT is to provide climate forecasting and time series data to support Europe's adaptation efforts to climate change. With respect to the energy sector, Climate-ADAPT recognizes the importance of resilience, especially as the number of days with heatwaves grows. The European Climate Data Explorer[25] within Climate-ADAPT contains several predictive climate datasets broken up by six categories (health, agriculture, forestry, energy, tourism, and coastal) and provides predictions up to 2099 (ECDE nd). As of 2022, the energy tab contains a forecasting dataset for climatological heatwaves that can help energy utilities with long-term energy system modeling as well as help foster resilience. The climatological heatwave data was calculated under two scenarios (medium versus high emissions) using bias-adjusted EURO-CORDEX[26] data. EURO-CORDEX is funded through the World Climate Research Program (WCRP); the program conducts European-specific climate-related simulations to facilitate adaptation (EURO-CORDEX nd).

The International Energy Agency (IEA), which is funded through the Organization for Economic Cooperation and Development (OECD), also provides a multitude of datasets at the country level that are either updated monthly or yearly or forecast future climate up to 2050. The European Commission also financially supports the tool-supported policy development for regional adaptation (ToPDAd) (ToPDAd 2023).[27] The focus of ToPDAd is to provide the energy, transportation, and tourism sectors with strategies for climate-related adaptation. Lastly, the Copernicus Climate Change Service (C3S),[28] which was created by the European Commission and implemented by the European Centre for Medium-Range Weather Forecasts (ECMWF), provides climate forecasting data for the energy sector and information on electricity demand and production of power from wind, solar, and hydropower sources (C3S nd).

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[22] https://disgeoportal.egs.anl.gov/ClimRR/
[23] https://climate-adapt.eea.europa.eu/en/about
[24] https://cal-adapt.org/about/
[25] https://climate-adapt.eea.europa.eu/en/knowledge/european-climate-data-explorer/
[26] https://www.euro-cordex.net/
[27] http://www.topdad.eu/
[28] https://climate.copernicus.eu/operational-service-energy-sector

7.0 Emerging Approaches

This section addresses emerging approaches in planning for climate change, including decision-making under uncertainty and storyline approaches.

7.1 Decision-Making Under Deep Uncertainty

One thing that climate change has made increasingly apparent is that our assumptions may no longer be valid, and probabilistic analysis of future conditions based on the past —as is traditional to IRPs—may not effectively characterize the deep uncertainties of climate change.

Climate models are not a perfect representation of Earth's climate and will never be. Projections for how climate change will impact generating resources and weather extremes are not significantly robust to allow confidence in long-term planning (Tipton and Seitter 2022). Alternative resource planning strategies, such as Decision Making Under Deep Uncertainty (DMDU), have been introduced in response to the uncertainties of future climate projections. Deep uncertainty occurs when the parties to a decision do not know or do not agree on the likelihood of alternative futures or how actions are related to consequences (Lempert et al. 2013; Walker, Lempert, and Kwakkel 2013). There are a few DMDU approaches that can be used to identify and develop robust plans that perform well over multiple futures. Rather than seeking confidence in a specific model, DMDU ultimately supports building confidence in a decision. The key principles of DMDU are the following (Toolkit 2022):

1. Consider multiple futures, not one single future, in your planning. Choose these futures to stress test your organization's plans.
2. Seek robust plans that perform well over many futures, not optimal plans designed for a single, best-estimate future.
3. Make your plans flexible and adaptive, which often makes them more robust.

DMDU is distinct from the traditional stochastic analysis conducted in utility planning in that traditional utility risk analysis is based on a "predict then act" paradigm whereas DMDU is based on the concepts of choosing a direction and then "monitoring and adapting" as necessary. Traditional utility risk management approaches assume that the future conditions can be predicted based on the past, even if elements of those futures vary stochastically. DMDU recognizes the principle of non-stationarity,[29] and that past conditions cannot necessarily be used to predict the future. DMDU-developed solutions are focused on preparation and adaptation to those items for which a deep uncertainty exists.

Under DMDU, the first step begins with the identification of strategies, which are then stress-tested against multiple future scenarios to understand how a particular strategy performs under a range of future conditions. This allows planners to identify new and revised strategies to fill the performance gaps. New strategies are then tested again until a set of robust options is generated. This type of analysis can align planning and decision-making with questions that deal with deep uncertainty, including the following (Toolkit 2022):

- Can a robust and flexible strategy perform well over a wide range of futures?
- What uncertainties are most important in determining the success or failure of our plans?

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[29] Non-stationarity occurs when a system's general behavior can no longer be assumed to be constant over time and the envelope of variability within which the system operates is no longer constant.

- What are key thresholds, beyond which systems will have problems and cannot operate effectively?
- What actions do we need to take now in order to keep future options open?
- What actions can we postpone?

Table 7.1 describes various DMDU approaches.

Table 7.1. Summary of DMDU Approaches

DMDU Approach	Methodology	Application	Benefits
Robust Decision-Making (RDM)	Proposed strategies are evaluated over a range of plausible futures, using stress testing to evaluate the performance of the strategy over combinations of uncertainties (Lempert 2018). Model runs are plotted to reveal vulnerabilities–where strategies succeed or fail over broad futures–in order to create a robust portfolio of options (Toolkit 2022). Includes robust stakeholder engagement.	Useful when parties may not agree on model accuracy of climate impacts, when probability distributions of impacts are deeply uncertain, and/or when there are stakeholder disagreements about the value of certain outcomes (e.g., increasing water supply vs. decreasing demand).	Describes strengths and weaknesses of strategies, not characteristics of future, allowing stakeholders to analyze tradeoffs and make informed decisions (RAND Corporation).
Dynamic Adaptive Pathways	"Tipping points" of the current system (or unacceptable outcome thresholds) are identified, policy actions are proposed, and pathways are visualized in a decision tree or score card, allowing for selection of initial and long-term actions based on tradeoffs between strategies.	Effective in decision-making spaces subject to inaction and gridlock or when "tipping point" conditions have already been reached.	Useful when decisions are needed during changing conditions; allows for comparison of alternative strategies (Haasnoot, Warren, and Kwakkel 2019).
Decision Scaling	Stress testing is conducted on the climate change factors of a strategy in order to understand the performance of the strategy and generate new options if needed.	Useful for understanding key climate change impacts simply and quickly.	Scalable to data inputs; Can be used with statistically downscaled datasets, perturbed historical climate record, or recently observed data that has been statically modified to generate alternative conditions (Toolkit 2022), (Lempert 2018).
Scenario Planning	A limited set of scenarios are developed that span the range of future uncertainties, based on identified driving forces.	Effective when uncertainty is minimized.	Cost-effective; Does not require technical resources or involved stakeholder engagement processes. Can be repurposed for stress tests (Heiligtag, Maurenbrecher, and Niemann 2017).

Scenario planning and decision scaling are the most easily accessible methods for utilities to use in planning for climate change, although planners have successfully adapted the adaptive pathways and robust decision-making approaches for developing climate change contingency plans.

7.1.1 Example Applications of Decision Making Under Deep Uncertainty Principles

An adaptive pathways approach was recommended by the state of California in its 2018 Sea Level Rise Guidance, a science-based methodology for state and local governments to assess the risks associated with sea level rise and incorporate these risks into their planning and investment decisions (OPC 2018). An adaptive pathways approach was also used by Con Edison in their Climate Change Vulnerability Study that they referred to as a flexible and adaptive approach adapted from Rozenzweig and Solecki (2014). About this flexible and adaptive approach, Con Edison states:

> *"A flexible and adaptive approach to managing and upgrading assets will allow Con Edison to manage risks from climate change at acceptable levels, despite uncertainties about future conditions. The flexible adaptation pathways approach allows Con Edison to adjust adaptation strategies as more information about climate change and external conditions that may affect Con Edison's operations is learned over time. (Con Ed 2019)"*

Figure 7.1 below is extracted and adapted from Con Edison's 2019 Climate Change Vulnerability Study; it illustrates how a flexible and adaptive approach can proactively support maintaining system risk within a tolerable threshold.

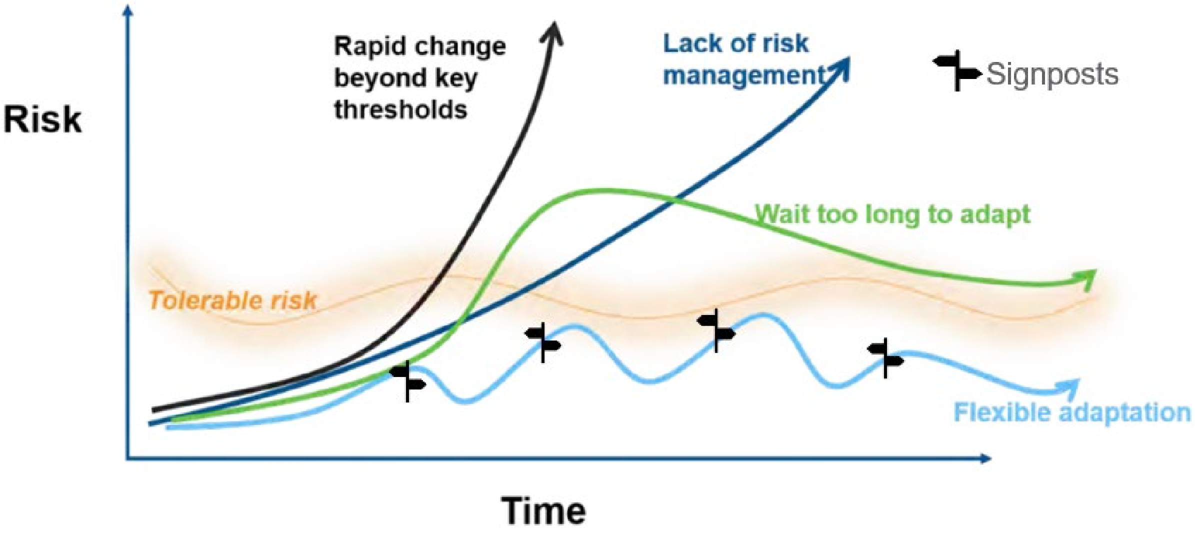

Figure 7.1. Illustration of Flexible and Adaptive Approach. Adapted from Con Edison Climate Change Vulnerability Study, December 2019 and Rosenzweig & Solecki, 2014.

Con Edison's approach includes monitoring indicators called "signposts" that provide information that can be used to inform adaptive management decisions. Specific thresholds were established by Con Edison related to signposts. When thresholds are met, that is a signal to Con Edison that action is needed to manage climate risk within an acceptable level. In Con Edison's study, signposts were established for the following broad categories:

- Observed climate phenomenon (e.g., higher operating temperatures and increased incidence of line sag)
- Updated available climate projections (e.g., better maps available of possible inundation areas)
- Climate impacts (e.g., sea level rise exceeds 1 foot)
- Policy, societal, and economic conditions (e.g., end of existing asset's useful life).

7.1.2 Challenges of Implementing Decision Making Under Deep Uncertainty

A literature review of applications of DMDU from Stanton and Roelich was published in 2021 (Stanton and Roelich 2021). Over 75% of case studies in the literature review covered water planning/infrastructure, and 5% looked at energy. Stanton and Roelich also point out that while DMDU approaches are recognized for navigating deep uncertainty and supporting robust and adaptable decisions, DMDU has been criticized for not reflecting the organization and individual contexts in which decisions are made. Stanton and Roelich point out that more progress is needed to move DMDU methods out of the academic realm. They note that the uptake of DMDU in practice is relatively limited, and more work is needed to tailor DMDU approaches to the differing institutional, organizational, and individual contexts and interests in decision-making (Stanton and Roelich 2021).

7.2 Storyline Approaches

Much like DMDU, the "storyline" approach to tackling climate uncertainties attempts to counter the limitations of probabilistic interpretations of climate model simulations by emphasizing the plausibility of future events. While probabilistic approaches quantify the likelihood of climate impacts or events (through extrapolation of the historic record, when available), the storyline approach emphasizes understanding unique climate uncertainties more qualitatively. For example, probabilistic thinking might ask how likely a climate impact is, but storyline thinking "might ask instead how much worse the event outcomes were because of [known climate change aspects], such as ocean warming" (Shepherd et al. 2018). The latter attempts to constrain the problem to articulate the nuances of what is known about climate processes, thereby supporting a deeper exploration of plausibility (as GCM projections alone may not paint a full picture). Rather than concentrating on general statistics, the storyline approach focuses on developing a qualitative description of unfolding past events and future pathways (Shepherd et al. 2018). Storylines can also be used to cover a series of sequential events and cascading impacts on several sectors.

Storylines can be based on past events, such as Superstorm Sandy—a hurricane that made landfall in New Jersey on October 29, 2012, resulting in the state's costliest natural disaster to date (NJ DEP 2022). The heavy rains, strong winds, and a storm surge event exposed critical utility vulnerabilities as more than two million people lost power and electric power equipment across the state flooded (NJ DEP 2022). While Superstorm Sandy was ultimately predicted ahead of its landfall, the conditions that allowed for its formation were unusual for late October (Donegan 2022) and its impacts revealed a gap in utility preparedness and infrastructure resilience. A storyline used to prepare for future events could build upon this historic example storyline, along with more granular climate data.

The New Jersey example represents a compound of extreme events (i.e., record storm surge and flooding), the risks of which are useful to analyze under the “storyline” lens because it allows for flexibility in defining the impacts of complex events (Shepherd et al. 2018). In contrast, a probabilistic approach to climate scenarios requires long time series data (that is not always available) and refined statistical methods to correct bias in multivariate relationships. Moreover, climate projections of compound events with GCMs are not always capable of showing the extent of impacts due to missing physics, insufficient sampling, and barriers in resolution. Under the storyline approach, GCMs are used as support tools to test theories, particularly as they relate to the physical interactions of various climate variables and processes. The qualitative grounding allows for the consideration of what we currently know about climate science, which cannot always be translated into GCM projections. For example, while GCMs robustly integrate our current understanding of the thermodynamic components of climate change (e.g., warmth and moisture), there is less confidence in the dynamic science (e.g., atmospheric circulation processes). Studies have already explored the contributions of thermodynamic climate change on the intensity and track of Superstorm Sandy, with Lackmann (2015) noting that increased warming and moistening of the upper troposphere did not substantially influence the strength of the hurricane. However, the capability of a GCM to project dynamic components, such as atmospheric and oceanic variables that control sea level dynamics and hurricane formation, are not as accurate (Lin et al. 2016). This provides an opportunity to combine GCM projections with the scientific understanding that is not currently captured in models to holistically understand the factors behind and impacts of compound events like Superstorm Sandy. With a storyline approach, impacts can be assigned “categorical plausibility” with statements like “regionally, at least one similar event has already occurred” (Shepherd et al. 2018).

Reasons for employing the storyline approach include greater alignment with human perception of risk, which tends to be event-based rather than probabilistic; development of stress tests better-suited for specific climate vulnerabilities; and greater confidence in the use of appropriate and reliable regional models. While the storyline approach to climate change has been used by some industries (e.g., insurance, water), it has not been applied to the electric sector to the knowledge of the authors.

8.0 Regulatory Considerations

Much of the information in this report can be helpful to both utilities and regulators as they work together on planning for climate variability. However, this section describes specific considerations for utility regulators. Regulators can support utilities' planning through developing requirements, conducting investigations, addressing utility reluctance and cost recovery concerns, and convening stakeholders to discuss what utilities should do to prepare the electric system for a changing climate. As mentioned previously in this report, some state regulators (i.e., CA and NY) have mandated that electric utilities conduct detailed climate change planning. Some state utility regulators have mandated that utilities file risk-specific plans, such as wildfire mitigation plans (i.e., CA, NV, OR, UT) or SPPs (i.e., FL). Additionally, in some cases, regulators are linking specific resilience planning or hardening activities with favorable cost recovery mechanisms, like cost riders. Table 8.1 lists states with state-level requirements and those where resilience activities of different kinds are tied to favorable cost recovery.

Table 8.1. States Requirements and Resilience Actions Tied to Cost Recovery

Climate-Related Process	California	Connecticut	D.C.	Florida	Hawaii	Louisiana	Maryland	Massachusetts	Michigan	Nevada	New Hampshire	New York	New Jersey	North Carolina	Oklahoma	Oregon	Pennsylvania	Rhode Island	Texas	Utah	Washington
State-level planning requirements																					
Requirement for climate vulnerability assessment and mitigation plans	●											●									
Requirement for storm management plans				●																	
Requirement for wildfire mitigation plan[1]	●									●						●				●	○
Requirement to consider climate change in distribution system planning									○												
Settlement agreement requires climate vulnerability assessment														●							
Resilience actions tied to cost recovery																					
Grid hardening or storm management actions tied to cost recovery surcharge		●	●		●	●	●	●			●		●	○	●		●	●	●		

● is used to indicate the statutory or legislative requirement exists, or utilities voluntarily developed the plans indicated.
○ is used to indicate that dockets are open in which the objective would apply.
[1] States apply several names, e.g., resource protection plans, but wildfire mitigation is a major part of such alternative plans.

Section 5.2.3 described the specific requirements the CPUC established for utility Climate Adaptation Vulnerability Assessments. By establishing clear goals, expectations, and metrics, regulatory commissions can help utilities prioritize climate change investment and reduce utility concerns about cost recovery for such investments. If the regulator requires a systematic review of risks to assets and a prioritization of the risks, utility investments can focus on the greatest risk areas, including those without other means for mitigating the risk. PUC-required climate assessments and prioritization can also identify climate adaptation work that can be conducted synergistically with otherwise ongoing projects, such as upgrading poor performing feeders or replacing aged substations (replacing such with facilities that are climate adapted), to reduce overall cost and improve resilience.

For risk averse utilities, building, upgrading, or replacing existing facilities to ensure climate-change resilience entails potential risk from the utility perspective for various reasons, including the risk of not recovering costs. In response to this, in some jurisdictions, regulators are providing favorable cost recovery for investments in resilience in the form of surcharges or rate riders. Table 8.1 lists the states that allow for the use of surcharges or rate riders for infrastructure hardening programs including the climate adaptation costs, storm and grid hardening costs, and mixed uses that include climate/storm related costs and more generalized grid modernization or replacement of aged grid components.

In prudence reviews of utility investments, when regulators ask what information was reasonably available at the time resource decisions were made, one piece of information that should be considered “reasonably available” would be projections of the impacts of climate change in the utility’s service territory. If regulatory bodies set clear goals and expectations, investments that have not been vetted through a climate adaptation process could be at some risk in a future prudence review.[30] Use of forward-looking climate data lacks the exactness that using historical weather data offers. However, the global climate models and the GHG cases available to a utility are becoming increasingly established in the scientific community, and documenting models and GHG cases should provide a justifiable base for reasonable decisions. Utilities have been downscaling and using global climate model data in planning models since at least 2011 (see RMJOC 2011, BC Hydro 2012, and Seattle City Light 2016).

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[30] It should be noted that climate projections are just that—projections. The exact timing of extreme events is going to be subject to some uncertainties. For example, the heat dome that struck the Pacific Northwest in 2021 is a phenomenon anticipated by global climate modeling, but according to some scientists, it was not anticipated until sometime after 2030 (Mubarik 2021). Because of this fact, basing analyses on accepted climate models and accepted greenhouse gas projections, and using reputable sources for downscaled climate data might need to be spelled out by regulators as steps that can protect utilities in the event of future prudence reviews.

9.0 Opportunities for Cooperation, Co-Developed Projects, and Cost Sharing

Small utilities may not be as well-equipped to plan for and adapt to the challenges of climate change. Government organizations, professional associations, and larger and better-resourced electric utilities can partner with smaller and rural utilities to share best practices approaches and lessons learned.

Climate change will not just impact electric utilities or the energy sector. Communities, businesses, and private organizations, and as well as different local and state agencies will also face challenges from climate change. The challenges of climate change require working across traditional silos and organizations and developing creative solutions that leverage different funding sources, synergistic investments, and operational collaboration. There is an important role for elected, legislative, and administrative officials in addressing the challenges of climate change. Coordination between electric utilities and other private and public organizations can be more effective than isolated action. Some states have used legislation as a tool for broadening the use of resilience planning and have passed laws or amended previous legislation to mandate the inclusion of climate adaptation and resilience in planning and zoning activities. Partnerships between government organizations and utilities may result in more comprehensive and equitable solutions where societal impacts are specifically considered in decision-making (SCE 2022a).

Below are examples of innovative funding organizations and co-development and cost sharing of resilience projects that can be an example to other states or partnerships for addressing climate change.

- **Pacific Gas & Electric (PG&E) SAFER Bay Project** – The SAFER Bay Project, co-developed by PG&E, the city of Menlo Park, and Meta (formerly Facebook), among other stakeholders, is an example of a joint project that will provide multiple benefits. The project has applied for a $50 million grant from FEMA's Building Resilient Infrastructure and Communities (BRIC) funding. The project protects a PG&E substation at risk due to sea level rise, while also providing more generation flood protection and protecting ponds at a wildlife refuge (SCE 2022a; Bradshaw 2021).
- **District of Columbia Undergrounding of Power Lines** – In the District of Columbia (DC), a series of major storms between 1999 and 2012 caused major electric distribution outage events. In August 2012, the mayor of DC issued Order 2012-13 establishing a task force to analyze the various reliability options available and to make recommendations for further actions. The task force evaluated several options for undergrounding overhead powerlines, and ultimately proposed undergrounding up to 60 of the poorest performing high voltage distribution lines. The task force also proposed a funding program for the approximately $1 billion program. The original financing proposal was for DC to fund $375 million through revenue bonds to be repaid through a surcharge on customer bills (not a tax). The utility serving DC, Pepco, was to fund $500 million to be paid through a separate surcharge. The District Department of Transportation (DDOT) would fund $62 million through the DDOT capital improvement program (Council of D.C. 2013). This is an example of multiple levels of state policymaking coordinating to address power system resilience.
- **The New Jersey Energy Resilience Bank Program** – The New Jersey Energy Resilience Bank Program was established in 2014 following Superstorm Sandy, with $200 million of Community Development Block Grant – Disaster Recovery funds allocated to New Jersey

by the U.S. Department of Housing and Urban Development (HUD). The program paid for resilient energy investments (combined heat and power and microgrids) at critical facilities (water, wastewater, hospitals) after Superstorm Sandy. Projects were prioritized that served low- and moderate-income communities (NY NJ TAP 2019).

- **Maryland Resilience Authorities** – In July 2020, the state of Maryland, through Senate Bill 457, authorized its counties to create resilience authorities to help address investments needed to mitigate effects of coastal flooding, sea level rise, increased precipitation, erosion, and heatwaves. Through resilience authorities, local jurisdictions can flexibly develop resilience funding structures and manage large-scale infrastructure projects designed to address the effects of climate change (Henshaw 2021). Resilience authorities can receive money from the state, local government, and non-profit organizations and can charge and collect fees for its services. Because the financing of these projects is separate from the county budget, they will not count toward the county's maximum debt ceiling and they make available more grant opportunities because some foundations do not fund government agencies.
- **Connecticut Municipal Climate Change and Coastal Resiliency Reserve Funds** – In 2019, Connecticut passed a bill authorizing the creation by municipalities of Municipal Climate Change and Coastal Resiliency Reserve Funds, which will draw from any cash surplus from the general fund of the municipality at the end of any fiscal year as well as the proceeds of bonds or other debt obligations issued by the municipality. It can be used to pay for municipal property losses, capital projects and studies related to mitigating hazards and vulnerabilities of climate change including, but not limited to, land acquisition.

10.0 Conclusions

Climate change is impacting electric utilities and communities across the United States. States, utilities, and scientists can learn from each other and work together to minimize adaptation costs and adverse impacts. The purpose of this report is to support electric utilities and regulators as they work together to increase the climate resilience of the power system in the United States.

Utilities can no longer rely on historic data to project future conditions. Forecasting approaches must be modified, and global climate models can be a useful tool in understanding potential future conditions. Electric utilities need to clearly define how climate data will be used may need support with accessing and translating the myriad climate forecasts available to them into actionable information. Utilities could use support translating future projected weather into extreme events and potential infrastructure impacts.

Climate-informed resource, asset, and contingency planning can help electric utilities respond to the impacts of climate change. Climate change can impact the loads and generation, and thereby impact resource planning. Utility assets can be compromised by climate change due to higher or lower temperatures, flooding and sea level rise, extreme storms, and wildfires. Utility assets can be evaluated against forecasted conditions, and design standards and equipment ratings can be adjusted to account for the realities of climate change. Contingency planning can be used to either plan for specific risks (wildfire or storms) or to conduct comprehensive climate vulnerability and adaptation plans. Without proactive resource, asset, and contingency planning, the reliability of the power grid is at risk.

Given the uncertainty associated with climate change and the inability of climate models to perfectly project future conditions, flexible and adaptive approaches are critical. Utilities and regulators should regularly monitor climate science and track trends and extreme events as well as adapt planning approaches and criteria, accordingly.

Regulators have an important role to play in supporting electric utilities with identifying and prioritizing investments that provide climate resilience. Regulators can support utilities' planning through investigations and convening stakeholders to discuss what utilities should do to prepare the electric system for a changing climate. In prudence reviews of utility investments, regulators can consider the extent to which utilities use widely available climate projections. If regulatory bodies set clear goals and expectations, investments that have not been vetted through a climate adaptation process could be at risk in a future prudence review.

Utilities, government organizations, and private sector organizations can coordinate on multi-faceted solutions that address the challenges of climate change. Smaller utilities may not be as able to plan for and adapt to climate change. Government organizations, professional societies, and larger and more advanced utilities can share resources, best practices, and lessons learned with smaller utilities, potentially in gatherings convened by regional or federal bodies, including DOE. Even for larger utilities, climate translators may be needed to help utilities and regulators navigate the uncertainty and myriad of climate and weather data and information available. New and innovative collaborations are needed to support electric system planning for resilience in the face of climate variability and change.

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