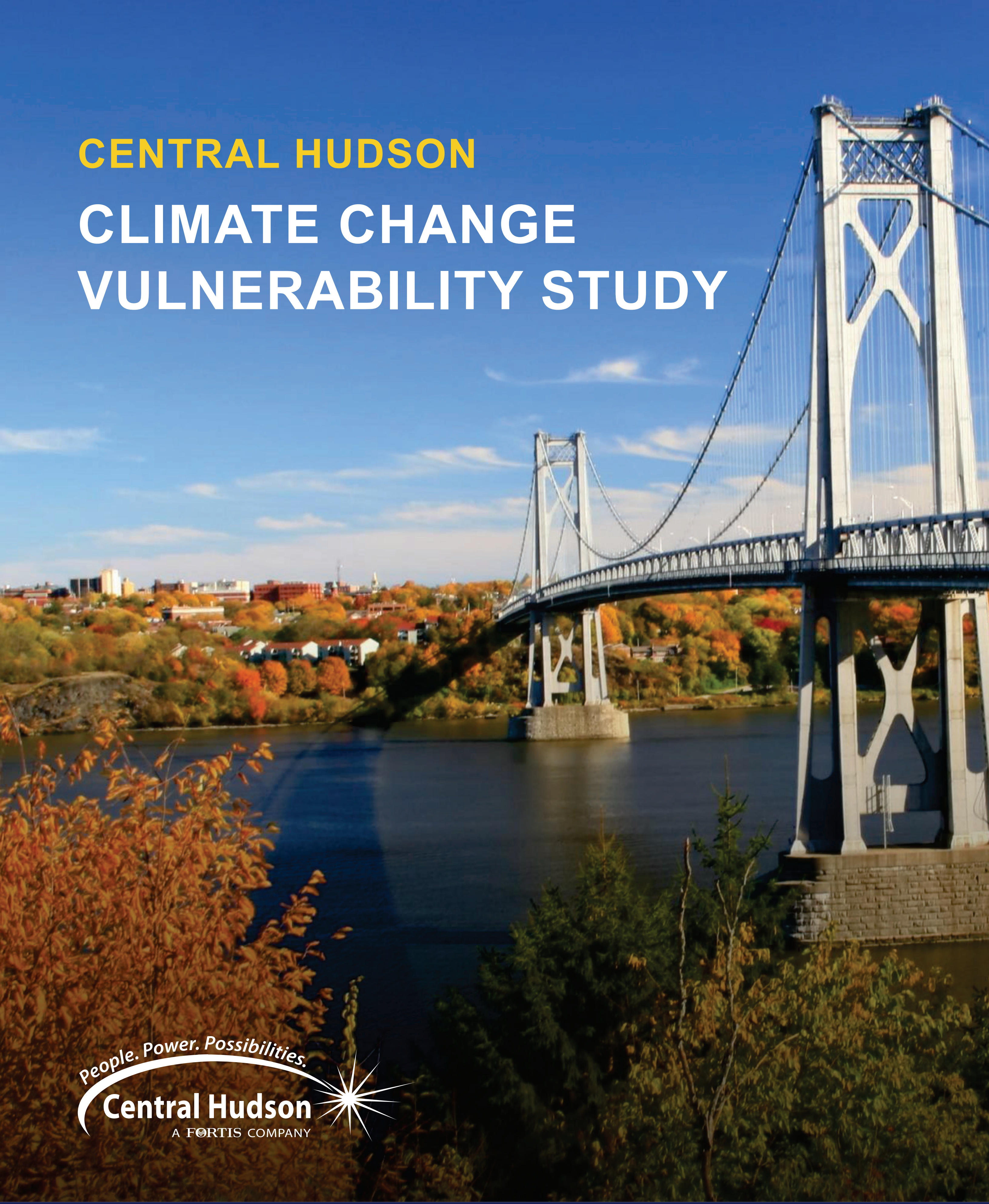

CENTRAL HUDSON

CLIMATE CHANGE VULNERABILITY STUDY

People. Power. Possibilities.
Central Hudson
A FORTIS COMPANY

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Acronym Glossary

AAR: Ambient Adjusted Ratings

AMI: Advanced Metering Infrastructure

CAPE: Convective Available Potential Energy

CCRP: Climate Change Resilience Plan

CCVS: Climate Change Vulnerability Study

CDD: Cooling degree days

CLCPA: Climate Leadership and Community Protection Act

CJWG: Climate Justice Working Group

CMIP6: Sixth Phase of the Coupled Model Intercomparison Project

CTHI: Cumulative temperature-humidity index

DACs: Disadvantaged communities

DOE: Department of Energy

EDCs: Electric distribution companies

FEMA: Federal Emergency Management Agency

FERC: Federal Energy Regulatory Commission

FLISR: Fault Location, Isolation, and Service Restoration

GCM: Global Climate Model

GHG: Greenhouse gas

HDD: Heating degree days

HILL: High impact and low likelihood

ICF: ICF Incorporated, L.L.C.

IPCC: Intergovernmental Panel on Climate Change

LTE: Long-term emergency

NOAA: National Oceanic and Atmospheric Administration

NYCA: New York Control Area

NYSERDA: New York State Energy Research & Development Authority

NYS: New York State

OIR: Order Instituting Rulemaking

OPM: Outage prediction model

PSC: Public Service Commission

RCP: Representative concentration pathway

SMEs: Subject matter experts

SSPs: Shared socioeconomic pathways

USCRT: United States Climate Resilience Toolkit

Executive Summary

This Climate Change Vulnerability Study analyzes Central Hudson Gas & Electric's (Central Hudson) assets and operational vulnerabilities to critical climate hazards and represents an important first step in Central Hudson's understanding of climate risk. The findings of this Study are meant to help Central Hudson, its investors, customers, and other stakeholders understand the utility's relative risk to climate change over the coming decades, highlighting priority areas for resilience investments.

This Study examines five distinct hazards Central Hudson has identified as being most pertinent to its ability to safely and reliably deliver power and energy: extreme heat, extreme cold, flooding, extreme precipitation, and wind. Using New York State-approved climate data, these hazards were evaluated by Central Hudson, with consultation from ICF Incorporated, L.L.C. (ICF), at present day and projected to mid- and late-century.

To understand the vulnerability of assets to climate hazards, the study pairs **exposure** data with metrics of **sensitivity** and **consequence** that estimate how an asset would likely be impacted by a hazard if exposed, and how great that impact would be. Using projected climate hazards, as well as interviews conducted with the utility's subject matter experts, this study also examines potential vulnerabilities of Central Hudson's operations.

The study included an analysis of the system's transmission and distribution assets, including 103 substations, 7,137 miles of overhead distribution lines, 1,661 miles of underground distribution lines, 263,569 distribution structures, 593 miles of overhead transmission lines, 8 miles of underground transmission lines, 8,576 transmission structures, and 602 manholes. **The results of this analysis indicate that the vulnerability of Central Hudson's assets varies by hazard (Table 1).** Substation assets are most vulnerable to extreme heat, although circuit breakers within switchgears are also vulnerable to flooding. Distribution assets are most vulnerable to flooding, although overhead structures are also vulnerable to extreme wind. Transmission assets are most vulnerable to extreme wind, although overhead conductors are also vulnerable to extreme precipitation and heat. Of the hazards, flooding, extreme precipitation, extreme wind, and extreme heat appear to be the greatest concerns. No asset types are found to be highly vulnerable to extreme cold and ice.

Based on these vulnerability findings, the study outlines a broad framework of adaptation options that can be used to address the vulnerabilities identified and will be built upon in the upcoming Resilience Plan.

This study fulfills the Climate Change Vulnerability Study requirement of Public Service Commission Case 22-E-0222. Central Hudson will also complete a Resilience Plan that will identify priority strategies to build resilience within the system through a framework that considers equity, cost effectiveness, and suitability to relevant climate hazards in the region.

Asset Types	Extreme Heat	Extreme Cold and Ice	Flooding	Extreme Precipitation	Extreme Wind
Transmission					
Line structures (poles/towers)	⬜	🟨	🟨	🟨	🟧
Conductors (overhead)	🟧	🟨	🟨	🟧	🟧
Conductors (underground)	🟨	⬜	🟨	🟨	⬜
Switching devices	⬜	🟩	🟩	🟩	🟩
Distribution					
Structures (overhead)	⬜	🟨	🟧	🟧	🟧
Conductors (underground)	🟨	⬜	🟧	🟧	⬜
Conductors (overhead)	🟨	🟨	🟩	🟩	🟧
Transformers (overhead)	🟩	🟩	🟩	🟩	🟩
Transformers (padmount)	🟩	🟩	🟨	🟨	🟩
Regulators (pole mounted)	🟨	🟩	🟩	🟩	🟨
Capacitors (pole mounted)	🟩	🟩	🟩	🟩	🟩
Switching devices	🟩	🟨	🟩	🟩	🟨
Surge arrestors	🟩	🟩	⬜	🟩	🟩
Reclosers	🟩	⬜	🟩	🟩	🟨
Manholes	🟩	🟩	🟨	🟨	⬜
Substations					
Substation transformers/ voltage regulators	🟧	🟩	🟨	🟨	🟨
Circuit breakers	🟧	🟩	🟧	🟧	🟨
Instrument transformers	🟨	⬜	🟩	🟩	🟩
Substation reactors	🟧	🟩	🟨	🟨	🟨
Controllers	🟨	🟩	🟩	🟩	🟩
Switching devices	🟨	🟨	🟨	🟨	🟨
Surge arrestors	🟩	🟩	⬜	🟨	🟩

Table 1. Vulnerability scores for all asset types and hazards. Orange = high, yellow = moderate, green = low, and gray = not applicable.

Introduction

Extreme weather and climate change impact New York State's economy, environment, and people.[1] Climate hazards are expected to continue and worsen in many cases. Extreme temperatures, heavy precipitation, and more frequent and widespread floods threaten the ability of energy utilities to deliver reliable power to customers. To respond to these hazards and support resilience planning, New York State (NYS) law[2] now requires combination gas and electric utilities in the state to each conduct a Climate Change Vulnerability Study (CCVS or "Study") and develop a Climate Change Resilience Plan (CCRP or "Plan"). Vulnerability studies help assess the impact of climate hazards on infrastructure, design specifications, and operational procedures. The study and plan must be updated at least every five years.

Central Hudson Gas & Electric (Central Hudson) is a regulated transmission and distribution utility serving customers in New York State's Mid-Hudson River Valley. To continue to serve its customers safely and reliably, Central Hudson is responding to climate impacts and NYS law through resilience planning. This report serves as the required study compliant with Case 22-E-0222 set forth by the NYS Public Service Commission (PSC). This Study will be followed by a CCRP that will identify strategies and opportunities to build resilience within the Central Hudson system by addressing vulnerabilities identified in this Study.

CLIMATE RESILIENCE IN THE ENERGY SECTOR

The importance of understanding climate vulnerabilities has been increasingly recognized as necessary to ensure safe and reliable service to customers. Several states besides New York have also developed requirements for utilities to focus their efforts on identifying climate vulnerabilities within their service territories. In addition to the recent New York State law described above requiring utilities such as Central Hudson to conduct a CCVS and develop a CCRP, California, Maine, and Connecticut have implemented similar requirements for utilities to evaluate vulnerabilities posed by climate hazards:

- **California.** The California Public Utilities Commission initiated Order Instituting Rulemaking (OIR) R.18-04-019 in 2018 to define climate change adaptation for energy utilities and promote efforts that work toward reliable and resilient service. In 2022 the Commission issued D.20-08-046, which requires investor-owned utilities to submit a Vulnerability Assessment, Community Engagement Plan, and a Disadvantaged Vulnerable Communities Survey Report.
- **Maine.** In 2022 Maine passed legislation to create greater accountability of transmission and distribution utilities. Part of the law requires transmission and distribution utilities to submit a 10-year climate change protection plan that addresses the expected effects of climate change on assets. It is required to be submitted no later than July 1, 2023, and must be updated every two years.
- **Connecticut.** In 2022 the Connecticut Public Utilities Regulatory Authority released Docket No. 17-12-03RE08, which requires utilities to

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[1] C. Rosenzweig, et al., (Eds.), "Responding to Climate Change in New York State: The ClimAID Integrated Assessment for Effective Climate Change Adaptation," Technical Report. Albany, NY: New York State Energy Research and Development Authority; 2011. https://www.nyserda.ny.gov/About/Publications/Energy-Analysis-Reports-and-Studies/Environmental-Research-and-Development-Technical-Reports/Response-to-Climate-Change-in-New-York.

[2] "Combination Gas and Electric Corporations; Administrative Sanctions; Recovery of Penalties," PBS Chapter 48, Article 1, Section 25-A, New York State Senate, accessed August 11, 2023, https://www.nysenate.gov/legislation/laws/PBS/25-A.

implement a resilience framework to evaluate capital programs. The proceeding requires electric distribution companies (EDCs) to determine whether the most cost-effective resilience solution has been chosen and assess how efficiently it has been implemented. In addition, EDCs are to conduct and submit a CCVS. The assessment will be later utilized as an input for future planning policies and to inform future iterations of the Reliability and Resilience Framework.

Beyond regulatory compliance, some utilities have also undertaken voluntary climate vulnerability studies. In 2019, Con Edison completed a climate vulnerability assessment due to an agreement in its post-Superstorm Sandy filing. Duke Energy has also performed a Climate Risk and Resilience Study to benefit its long-term planning and future investment projects.

ASSESSING CLIMATE VULNERABILITY

A CCVS is one step in a larger resilience planning process (Figure 1). Many different resilience planning frameworks exist. To develop the Steps to Resilience for the United States Climate Resilience Toolkit[3] (USCRT), the National Oceanic and Atmospheric Administration (NOAA) benchmarked climate risk management processes already in use in Europe and by U.S. federal agencies, including the Department of Energy's (DOE) *Climate Change and the Electricity Sector: Guide for Climate Change Resilience Planning*. NOAA's benchmarking process for the Steps to Resilience illustrates how resilience planning processes generally follow similar steps, which start with an assessment of vulnerability or risk.

Figure 1. U.S. Climate Resilience Toolkit Steps to Resilience.

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[3] "Assess Vulnerability & Risk," U.S. Climate Resilience Toolkit, last modified July 15, 2021, accessed August 10, 2023, https://toolkit.climate.gov/steps-to-resilience/assess-vulnerability-risk.

Within this first step, climate vulnerability and risk assessments vary. DOE's Vulnerability Assessment and Resilience Planning Guidance[4] develops a risk matrix to characterize vulnerability by considering the likelihood of climate hazards (exposure) and potential impact (determined through evaluation of the potential costs and consequences of inaction) to each critical asset and infrastructure system. The USCRT[5] combines exposure and sensitivity to generate potential impact, which helps evaluate whether a climate hazard can damage an asset. Magnitude of consequence is also accounted for in the USCRT approach, alongside probability of climate hazard to identify risk. The DOE matrix also applies a low-high scoring approach to allow results to be compared and ranked. Both frameworks build on work developed through the Intergovernmental Panel on Climate Change (IPCC).[6,7] Although the methodologies above contain slight nuances between each other and the approach adopted for this assessment, a common thread to all approaches is the consideration of how, if, and when assets are likely to be affected by specific climate hazards. Vulnerability assessments typically score assessed hazards in a matrix format.

Building on these methods and on work done for Con Edison in 2019, and with extensive input from Central Hudson subject matter experts (SMEs), ICF's team of resilience experts calculated vulnerability scores for each asset–hazard combination based on the asset's **exposure** to climate hazards, the asset's **sensitivity** to hazards, and the **consequences** of the asset's failure or degraded operations (Figure 2).

- **Exposure** is the degree to which assets could face climate hazards based on their physical locations.
- **Sensitivity** is the degree to which assets, operations, or systems could be affected by exposure.
- **Consequence** is defined as the potential for impacts to sensitive assets to result in negative outcomes for Central Hudson's system, customers, or staff.

As required by PSC, this Study evaluates the vulnerability of Central Hudson's infrastructure, design specifications, and procedures to climate-driven risks. In addition, this Study addresses geography and topography specific to Central Hudson's service territory and analyzes data and

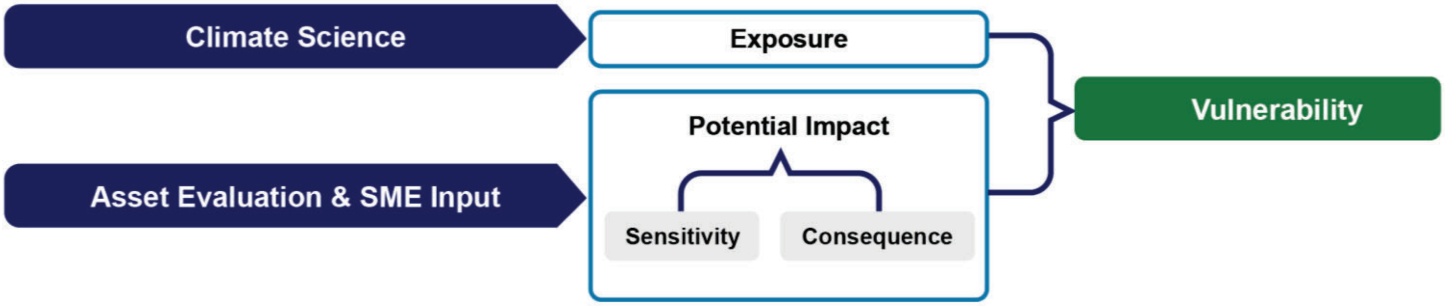

Figure 2. Vulnerability assessment process.

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[4] U.S. Department of Energy, *Vulnerability Assessment and Resilience Planning Guidance*, 2021

[5] "Assess Vulnerability & Risk," U.S. Climate Resilience Toolkit, last modified July 15, 2021, accessed August 10, 2023, https://toolkit.climate.gov/steps-to-resilience/assess-vulnerability-risk.

[6] Intergovernmental Panel on Climate Change, "Climate Change 2022: Impacts, Adaptation and Vulnerability," in *IPCC Sixth Assessment Report,* accessed August 10, 2023, https://www.ipcc.ch/report/ar6/wg2/.

[7] Christopher Field, et al. (eds.), Intergovernmental Panel on Climate Change, *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change* (Cambridge, UK: Cambridge University Press, 2012), 582.

impacts concerning expected changes in temperature, wind, precipitation, and sea level.

BASELINE ASSUMPTIONS

This Study presents a robust analysis using the best available climate science and datasets with several underlying assumptions. First, this Study assumes that the asset and systemwide operations data provided by Central Hudson represent the current state of the system. Second, this Study does not include the impacts of existing and future risk mitigations that may affect the vulnerability and resiliency of the system; rather, it focuses on the vulnerability of existing impacts and operations. Third, the Columbia University and the New York State Energy Research and Development Authority (NYSERDA) weather station-based exposure approach generalizes exposure across three weather stations in the vicinity of the service territory. One centrally located weather station, Mohonk, represents the climate for the majority of Central Hudson's service territory. This approach, while utilizing the best available data, potentially obscures regional differences in exposure to climate hazards. As future data and best practices for analyzing climate risk become available, Central Hudson will work with NYSERDA and PSC to update its analysis and ensure that the results in this report are as accurate and informative as possible.

SUMMARY OF PRIORITY HAZARDS

The scope of this report analyzes five key climate-related hazards: extreme heat, extreme cold, flooding (combining coastal and inland flooding), extreme precipitation, and extreme wind. ICF worked with Central Hudson SMEs to select these hazards based on historic impacts to the utility assets, as well as potential impacts in light of expected change over the next century.

Extreme heat: Both acute and chronic heat pose substantial challenges for reliable and safe delivery of electricity. Heat can limit the capacity of the grid to deliver power to customers and cause premature aging or sudden failure of many different critically important asset types. Climate change is expected to raise ambient temperatures and increase the frequency of extreme heat events (i.e., heat waves).

Extreme cold: While extreme cold is expected to substantially decrease in Central Hudson's service territory with climate change, it has posed challenges to the utility assets in the past and was included to document its shift in the risk that it poses to the system.

Flooding: Flooding poses a threat to a variety of assets. Because Central Hudson's service territory is largely upstream of the tidally influenced areas of the Hudson River, inland flooding is the primary type of flooding evaluated; however, sea level rise was also considered because it impacts the Hudson River.

Extreme precipitation: Extreme precipitation is a significant driver of inland flooding, especially during flash flood events. The northeastern United States has already experienced significant increases in extreme precipitation. Climate change is expected to continue to increase precipitation, and as a result it is critical to evaluate its impacts as part of this CCVS.

Extreme wind: Extreme wind can pose a significant threat to overhead transmission and overhead distribution assets and has resulted in many outages within the Central Hudson territory by downing trees and causing direct damage to conductors and overhead structures. As such, it was deemed important to understand how climate change may impact this hazard.

EQUITY IN RESILIENCE PLANNING

Equity is an increasingly important and deliberate part of energy resilience planning because the impacts of climate change are not distributed equally and can further exacerbate existing inequities (Energy Equity Project 2022). As part of the law giving rise to this CCVS, PSC requires that equity be explicitly considered as part of the CCRP. Additionally, the NYS Climate Leadership and Community Protection Act (CLCPA) of 2019 directs the entirety of the state government, including the NYS Department of Public Service and PSC, to consider equity in its planning and analysis efforts when addressing climate risk. Consistent with the CLCPA, equity must be considered in all investment decisions that stem from this climate analysis to ensure that disadvantaged communities are not disproportionately affected by environmental and climate change risks.

Equity in resilience planning often includes considerations of procedure (or process), distribution of benefits and impacts, and recognition of contextual factors that shape vulnerability. The CLCPA established a Climate Justice Working Group (CJWG) charged with the development of criteria to identify disadvantaged communities (DACs) based on socioeconomic data (e.g., energy burden, poverty rate) and the development of a process to gather public input. The resulting map of DACs helps provide a picture of the distribution of impacts and benefits and can complement Central Hudson's CCVS, which primarily focuses on physical climate hazards. Figure 3 maps disadvantaged communities in the Central Hudson service territory. Additionally, consistent with the above-referenced NYS law and PSC guidance, Central Hudson convenes an external working group to strengthen its understanding of context (contextual equity) and incorporate stakeholder feedback (procedural equity).

Central Hudson will specifically address equity concerns from the external working group in the development of the CCRP. Additionally, spatial comparisons can be drawn between the DAC and climate vulnerability data to help distribute and prioritize benefits associated with resilience strategies. Central Hudson may also consider more extensive engagement and capacity building efforts with customers in DACs as a resilience strategy. Finally, because all the factors that contribute to vulnerability change over time, the CCRP can address how to adaptively support different areas within its service territories when conditions change.

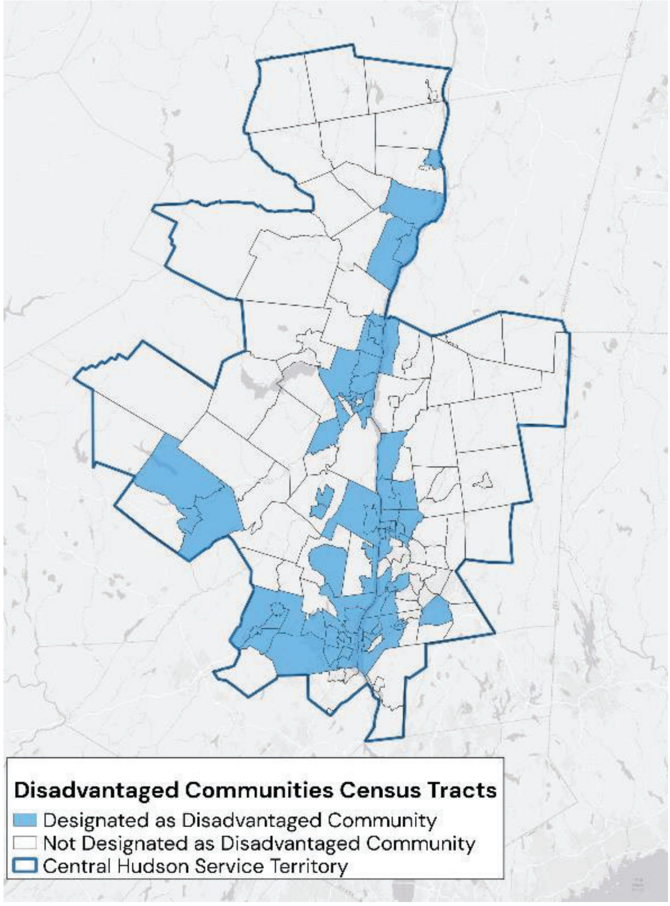

Figure 3. CJWG-designated disadvantaged communities in the Central Hudson service territory.

Historical Climate Data and Future Projections

Climate is the result of fluctuations in weather patterns and ocean conditions averaged over longer periods of time (e.g., months, seasons, years, decades). Climate varies on a year-to-year and decade-to-decade basis. For example, some climate patterns, such as the El Niño Southern Oscillation, can cause higher than average temperatures or precipitation in a given year. **Climate change** refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability over an extended period of time. Climate variability and change influence extreme weather events (e.g., a hurricane or a drought), although individual events are not always caused by climate change. Forward-looking climate projections are critical to understand how climate and extreme weather change over time and how different actions will impact future climate, particularly how human activity via greenhouse gas emissions affects Earth's climate. **Climate projections are not precise weather forecasts for a specific day in the future; rather, they equip Central Hudson with data to prepare for a range of potential future climate and extreme weather outcomes to improve system resiliency.**

To support the CCVS, the ICF Study team synthesized best available climate projections to help assess impacts on Central Hudson's system. First, the Study team worked with Central Hudson SMEs to identify and tailor climate variables based on historical conditions and impacts related to climate and extreme weather and priority hazards for New York State. Ultimately, the Study team identified variables related to extreme heat, extreme cold, extreme precipitation, coastal and inland flooding, sea-level rise, and extreme wind.

Climate projections of daily temperature and precipitation are primarily drawn from an ensemble of statistically downscaled Global Climate Model[8] (GCM) datasets developed by Columbia University in collaboration with NYSERDA. These datasets align with the latest climate science developed for the United Nations *IPCC Sixth Assessment Report* published in 2021, which is internationally considered the authoritative source of science on global climate change and impacts. The GCMs illustrate a range of possible climate futures, depending on both future global trends in greenhouse gas (GHG) emissions, the sensitivity of the climate system to those emissions, and other factors. Trends in GHG emissions are defined by Shared Socioeconomic Pathways (SSPs), developed for the Sixth Phase of the Coupled Model Intercomparison Project[9] (CMIP6). SSPs represent potential socioeconomic trajectories related to energy and land use, resource use, and governance, all of which affect GHG emissions. To avoid sensitivity to one model or to one SSP,

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[8] GCMs are models that integrate climate system components to generate future projected climate conditions. GCMs are critical to understanding how different actions will impact future climate, particularly how different greenhouse gas emissions pathways affect future climate. These models inform our understanding of how the climate has changed in the past and may change in the future.

[9] CMIP is a collaborative project among international organizations to advance and establish the state of climate science through a set of standardized climate model simulations. CMIP is the primary modeling framework featured in the United Nations' Intergovernmental Panel on Climate Change (IPCC) assessment reports, which assess global scientific, technical, and socioeconomic information regarding climate change.

climate scientists use an ensemble approach, combining results from multiple GCMs.

Columbia University statistically downscaled GCMs using historical weather observations across New York State to improve model bias and account for smaller-scale variations in climate across the service territory. The projections are relative to a historical baseline of observed climate data from 1981 to 2010 at each weather station. The Mohonk, Dobbs Ferry, and Albany weather stations were used for this Study. For each SSP, the results from the ensemble of statistically downscaled GCMs can be used to derive probability distributions. The Study team evaluated model-based probabilistic projections using the Columbia and NYSERDA model ensembles, developing projections for the 10th, 25th, 50th, 75th, and 90th percentiles for each SSP. To plan for and anticipate multiple climate futures, this Study focuses on three SSPs, one of which will be used as Central Hudson's climate change planning scenario for the CCRP:

- **SSP2-4.5 50th percentile scenario (lower bound):** Reflecting aggressive global GHG emissions reductions by mid-century and middle-of-the-road assumptions on climate system sensitivity.
- **SSP5-8.5 90th percentile scenario (upper bound):** Reflecting a *high-end, lower-likelihood* outcome from continued GHG emissions and high-end climate sensitivity.
- **SSP5-8.5 50th percentile scenario (likely planning scenario):** Reflecting a *middle-of-the-road* outcome from the failure of global GHG emissions reduction efforts and high-end climate sensitivity. This represents a high-risk aversion level in planning for future climate change.

The Study team focused on variables such as days with average ambient temperatures above 86°F and maximum five-day precipitation totals. In order to account for interannual and interdecadal variability in the daily temperature and precipitation datasets, the Study team calculated variables as 30-year averages surrounding each time horizon of interest. For example, data generated for 2050 averages daily data from 2036 to 2065, which can be used to summarize long-term averages of climate and extreme weather in the future. Consequently, variables are referenced throughout the document as being annual averages.

This analysis focuses on mid-century (2050) and late-century (2080) decadal time horizons to capture potential change over the course of the century relative to the baseline historical period. While the analysis in this Study focuses on mid-century and late-century timeframes, climate projections were developed for each decade from 2030 through 2080. The 2050 time horizon aligns with Central Hudson's infrastructure investment horizon and provides a useful comparison from baseline conditions. The 2080 time horizon spans the useful life of energy infrastructure and allows for assessment of climate conditions that are the result of current and future GHG emissions. This approach also aligns with other peer utilities in New York.[10]

Inland flooding was evaluated using present-day Federal Emergency Management Agency (FEMA) flood zones. The FEMA maps illustrate the extent of 100-year flood zones from rivers, streams, and tributaries across the service territory, except for territory in Columbia County where FEMA floodplain data is not available. Present-day FEMA flood maps are commonly used to estimate areas potentially exposed to flooding based on historical and present-day data, but they notably do not model future flood exposure based on projections. The frequency, magnitude, and duration of flooding are expected to increase as a result of climate change. However, in areas dominated by inland flooding (as opposed to coastal flooding), the extent

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[10] Con Edison, for example, also used near- (2030), intermediate- (2050), and long-term (2080) time horizons in its Climate Change Vulnerability Study.

of future flood risk is difficult to project accurately with the data available.

Coastal flooding was evaluated for tidally influenced portions of the Hudson River[11] using projections of 100-year tidal flood extent combined with projected sea level rise at midcentury (2050) and late century (2080). Sea-level rise projections were derived from tide gauge data provided by NYSERDA and Columbia University.[12] The annual 1% chance (or 100-year) coastal flood extent was derived from the Hudson River Flood Impact Decision Support System Version 2.[13] The Hudson River Flood Impact Decision Support System uses a dynamic water flow model combining tide, storm surge, sea level rise, and tributary freshwater inputs to the Hudson River to estimate floodplain extent.

Finally, regional projections for extreme weather hazards, such as extreme wind, ice storms, and cold snaps, are typically beyond the resolution of statistically downscaled GCMs. As a result, projections for these hazards relied on a broad review of recent scientific literature and historical data, including wind speeds from Central Hudson's weather station monitoring network.

For ice storms and cold snaps, a high impact and low likelihood (HILL) extreme weather scenario is provided for a severe multi-day ice storm followed by a cold spell. The HILL extreme weather scenario aims to supplement projections from Columbia's climate projections and provide a stress test of a potential climate hazard impacting Central Hudson's service territory. The HILL scenario uses historical analog events and climate projections to generate a near worst-case scenario that, while highly unlikely, portrays high-impact weather events under projected climate change. This scenario explores an event that could motivate an expanded set of resilience measures beyond system hardening alone and may help identify where a broader set of potential resilience investments may be needed.

EXPOSURE

Climate change could intensify current climate hazards in the Central Hudson service territory in several ways, including increasing frequency and intensity of extreme temperatures, driving more severe heavy precipitation events, and causing more frequent and widespread flooding. To support Central Hudson's understanding of these hazards under climate change, this Study considers *asset exposure* from projected climate-related changes that may occur in the Central Hudson service territory.

Exposure is the degree to which assets could face climate hazards based on their physical locations and is determined independently of asset sensitivity to climate. In combination with asset sensitivity to hazards and consequences of asset failure or degraded operations, asset exposure to climate hazards is used to calculate vulnerability scores in subsequent sections for each asset-hazard combination.

EXPOSURE METHODS

To map climate exposure in Central Hudson's service territory, the Study team used a nearest-neighbor approach to associate assets with the closest weather station and climate projections. The nearest-neighbor approach was chosen because it allowed assets to be assigned to the closest weather stations. The approach operates

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[11] Tidal portions of the tributaries were not evaluated as part of the coastal floodplain modeling and mapping analysis.
[12] Sea-level rise projections use the 50th percentile of the combined SSP2-4.5-medium confidence, SSP5-8.5-medium confidence, and SSP5-8.85-low confidence sea-level rise scenarios from the *IPCC Sixth Assessment Report* from three tide gauges in New York State: Battery, Montauk Point, and Albany/Troy Dam.
[13] Philip Orton et al., "Hudson River and Western Long Island Sound Flood Elevations from Tides, Storm Surge and Rainfall," New York, 2018, accessed August 10, 2023, http://www.ciesin.columbia.edu/hudson-river-flood-map/.
For technical and methodological information, see http://fidss.ciesin.columbia.edu/fidss_files/documents/Hudson_River_Flood_Impact_Decision_Support_Tool_Technical_Report.pdf.

under the assumption that climate patterns are more similar in closer proximities; it may not account for microclimates driven by topography or other factors.[14] Figure 4 shows the region-specific nearest-neighbor zones at each weather station that the Study team used, along with the NYSERDA climate regions.

Asset exposure to climate hazards was considered for Central Hudson's transmission and distribution lines, structures, and substations, as well as manholes, depending on sensitivity to each climate hazard. Table 2 summarizes the total asset coverage for Central Hudson's service territory.

To understand asset exposure to both inland and coastal flooding within Central Hudson's service territory, this analysis evaluates the intersection of flood extent with individual assets across the service territory. The Study team evaluated flood exposure by overlaying territory-wide geospatial flood extent on Central Hudson asset datasets to identify which assets would be exposed to flooding.

Last, the Study team assessed exposure to average and extreme wind speed and wind gusts across the full service territory, rather than on a climate-region basis, in order to align with available projections.

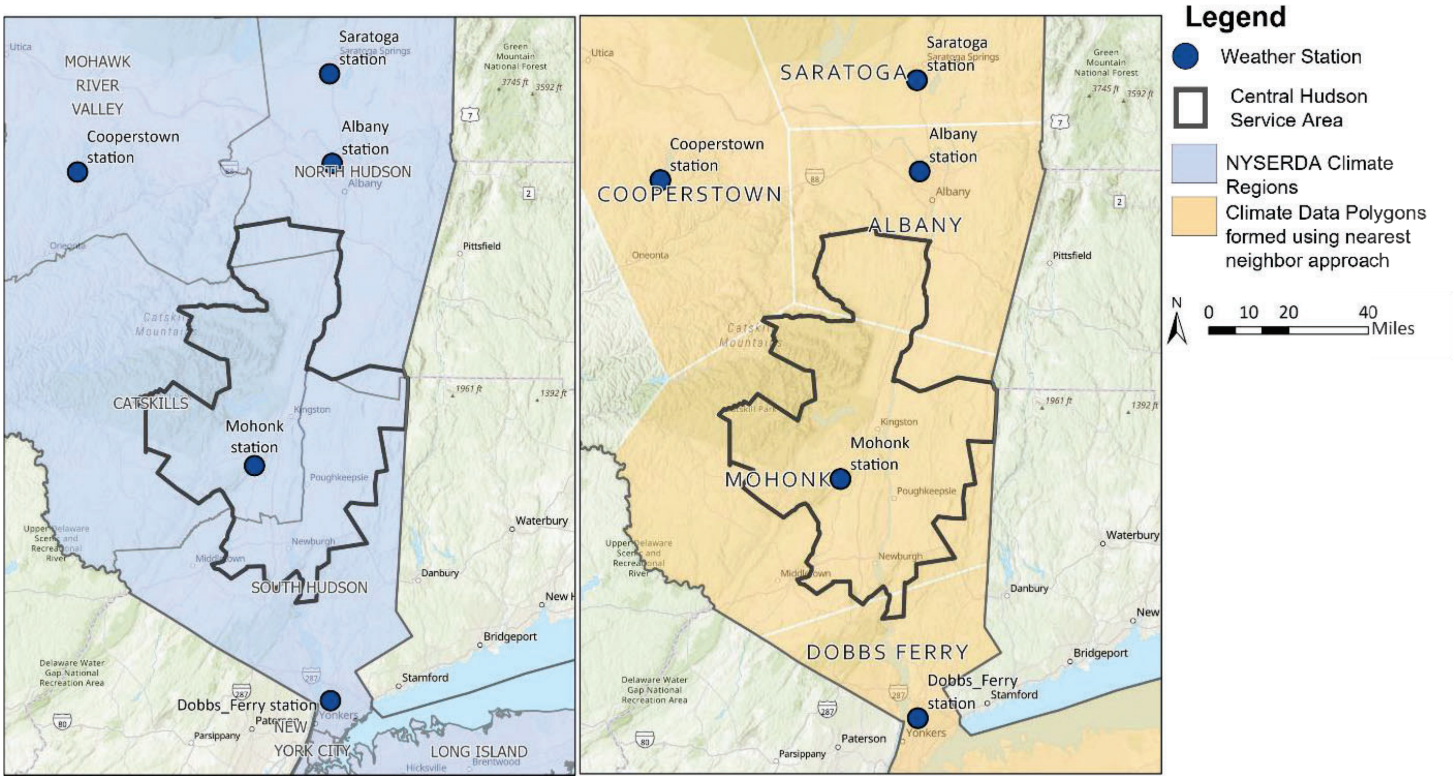

Figure 4. NYSERDA climate regions and weather stations (left) and polygons (right). The polygons were created using a nearest-neighbor approach representing the shortest distance within each location to a weather station. The final nearest-neighbor polygons are used in the asset exposure analysis.

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[14] For example, temperature distributions vary within and between each nearest-neighbor polygon, and these numbers should not be interpreted as exact projections for future time horizons at individual assets. Rather, if assets near one weather station are projected to experience 20 days each year above 86˚F, while assets near a second station are projected to experience 13 days each year, it is reasonable to infer that assets between the two stations are projected to experience between 13 and 20 days each year above 86˚F.

Asset Group	Asset Type	Total Count (number) or Distance (mi)
Distribution	Overhead distribution lines	7,137 miles
	Underground distribution lines	1,661 miles
	Distribution poles	263,569 poles
Transmission	Overhead transmission lines	593 miles
	Underground transmission lines	8 miles
	Transmission structures	8,576 structures
Substations	Substations	91 substations
Manholes	Manholes	602 manholes

Table 2. Total asset counts (poles, structures, substations, manholes) and line miles for Central Hudson's service territory.

EXPOSURE RESULTS

Service territory-wide exposure scores are summarized in Table 3 below, which uses the representative Mohonk weather station projections to estimate future changes in climate hazards, as this weather station covers the majority of the service territory and assets. Note that for flooding, service territory-wide exposure scores are assigned using proportional increase in the number of assets exposed. For extreme wind, exposure is assessed across the full service territory, rather than on a climate-region basis, using a combination of historical data and a broader understanding of future projections from the scientific literature cited in Section 3.3.5.

Exposure scores represent future magnitudes of change for each main climate hazard by mid-century (2050) and late-century (2080) relative to the historical baseline. Exposure scores follow the conceptual framework highlighted in Table 4 independent of asset sensitivity to climate.

Low	**Low:** Exposure to this hazard is likely to experience little to no change relative to historical conditions or will shift to more favorable climate conditions over time.
Moderate	**Moderate:** Exposure to this hazard is likely to experience change toward less favorable climate conditions over time, but the changes are likely to be of gradual or small magnitude.
High	**High:** Exposure to this hazard is likely to experience rapid or very high magnitude change toward less favorable climate conditions over time.

Table 4. Exposure score framework.

The following sections present site-specific exposures for each asset group, which were developed by overlaying climate projections (temperature and precipitation) and floodplains with select assets.

Extreme Heat Exposure

The overall asset exposure to extreme heat is projected to be **moderate** by mid-century and **high** by late-century. As temperatures warm through the 21st century, a greater proportion of Central Hudson's service territory could be exposed to a higher frequency and intensity of extreme heat and resulting high-load events.

	Extreme Heat			Extreme Cold			Flooding (coastal and inland flooding)			Extreme Precipitation			Extreme Wind		
	Present	2050s	2080s	Present	2050s	2080s	Present	2050s	2080s	Present	2050s	2080s	Present	2050s	2080s
Distribution	🟩	🟨	🟧	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟩	🟨	🟨
Transmission	🟩	🟨	🟧	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟩	🟨	🟨
Substation	🟩	🟨	🟧	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟩	🟨	🟨
Manholes	🟩	🟨	🟧	🟩	🟩	🟩	🟩	🟨	🟨	🟨	🟨	🟨	🟩	🟨	🟨

Table 3. Summary exposure scores for asset groups across the service territory in mid- and late-century.

Distribution lines and structures

Distribution assets are projected to experience moderate increases in extreme heat exposure by mid-century and substantial increases by late-century. For example, Figure 5 illustrates distribution line exposure to historical and projected days with daily maximum temperatures over 95◦F. Historically, distribution assets in the northern portion of the service area were exposed to one day each year with daily maximum temperatures over 95◦F, and assets in the southernmost portion were exposed to 3.5 days each year. Under the high-end SSP5-8.5 90th percentile scenario, distribution assets are projected to be exposed to 20 to 41 days each year of daily maximum temperatures above 95◦F across the service area by 2050.

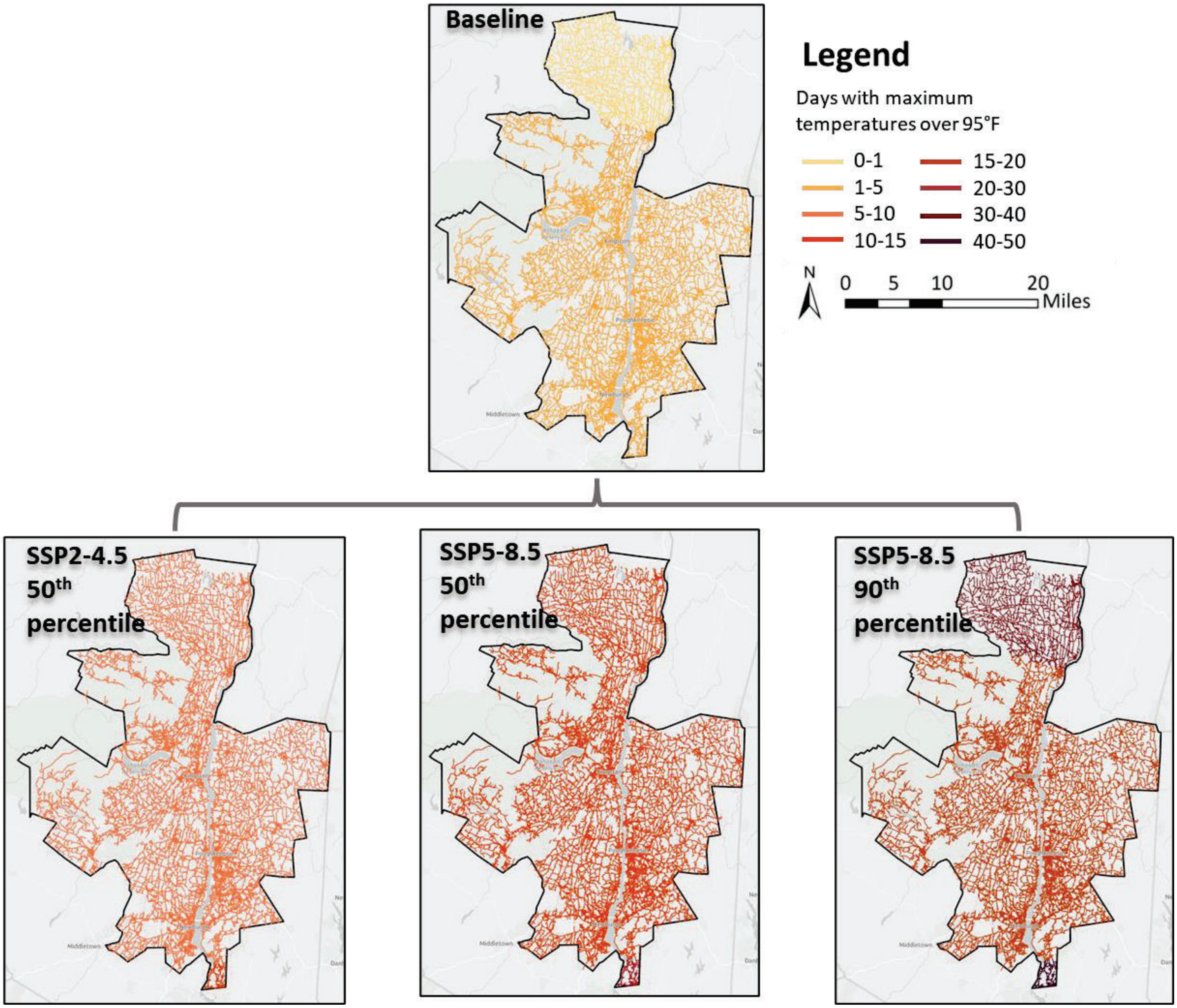

Figure 5. Distribution line exposure to the number of days each year with maximum temperatures exceeding 95◦F in 2050 under SSP2-4.5 50th percentile, SSP5-8.5 50th percentile, and SSP5-8.5 90th percentile climate change scenarios.

Transmission lines and structures

Transmission assets are also projected to experience moderate increases in extreme heat exposure by mid-century and substantial increases by late-century. For example, almost all transmission assets (99%) have historically been exposed to less than one day each year with daily average temperatures above 86°F. By 2050, transmission assets closest to Mohonk are projected to be exposed to 13 days each year, assets closest to Albany are projected to be exposed to 15 days, and assets closest to Dobbs Ferry are projected to be exposed to as many as 23 days each year with daily average temperatures above 86°F under the high-end SSP5-8.5 90th percentile scenario (Figure 6).

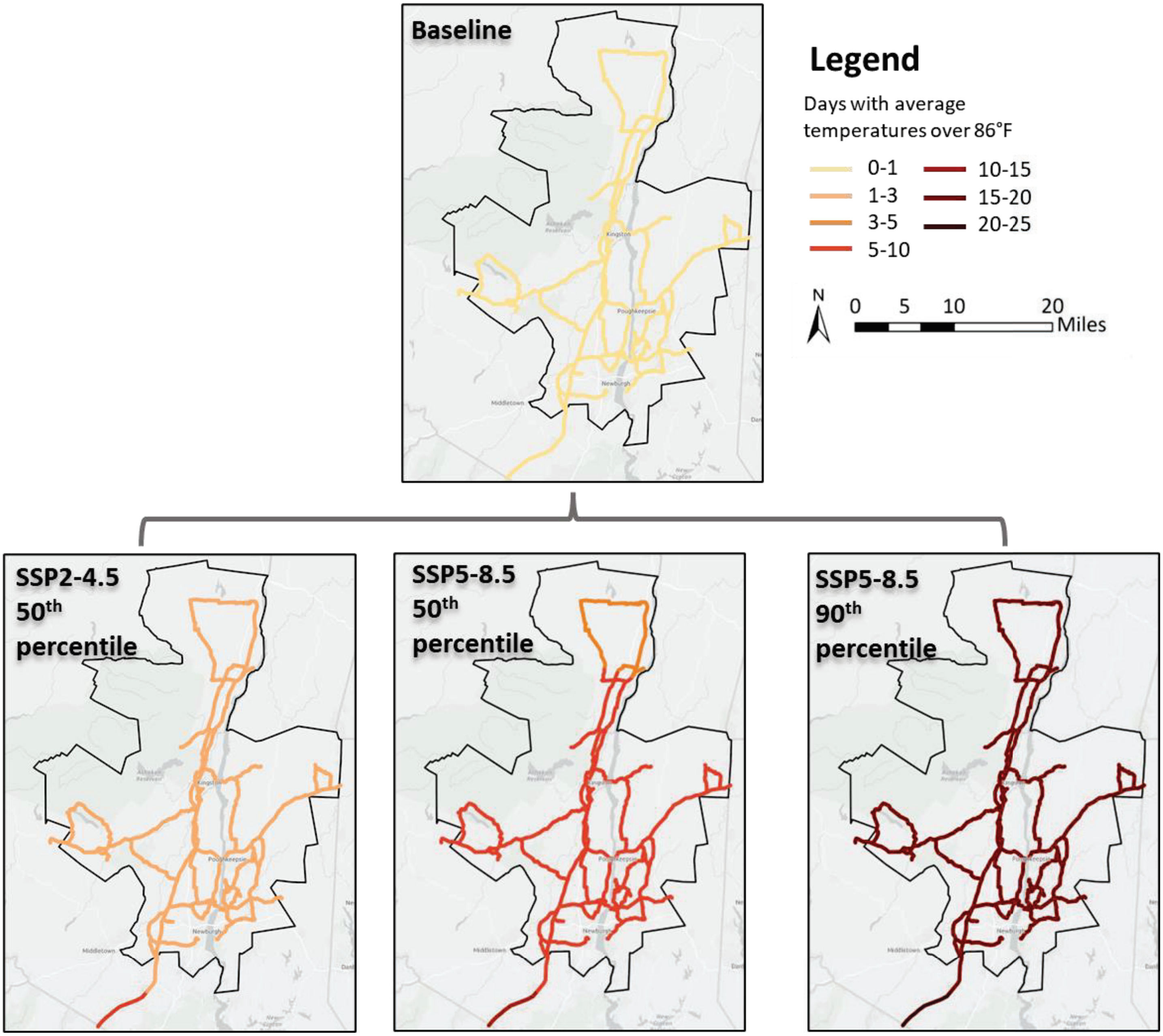

Figure 6. Transmission line exposure to the number of days each year with average temperatures exceeding 86°F in 2050 under SSP2-4.5 50th percentile, SSP5-8.5 50th percentile, and SSP5-8.5 90th percentile climate change scenarios.

Substations

Similar to transmission and distribution assets, substations are projected to experience increased exposure to extreme heat by mid- and late-century. For example, substations in Central Hudson's territory have historically never experienced daily maximum temperatures above 104°F (Figure 7). However, under the high-end SSP5-8.5 90th percentile scenario, substations closest to the Albany and Mohonk stations could be exposed to approximately two days, while substations closest to the Dobbs Ferry station could be exposed to more than seven days each year with temperatures exceeding 104°F by 2050.

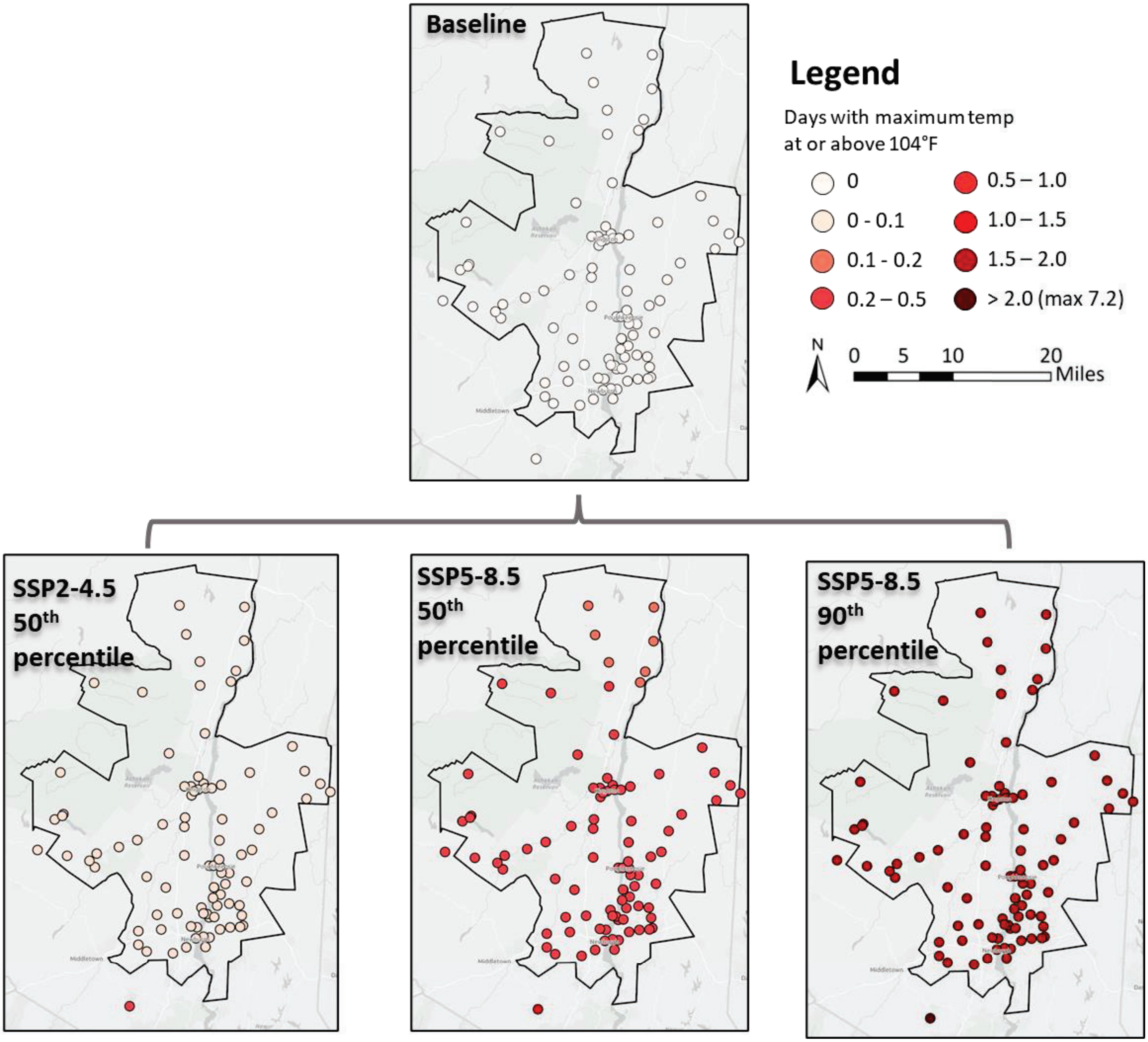

Figure 7. Substation exposure to the number of days each year with maximum temperatures exceeding 104°F in 2050 under SSP2-4.5 50th percentile, SSP5-8.5 50th percentile, and SSP5-8.5 90th percentile climate change scenarios.

Freezing and Extreme Cold Temperature Exposure

The overall asset exposure to freezing and extreme cold temperatures is projected to be **low** by both mid- and late-century. As temperatures warm through the 21st century, the frequency of freezing and extreme cold temperatures is projected to decrease, and a smaller proportion of Central Hudson's service territory could be exposed to extreme cold temperatures.

Distribution lines and structures

Distribution assets are projected to experience more favorable conditions in extreme cold by mid- and late-century. For example, distribution asset exposure could decrease to 68 days (from 139 days) closest to the Albany station, 56 days (from 124 days) closest to the Mohonk station, and 35 days (from 105 days) each year with daily minimum temperature below 32°F closest to the Dobbs Ferry station under the high-end SSP5-8.5 90th percentile scenario by 2050 (Figure 8).

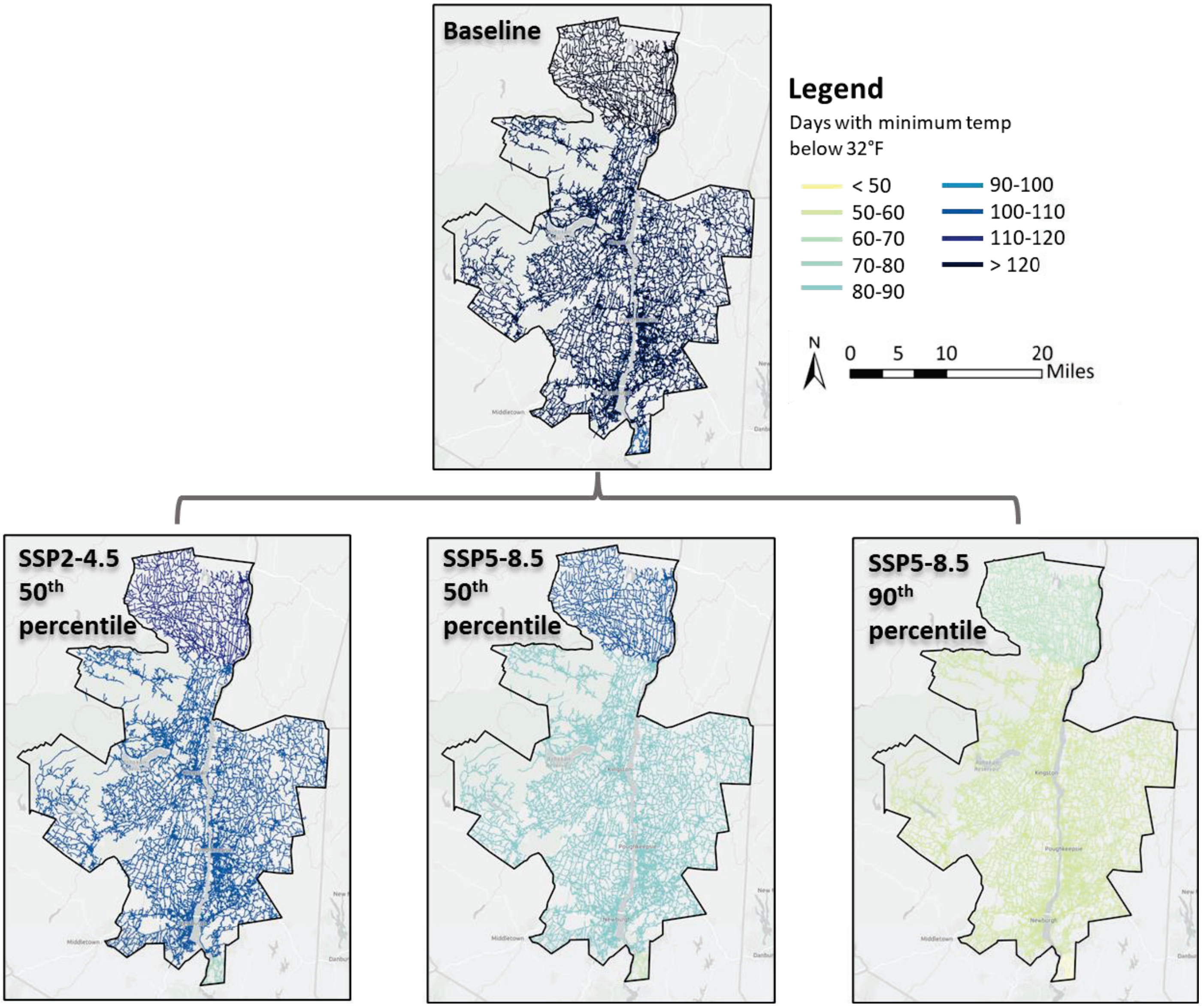

Figure 8. Distribution line exposure to the number of days each year with minimum temperatures below 32 °F in 2050 under SSP2-4.5 50th percentile, SSP5-8.5 50th percentile, and SSP5-8.5 90th percentile scenarios.

Transmission lines and structures

Transmission assets are also projected to experience more favorable conditions in extreme cold by mid- and late-century. For example, Figure 9 illustrates transmission line exposure to days each year with daily minimum temperatures below freezing. Similar to distribution assets, the majority of transmission assets (525 miles of overhead transmission lines and 7,699 structures, making up around 90% of all transmission assets in Central Hudson's service territory) are projected to be exposed to between 56 (SSP5-8.5 90th percentile) and 100 days (SSP2-4.5 50th percentile) each year with daily minimum temperatures below freezing in 2050 and between 4 (SSP5-8.5 90th percentile) and 67 days (SSP2-4.5 50th percentile) each year in 2080.

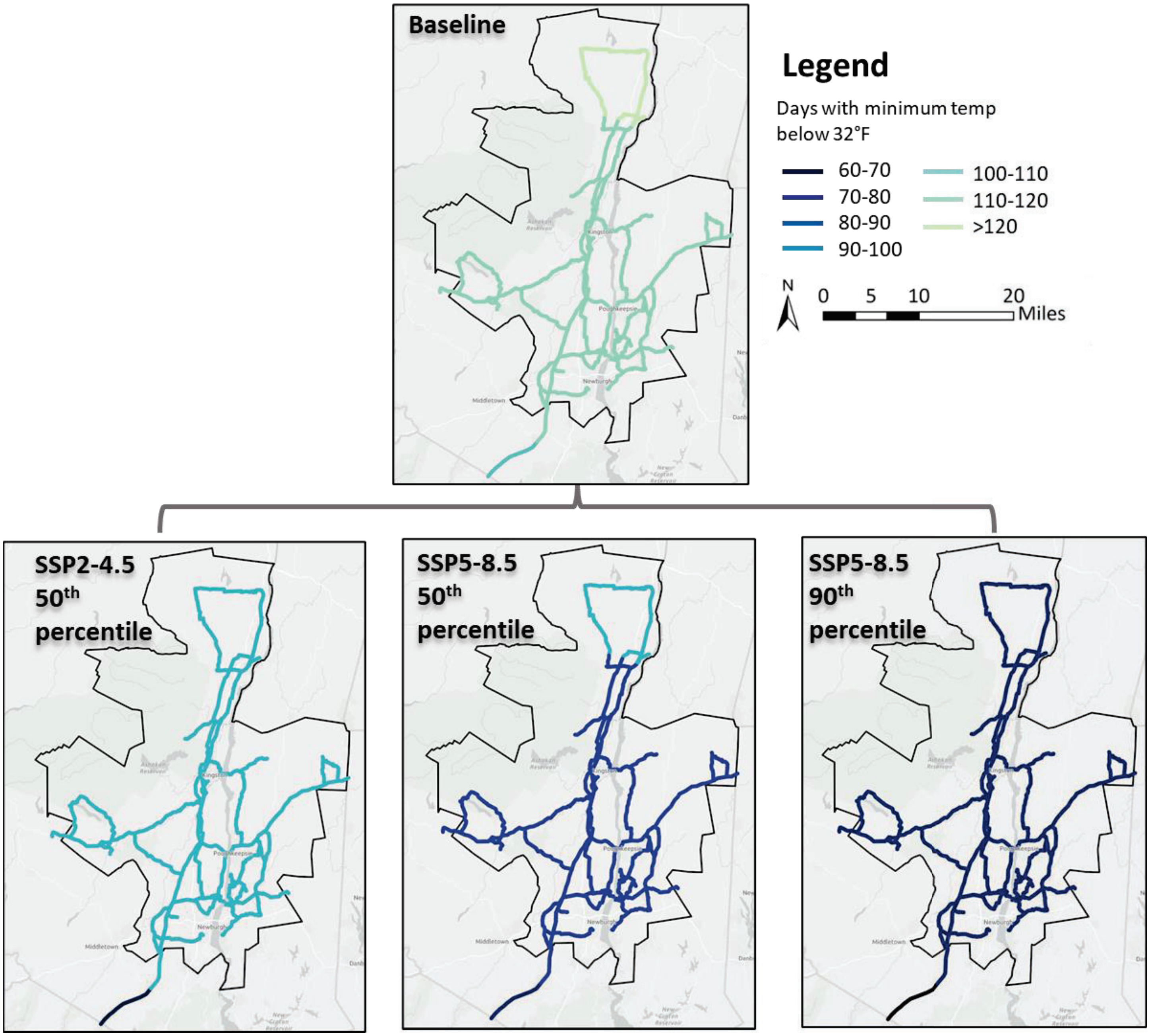

Figure 9. Transmission line exposure to the number of days each year with minimum temperatures below 32 °F in 2050 under SSP2-4.5 50th percentile, SSP5-8.5 50th percentile, and SSP5-8.5 90th percentile scenarios.

Extreme Precipitation Exposure

The overall asset exposure to extreme precipitation is projected to be **moderate** by both mid- and late-century. The intensity of the most extreme precipitation events is expected to increase, although the magnitude of change is not projected to be a major departure from present day. A greater proportion of Central Hudson's service territory, however, is projected to be exposed to higher-magnitude extreme precipitation.

Importantly, extreme precipitation projections are drawn from annual maximum *long-duration*, five-day precipitation totals, which do not capture pluvial flooding impacts from *short-duration*, high-intensity rainfall events leading to accumulation of water independent of floodplain. Pluvial (precipitation-based) flooding is most common in urban environments due to a greater area of impermeable surfaces. The scientific consensus is that the highest-intensity precipitation events may be increasing faster than lower-intensity events, indicating that urban areas may face increased exposure to these events. The *IPCC Sixth Assessment Report* explicitly states with high confidence that heavy precipitation events are very likely to increase in intensity and frequency with warming temperatures, with roughly a 7% increase in intensity for each 1˚C increase in global temperature.[15] At a local scale, intensity-duration-frequency curves developed by Cornell University for New York State[16] indicate that 1-in-25 year 24-hour precipitation intensities could increase up to 1 inch by 2085 (under a high-emission representative concentration pathway 8.5 scenario) through late-century at the Mohonk weather station.

Distribution lines and structures

Distribution assets are projected to experience moderate exposure to extreme precipitation by mid- and late-century relative to other climate hazards. For example, distribution assets closest to Mohonk have historically been exposed to maximum five-day precipitation totals of 5.2 inches. Looking ahead, distribution assets closest to Mohonk relative to other weather stations could experience an increase in maximum five-day precipitation totals upwards of 6.1 inches (17% increase over historic values) by 2050 and upwards of 6.8 inches (31% increase over historic values) by 2080 based on the high-end SSP5-8.5 90th percentile scenario.

Transmission lines and structures

Transmission assets are also projected to experience moderate exposure to extreme precipitation by mid- and late-century relative to other climate hazards. For example, transmission assets closest to Mohonk relative to other weather stations (i.e., 90% of all transmission lines and structures) have historically been exposed to maximum five-day precipitation totals of 5.2 inches. Looking ahead, transmission assets near Mohonk could experience an increase in maximum five-day precipitation totals upwards of 6.1 inches (17% increase over historic values) by 2050 and upwards of 6.8 inches (31% increase over historic values) by 2080, based on the high-end SSP5-8.5 90th percentile scenario.

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[15] Intergovernmental Panel on Climate Change, "Climate Change 2021: The Physical Science Basis," in *IPCC Sixth Assessment Report,* accessed August 11, 2023, https://www.ipcc.ch/report/ar6/wg1.

[16] "Intensity Duration Frequency Curves for New York State: Future Projections for a Changing Climate," Cornell University, accessed August 11, 2023, https://ny-idf-projections.nrcc.cornell.edu.

Substations

Substations are also projected to experience moderate exposure to extreme precipitation by mid- and late-century relative to other climate hazards. For example, most (94%) of Central Hudson's substations are closest to Mohonk relative to other weather stations and have historically been exposed to maximum five-day precipitation totals of 5.2 inches. Looking ahead, these substations could experience an increase in maximum five-day precipitation totals upwards of 6.1 inches (17% increase over historic values) by 2050 and upwards of 6.8 inches (31% increase over historic values) by 2080, based on the high-end SSP5-8.5 90th percentile scenario (Figure 10).

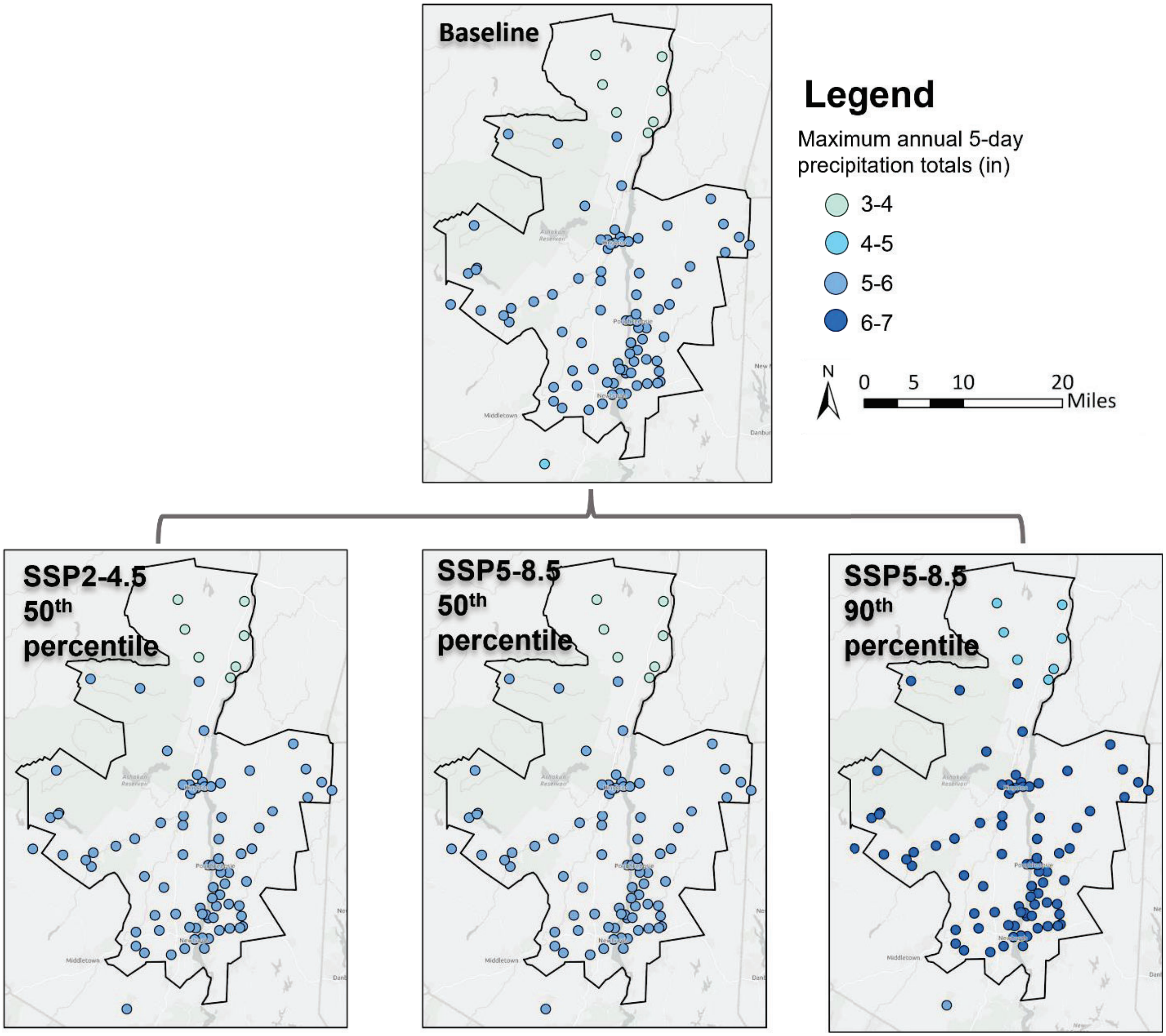

Figure 10. Substation exposure to maximum annual 5-day precipitation totals in 2050 under SSP2-4.5 50th percentile, SSP5-8.5 50th percentile, and SSP5-8.5 90th percentile scenarios.

Flooding (Inland Flood and Sea Level Rise) Exposure

The overall asset exposure to flooding (coastal and inland) is projected to be **moderate** by both mid- and late-century. While inland floodplains represent present-day climate, they demonstrate areas that may be vulnerable to flooding in the future. Due to projected increases in the intensity of the most extreme precipitation events, there could be a small increase in the number of assets exposed in the 100- and 500- year floodplains, which include tributaries to the Hudson River. The future floodplain extent is provided for coastal flooding. There could be increased exposure to coastal floodplains that results from 100-year storm surge combined with sea-level rise extending from tidally influenced portions of the Hudson River.[17]

Relatively few assets are exposed to inland flooding (Table 5). In the present-day 100-year floodplain, the asset type with the highest percentage of exposed assets is transmission structures, with 675 structures (8% of assets) located in the floodplain. This is followed by three substations (3%) and 10,731 distribution poles (4%). In the 500-year floodplain, a greater proportion of assets could be exposed as the floodplain extent increases. The most exposed asset types are transmission structures and substations, with 761 structures (9%) and six substations (7%) located in the floodplain. For the remaining asset types, 5% or less are exposed.

Asset exposure to coastal flooding is relatively low given the service territory's distance from the coastline (Table 6). However, a small proportion of assets could be exposed to coastal flooding from storm surge and sea-level rise along tidally influenced portions of the Hudson River. By 2050, 2 substations (2%), 7 manholes (< 1%), 1,153 distribution poles and 10.9 underground line miles (< 1% each), and 15 transmission structures (< 1%) are projected to be exposed to coastal flooding (inundation from 100-year storm surge plus 16 inches of sea-level rise). By 2080, 1 additional manhole, 165 additional distribution poles, 0.6 additional line miles, and 5 additional transmission structures are projected to be exposed to coastal flooding (inundation from 100-year storm surge plus 30 inches of sea-level rise).

FEMA Floodplain	Underground Distribution Line Miles	Distribution Poles	Transmission Structures	Manholes	Substations
100-year floodplain	54.5 (3%)	10,731 (4%)	675 (8%)	13 (2%)	3 (3%)
500-year floodplain	69.2 (4%)	14,258 (5%)	761 (9%)	25 (4%)	6 (7%)

Table 5. Number of assets exposed to the 100-year and 500-year FEMA floodplain.

Year	Sea-Level Rise Height (inches)	Underground Distribution Line Miles	Distribution Poles	Transmission Structures	Manholes	Substations
2050	16	10.9 (< 1%)	1,153 (< 1%)	15 (< 1%)	7 (< 1%)	2 (2%)
2080	30	11.5 (< 1%)	1,318 (< 1%)	20 (< 1%)	8 (< 1%)	2 (2%)

Table 6. Number of assets exposed to coastal flooding from the 100-year storm surge combined with sea-level rise by 2050 and 2080.

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[17] Tidal portions of the tributaries were not evaluated as part of the coastal floodplain modeling and mapping analysis, but tributaries are considered for present-day FEMA floodplains.

Distribution lines and structures

Distribution assets experience moderate exposure to inland flooding. For example, roughly 54.5 miles of underground distribution lines (3%) are exposed to the present-day 100-year inland floodplain and 69.2 miles (4%) are exposed to the present-day 500-year inland floodplain (Table 5). Exposed distribution assets in the present-day 100-year inland floodplain are clustered in Kingston and the southeastern part of the service territory covering a broad area to the east and southeast of Poughkeepsie, with increasing exposure near Kingston and Lake Katrine to the 500-year floodplain (Figure 11).

Less than 1% of underground distribution lines and aboveground poles are expected to be exposed to increased coastal flooding by 2050 and 2080. However, 11.5 miles of underground distribution lines and 1,318 distribution poles could be exposed as sea-level rise increases storm surge from the Hudson River beyond present-day boundaries (Table 6).

Transmission lines and structures

Transmission assets also experience moderate exposure to inland flooding. Of all asset types, transmission structures face the highest proportional exposure to inland flooding in the present-day 100-year floodplain, with 675 structures (8%) located in the floodplain (Table 5). Exposed transmission structures are distributed throughout the service territory, with clustered exposure near Kingston and in the areas north and south of Poughkeepsie. Comparatively more transmission structures are exposed in the present-day 500-year floodplain, with increased exposure primarily near the Hudson River and its tributaries.

Less than 1% of transmission structures are expected to be exposed to increased coastal flooding by 2050 and 2080. However, 20 transmission structures could be exposed by 2080 (Table 6).

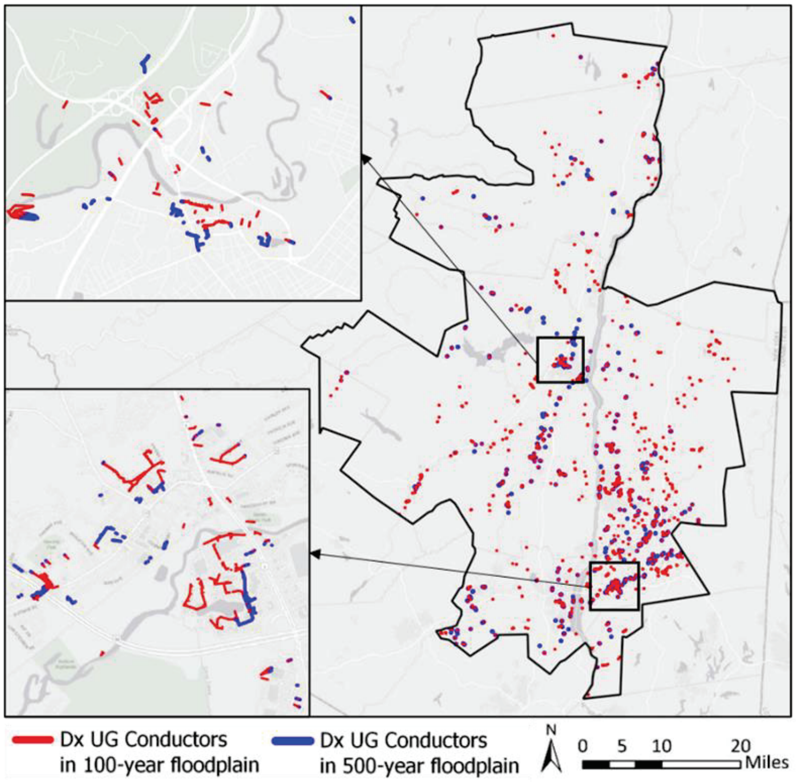

Figure 11. Underground distribution line (Dx UG Lines) exposed to the present-day FEMA 100- and 500-year floodplains, with an example zoom-in to demonstrate the dataset in more detail surrounding Kingston, New York. Lines that would be exposed under each floodplain are color-coded.

Substations

Substations also experience moderate exposure to inland flooding. Three substations (3%) are exposed in the present-day 100-year floodplain, while six substations (7%) are exposed in the present-day 500-year floodplain (Table 5). Of the three that are located in the 100-year floodplain, two are in the southeastern portion of the service territory, two are near Kingston, and one is in the western portion of the territory (Figure 12). Of the three additional substations in the 500-year floodplain, two are near Kingston and another is in the northwest portion of the service territory.

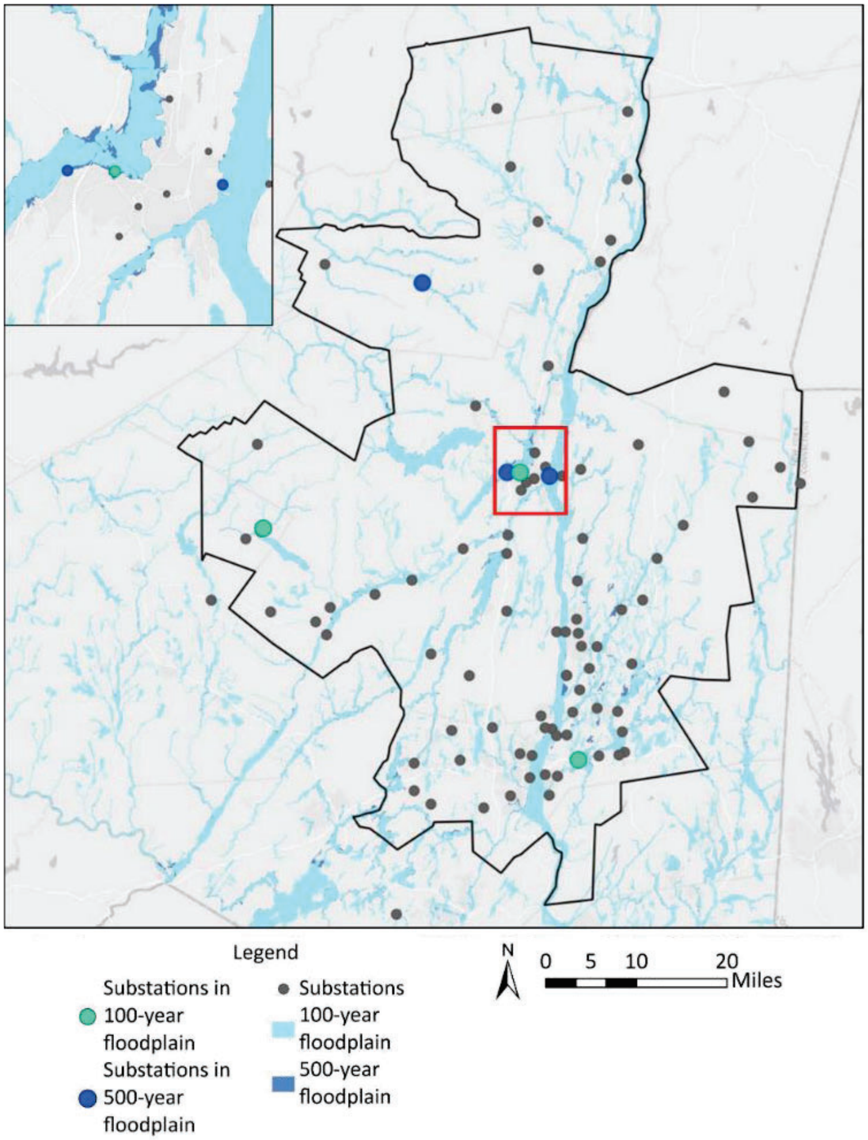

Figure 12. Substation exposure to the present-day FEMA 100- and 500-year floodplains, with an example zoom-in to demonstrate the dataset in more detail surrounding Kingston, New York. Substations that would be exposed under each floodplain are color-coded.

Substations could experience increased exposure to coastal flooding by mid- to late-century. Two substations (2% of assets) are exposed to sea-level rise with storm surge in both 2050 and 2080 (Table 6), both located near Kingston and Newburgh along the Hudson River (Figure 13).

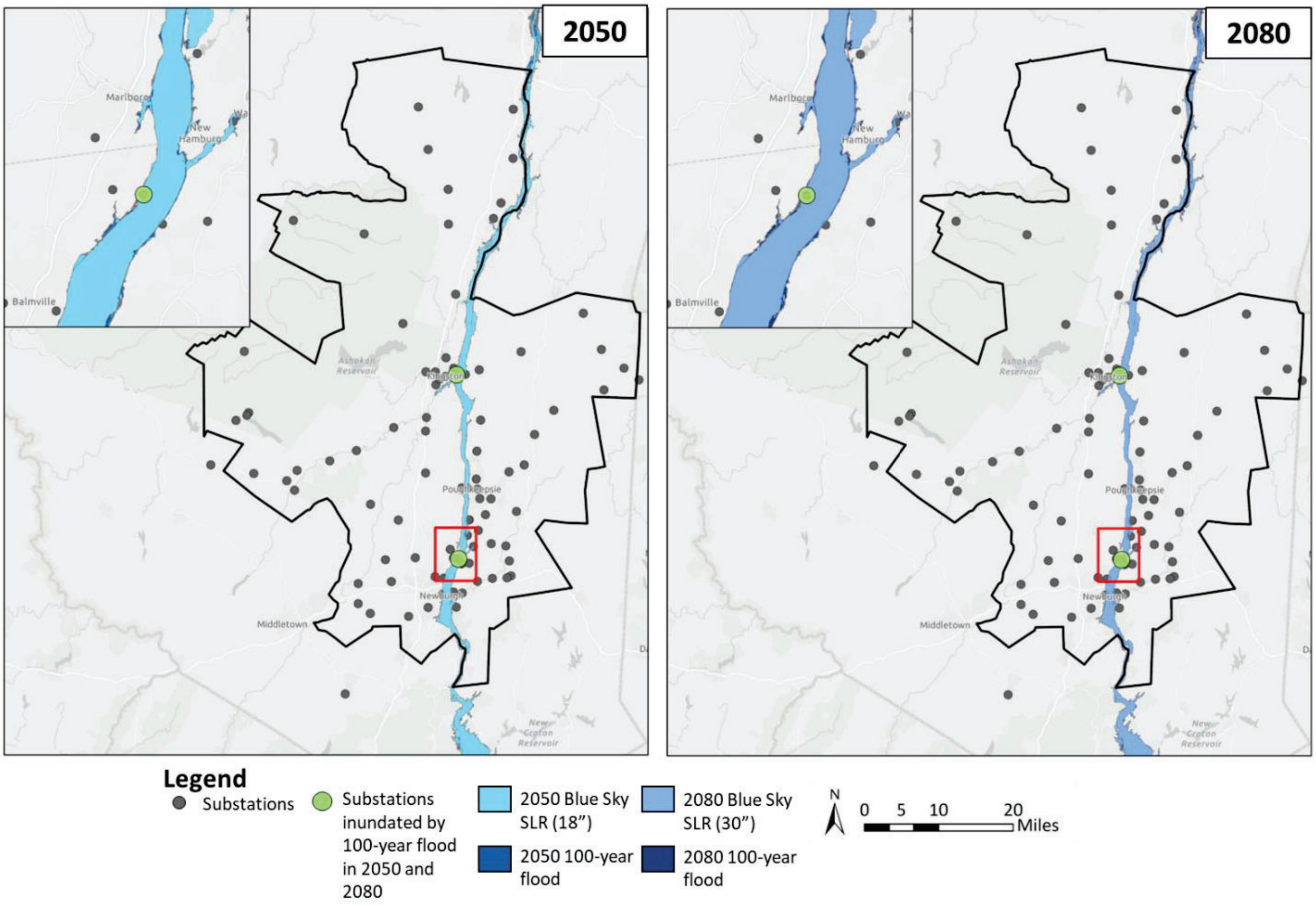

Figure 13. Substation exposure to the Hudson River floodplains under 2050 and 2080 sea-level rise (SLR) scenarios, with an example zoom-in to demonstrate the dataset in more detail surrounding Newburgh and Beacon, New York. Sea-level rise scenarios consider 100-year storm surge (100-year flood) and no storm surge (SLR Blue Sky). Substations that would be exposed under each floodplain are color-coded.

Manholes

Last, manholes experience the lowest number of assets exposed to inland flooding, as most are installed in more populated municipalities farther from bodies of water. Thirteen manholes (2% of assets) are exposed to the present-day 100-year floodplain, and 25 manholes (4%) are exposed to the present-day 500-year floodplain. Most of these exposed manholes are clustered around Kingston, Newburgh, and Poughkeepsie, with increased exposure to the 500-year floodplain surrounding Kingston and Newburgh near the Hudson River (Figure 14).

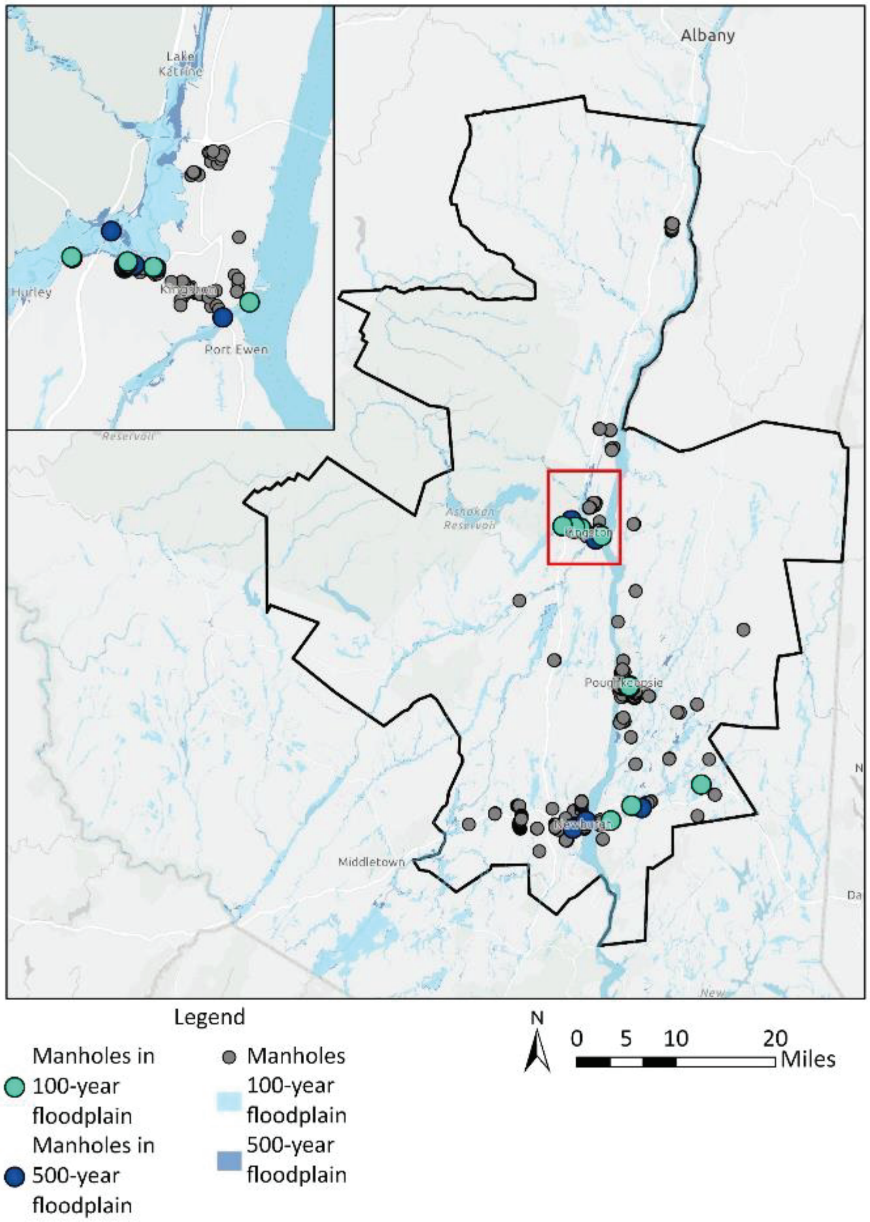

Figure 14. Manhole exposure to the present-day FEMA 100- and 500-year floodplains, with an example zoom-in to demonstrate the dataset in more detail surrounding Kingston, New York. Manholes that would be exposed under each floodplain are color-coded.

Seven manholes are projected to be exposed to coastal flooding by 2050, increasing to eight manholes by 2080, representing fewer than 1% of manholes (Table 6). The exposed manholes would mainly be located in nearby Kingston, Poughkeepsie, and Newburgh near the Hudson River (Figure 15).

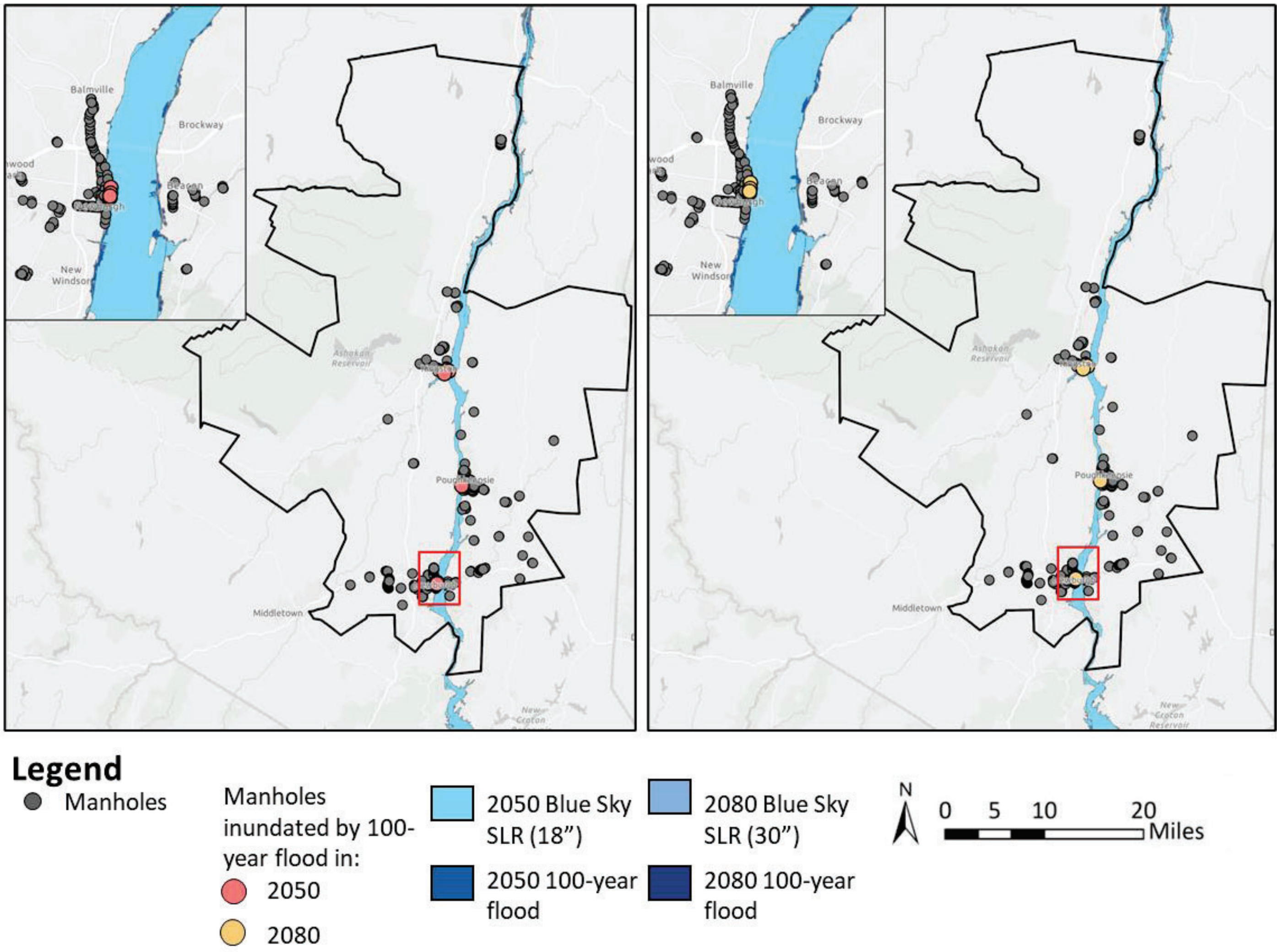

Figure 15. Manhole exposure to the Hudson River floodplains under 2050 and 2080 sea-level rise (SLR) scenarios, with an example zoom-in to demonstrate the dataset in more detail surrounding Newburgh and Beacon, New York. Sea-level rise scenarios consider 100-year storm surge (100-year flood) and no storm surge (SLR Blue Sky). Manholes that would be exposed under each floodplain are color-coded.

Extreme Events – Extreme Wind

The overall asset exposure to wind is projected to be **moderate** by both mid- and late-century. While average wind speed is projected to change minimally across the service territory, the most extreme wind speeds and gusts are projected to increase in both frequency and intensity.

Overall Asset Exposure to Extreme Wind

A broad review of recent scientific literature and historical data indicates that there could be moderate change to the historical profile of extreme wind patterns across the Central Hudson service territory by both mid- and late-century. The limited quantitative modeling studies on future wind speed projections suggest that extreme wind, low probability, and high-impact wind speeds and gusts that occur during tropical cyclones and thunderstorms are projected to increase in intensity and frequency across the service territory. For example, one study indicates that maximum 3-second wind gusts could increase from 80 miles per hour (mph)[18] (1973–2017) to 110 mph (2017–2050) by mid-century, and even less frequent 700-year wind gusts could increase from 115 mph present-day to 124 mph by mid-century,[19] consistent with a projected increase in wind speeds of North Atlantic tropical cyclones of roughly 8% per decade.[20] While models project a minimal trend in *average* wind speed, suggesting that exposure to chronic (consistent) high wind speed will be low, exposure to extreme winds is projected to increase by mid-century. Extreme winds often occur during thunderstorm and severe weather outbreaks (derecho) in the region. During these severe storms, tornadoes have the potential to produce damaging winds exceeding hurricane-force wind speeds. Evaluating Central Hudson's weather station inventory,[21] most weather stations in the service territory experienced average 10-second wind speeds in the range of 2–6 mph, while maximum one-hour peak wind gusts ranged from 43 to 70 mph. The peak wind gust of 70 mph was recorded at the Saugerties weather station during a severe weather outbreak (derecho) on May 15, 2018.[22]

Overall, there is limited scientific evidence that the Central Hudson service territory will experience an increase in *average* wind speeds through mid-century. Northern Hemisphere average wind speeds are projected to change marginally or decrease through the 21st century,[23] with similar trends projected across North America.[24] In the Hudson Valley, projected increases in average daily wind speed could range from 0 to 1 mph (approximately 0% to 5% increase) during the period of 2025–2041 relative to 2006–2020. Projections for extreme hourly-averaged wind speeds exhibited minimal change through 2041 (increases on the order of 0–2 mph or upwards of a 3% increase),[25] suggesting that hourly extreme wind magnitudes in the Central Hudson service territory may not change significantly by mid-century.

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[18] Recorded during Hurricane Sandy on October 29–30, 2012, near New York City. See: Daniel Comarazamy, Jorge E. González-Cruz, and Yiannis Andreopoulos, "Projections of Wind Gusts for New York City Under a Changing Climate," *Journal of Engineering for Sustainable Buildings and Cities* 1, no. 3 (August 2020):031004, https://doi.org/10.1115/1.4048059.

[19] Daniel Comarazamy, Jorge E. González-Cruz, and Yiannis Andreopoulos, "Projections of Wind Gusts for New York City Under a Changing Climate," *Journal of Engineering for Sustainable Buildings and Cities* 1, no. 3 (August 2020):031004, https://doi.org/10.1115/1.4048059.

[20] James Kossin, et al., "Global Increase in Major Tropical Cyclone Exceedance Probability Over the Past Four Decades," *Proceedings of the National Academy of Sciences of the United States of America* 117, no. 22 (2020), https://dx.doi.org/10.1073/pnas.1920849117.

[21] Sourced from weather station inventory of hourly maximum and average wind speeds and wind gusts provided by Central Hudson's monitoring network. Peak wind gusts were cross-referenced with known historical events to determine maximum recorded wind speeds (e.g., extreme wind speed of 89 mph on a calm weather day was flagged as an observational error).

[22] "May 15, 2018 Severe Weather Outbreak," NOAA National Weather Service, accessed August 11, 2023, https://www.weather.gov/okx/SevereEvent051518.

[23] Jinlin Zha, et al., 2021, "Projected Changes in Global Terrestrial Near-Surface Wind Speed in 1.5° C–4.0° C Global Warming Levels," *Environmental Research Letters* 16, no. 11 (2021):114016, https://doi.org/10.1088/1748-9326/ac2fdd.

[24] Dae Jeong and Laxmi Sushama, "Projected Changes to Mean and Extreme Surface Wind Speeds for North America Based on Regional Climate Model Simulations," *Atmosphere* 10, no. 9 (2019):497, https://doi.org/10.3390/atmos10090497.

[25] Komurcu and Paltsev, "Toward Resilient Energy Infrastructure: Understanding the Effects of Changes in the Climate Mean and Extreme Events in the Northeastern United States," *Joint Program Report Series Report,* no. 352 (June 2021):16, http://globalchange.mit.edu/publication/17608.

The findings of these studies indicate that the most intense, low probability wind gusts may increase significantly in magnitude by mid-century. Although daily average wind speed is not projected to be heavily impacted by climate change, the most extreme winds and wind gusts during severe weather events could increase by the end of the 21st century. New York City and surrounding areas, for example, are projected to experience higher future maximum wind gusts through 2050 under a high-end representative concentration pathway (RCP) 8.5 scenario,[26] leading to an increase to 110 mph by mid-century from the recent 1973–2017 maximum wind gust of 80 mph. The historical 700-year return period event is currently 115 mph and could increase to 124 mph during the period 2017–2050.[27]

The potential for higher-intensity tropical cyclones will likely increase during the 21st century in the North Atlantic basin. Globally, hurricane maximum sustained wind speed intensity is expected to increase under climate change, with uncertain changes to overall hurricane frequency. Future tropical cyclones are projected to have higher maximum-sustained wind speeds, a larger radius of hurricane force wind speeds, and will be more likely to reach major hurricane status (hurricane scale 3 or above).[28]

Overall, wind associated with severe storms and extreme weather, such as tornadoes, could increase in New York during the 21st century. In the Hudson Valley, extreme winds most commonly occur during severe storms, such as thunderstorms. Severe storms are bolstered by energy from unstable atmospheric conditions which are quantified using Convective Available Potential Energy (CAPE). Several studies project that warming surface temperatures and increases in moisture availability could drive global increases in average CAPE. Models also project that increases in CAPE and favorable conditions for severe weather could be largest in the summertime, leading to increased potential for thunderstorm activity and extreme wind events.[29]

Extreme Events – Ice Storm Followed by a Cold Spell HILL Scenario

Due to the low likelihood and specific nature of HILL scenarios, asset exposure to ice storms followed by a cold spell is not scored. Projected directional trends in ice storms and cold snaps can be assessed, however. Overall, despite high uncertainty in future trends, models project decreasing frequency (or likelihood) of ice storms, but the ice accumulation of the highest-intensity ice storms could increase. Climate change is also projected to lead to warmer winter temperatures and reduced cold spell frequency.

Overall Projections

A broad review of recent scientific literature and historical data indicates that, while the frequency of ice storms and cold spells is projected to decrease across the Central

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[26] Developed for and used in the Fifth Phase of the Coupled Model Intercomparison Project (CMIP5), RCPs represent a range of scenarios that depict how global greenhouse gas concentrations could evolve over the course of this century. Developed for the updated CMIP6 simulations, SSPs represent a range of future climate change scenarios *and development pathways* that encompass various trajectories of global greenhouse gas emissions. The CMIP5 RCP 8.5 scenario is most comparable to the CMIP6 SSP5-8.5 scenario used in this exposure assessment.

[27] Daniel Comarazamy, Jorge E. González-Cruz, and Yiannis Andreopoulos, "Projections of Wind Gusts for New York City Under a Changing Climate," *Journal of Engineering for Sustainable Buildings and Cities* 1, no. 3 (August 2020):031004, https://doi.org/10.1115/1.4048059.

[28] Intergovernmental Panel on Climate Change, "Climate Change 2021: The Physical Science Basis," Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 2021 [Masson-Delmotte, V., et al. (eds.)]. Cambridge University Press, doi:10.1017/9781009157896, https://www.ipcc.ch/report/ar6/wg1.

Thomas Knutson, et al., "Tropical Cyclones and Climate Change Assessment: Part II: Projected Response to Anthropogenic Warming," *Bulletin of the American Meteorological Society* 101, no. 3 (2020):E303-E322, https://doi.org/10.1175/BAMS-D-18-0194.1.

[29] H.E. Brooks, "Severe Thunderstorms and Climate Change," *Atmospheric Research,* 123 (2012):129–138, https://doi.org/10.1016/j.atmosres.2012.04.002.

Anthony Del Genio, et al., "Will Moist Convection Be Stronger in a Warmer Climate?" *Geophysical Research Letters* 34, no. 16 (2007): L16703, http://dx.doi.org/10.1029/2007GL030525.

Robert Trapp, et al., "Transient Response of Severe Thunderstorm Forcing to Elevated Greenhouse Gas Concentrations," *Geophysical Research Letters* 36, no. 1 (2009): L01703, http://dx.doi.org/10.1029/2008GL036203.

Hudson service territory, the ice accumulation of the most intense ice storms may increase by mid- to late-century. The projected increase in temperature and projected decrease in the number of days each year below freezing, however, suggest that by late century, cold spells following ice storms may not last as long as present day and may have a warmer peak intensity. However, climate change does not preclude the occurrence of cold snaps, and some evidence suggests that complex processes amplified by climate change could worsen some cold spells, such as polar vortex events.

Models project that winter storms will experience a decrease in frequency as temperatures warm, which may lead to more *liquid* precipitation. Even though the overall likelihood of a winter storm with frozen precipitation is projected to decrease, leading to decreases in the frequency of frozen precipitation events in the future, winter storms could produce frozen precipitation at a higher intensity than present day if the atmospheric conditions are cold enough at the surface to support freezing rain.[30] These findings suggest that when ice storms occur, they could be more intense, even though the frequency of these storms is projected to decrease.

The likelihood of more extreme freezing rain events is also projected to shift farther north as temperatures warm over the region,[31] leading to a decrease in the number of hours of freezing rain.[32] In addition, the total annual freezing precipitation under several warming scenarios is projected to decrease south of the Canadian-U.S. border,[33] leading to a precarious north-south contrast in future icing intensity trends as temperatures warm. This trend is consistent with recent observations of a gradual northward migration of the rain-snow transition zone across the United States.[34]

Global climate models project the likelihood of the most extreme cold spells to decrease by mid- to late-century. To identify areas with cold temperature risk in Central Hudson's service territory, the Study team evaluated future cold temperature frequency and intensity using statistically downscaled global climate model projections developed by Columbia University with NYSERDA. Specifically, the Study team evaluated projections for future annual daily minimum temperature (i.e., the coldest temperature each year) and the number of days each year with daily minimum temperature below 32°F (or freezing), the threshold at which liquid precipitation freezes at the surface. Columbia projections of 30-year averaged annual coldest daily minimum temperature at the Mohonk weather station suggest the service territory could experience increases from -5°F in the historical baseline to approximately 6.2°F and 12.9°F by 2050 and 2080, respectively, based on SSP5-8.5 50th percentile projections. While the projected coldest temperature increases, it would still remain well below freezing, suggesting that both extreme cold spells and freezing rain could still occur through the 21st century, although the cold temperature extremes are projected to be less pronounced. Consistent with coldest temperatures increasing, Columbia projections of 30-year averaged annual number of days with daily

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[30] Colin Zarzycki, "Projecting Changes in Societally Impactful Northeastern U.S. Snowstorms," *Geophysical Research Letters* 45, no. 21 (2018): 12067–12075, https://doi.org/10.1029/2018GL079820.

[31] Chad Shouquan Cheng, Guilong Li, and Heather Auld, "Possible Impacts of Climate Change on Freezing Rain Using Downscaled Future Climate Scenarios: Updated for Eastern Canada," *Atmosphere-Ocean* 49, no. 1 (2011): 8–21, https://doi.org/10.1080/07055900.2011.555728.
Steven Lambert and Bjarne Hansen, "Simulated Changes in the Freezing Rain Climatology of North America Under Global Warming Using A Coupled Climate Model," *Atmosphere-Ocean* 49, no. 3 (2011): 289–295, https://doi.org/10.1080/07055900.2011.607492.

[32] Christopher McCray et al., "A Multi-Algorithm Analysis of Projected Changes to Freezing Rain Over North America in an Ensemble of Regional Climate Model Simulations," *Journal of Geophysical Research: Atmospheres* 127*,* no. 14 (2022): e2022JD036935, https://doi.org/10.1029/2022JD036935.

[33] Dae Jeong, Alex Cannon, and Xuebin Zhang, "Projected Changes to Extreme Freezing Precipitation and Design Ice Loads Over North America Based on a Large Ensemble of Canadian Regional Climate Model Simulations," *Natural Hazards and Earth System Sciences* 19, no. 4 (2019): 857–872, https://doi.org/10.5194/nhess-19-857-2019.

[34] David Easterling et al., "Chapter 7: Precipitation Change in the United States," in *Climate Science Special Report: Fourth National Climate Assessment, Volume I,* 2017, U.S. Global Change Research Program, https://doi.org/10.7930/J0H993CC.

minimum temperature below 32°F at the Mohonk weather station show a decrease from 124 days per year to 100, 87, and 73 days per year in 2030, 2050, and 2080, respectively.

Despite a projected decrease in frequency of ice storms and cold spells and increase in maximum intensity of ice storms, future changes to the intensity of ice storms and cold spells come with a high degree of uncertainty due to the specific atmospheric conditions required to occur relative to other high-impact hazards, particularly ice storms.[35]

Future Narrative

To illustrate a potential HILL event, the Study team compiled an extreme "near worst-case scenario" for mid-century in which a severe multi-day ice storm followed by a cold spell impacts the Central Hudson service area. The purpose of this narrative is to explore a potential future extreme event that could motivate an expanded set of resilience measures beyond system hardening alone, informing areas where a broader set of potential resilience investments may be needed. For example, the cascading impacts of a severe ice storm followed by a prolonged cold spell could necessitate investments related to system recovery following a prolonged outage. This narrative highlights a scenario that is extreme and highly unlikely but portrays a high-impact event that could occur under projected climate change by mid-century.

In this HILL scenario, a strong, relatively warm low-pressure system slowly approaches the service territory before colliding with an anomalously cold air mass. This leads to snow, sleet, and freezing rain for much of eastern New York State. The greatest ice accumulations occur in the northern Hudson Valley, with high snowfall totals to the north in the Adirondacks. Freezing rain causes ice accumulations ranging from trace amounts to over an inch across a large portion of eastern New York, including the service territory. Wind gusts from this system reach over 70 mph near the storm center between Mohonk and Poughkeepsie. As the storm moves out of the region, northerly winds on the backend of the storm draw in cooler arctic air from the north, leading to temperatures below 0°F across most of eastern New York State. The coldest overnight minimum temperatures range from -30°F in Albany to -25°F in Poughkeepsie and remain below freezing for one week after the event exits the region, enabling untreated surfaces and structures to remain frozen during this time.

REVISITING CLIMATE TRENDS

Adaptation to climate change is an iterative process of revisiting and adjusting design standards and planning guidelines to mitigate the impacts of climate change. The frequency with which adaptation plans should be updated depends on advances in climate science (e.g., the availability of climate data resources), the advent of new or emerging climate adaptation issues, updates to NYS policy, and real-time changes in climate conditions.

IPCC's public assessment report includes the GCM projections used to quantify and qualify climate change in Central Hudson's CCVS. Despite an update in GCM model framework and projections every six to eight years, Central Hudson can continue to monitor and evaluate how potential climate trajectories increase (or decrease) over shorter timescales. Central Hudson's instrumental monitoring network can provide real-time benchmarks to compare with climate change projections and act as a point of reference for future updates. For example, Central Hudson could consider higher levels of Hudson River tidal effects or warming if realized observations exceed projections in the near-term.

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[35] Intergovernmental Panel on Climate Change, "Climate Change 2021: The Physical Science Basis," Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 2021 (Masson-Delmotte, V., et al. [eds.)]. Cambridge University Press, doi:10.1017/9781009157896, https://www.ipcc.ch/report/ar6/wg1.

Vulnerability Assessment

Central Hudson assessed the vulnerability of its assets and operations to the key climate hazards described above. This section describes the process for arriving at asset vulnerability scores using the exposure results described above in combination with an analysis of asset sensitivity and potential consequences, the results of that analysis, and operational vulnerabilities in six key operational areas as defined in Section 4.3 below.

METHODS

The Study team calculated vulnerability scores for each asset-hazard combination based on the asset's **exposure** to climate hazards, the asset's **sensitivity** to hazards, and the **consequences** of the asset's failure or degraded operations (Figure 16). This methodology is based on leading practices used by DOE, NOAA, and IPCC.[36,37,38,39] That is, this Study analyzes **how, if,** and **when** climate hazards might impact assets.

Exposure

The Study team determined site-specific **exposures** for each asset group by overlaying climate projections (temperature and precipitation) and floodplains with select assets as described in Section 3.3, and using the scoring rubric from Table 7.

Exposure Score	Numerical Score
Low	1
Moderate	2
High	3

Table 7. Exposure scoring matrix.

Potential Impact

Potential impact is the likelihood for negative outcomes to occur in the event of climate hazard exposure. Sensitivity is assessed alongside consequence to determine the potential impact for asset/hazard combinations. Results from the assessment are communicated and simplified through scores, which are ranked as follows: high (red), medium (yellow), low (green), or gray (not applicable).

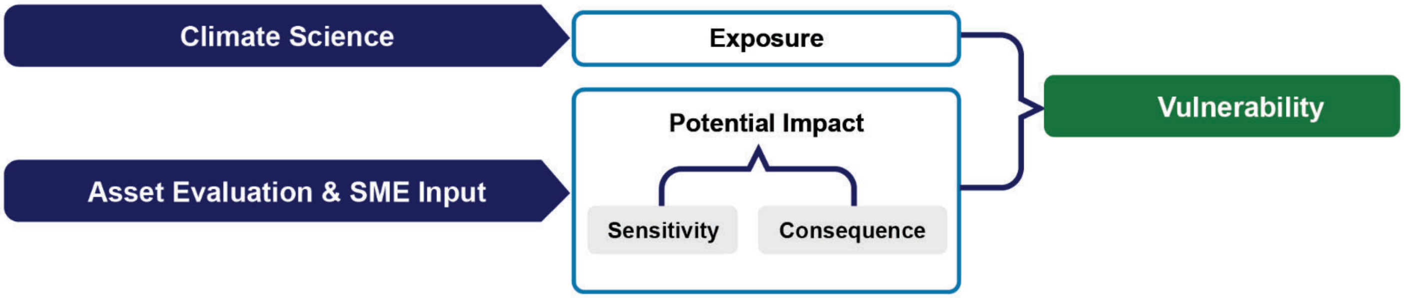

Figure 16. Vulnerability assessment process.

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[36] U.S. Department of Energy, *Vulnerability Assessment and Resilience Planning Guidance*, 2021.
[37] "Assess Vulnerability & Risk," U.S. Climate Resilience Toolkit, last modified July 15, 2021, accessed August 10, 2023, https://toolkit.climate.gov/steps-to-resilience/assess-vulnerability-risk.
[38] Intergovernmental Panel on Climate Change, "Climate Change 2022: Impacts, Adaptation and Vulnerability," in *IPCC Sixth Assessment Report,* accessed August 10, 2023, https://www.ipcc.ch/report/ar6/wg2/.
[39] Intergovernmental Panel on Climate Change, *The Concept of Risk in the IPCC Sixth Assessment Report: A Summary of Cross-Working Group Discussions*, accessed August 11, 2023, https://www.ipcc.ch/site/assets/uploads/2021/02/Risk-guidance-FINAL_15Feb2021.pdf.

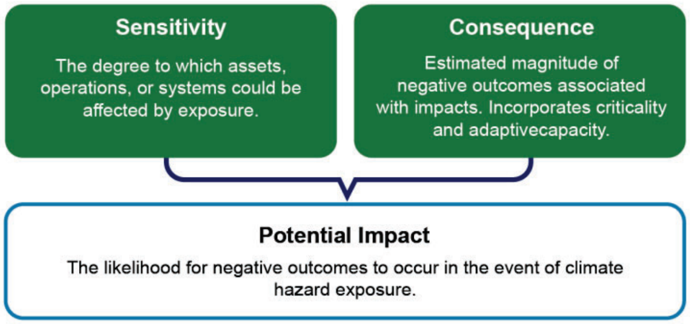


Figure 17. Potential impact assessment methodology.

Sensitivity is the degree to which assets, operations, or systems could be affected by exposure. Each asset was given a sensitivity rating for each hazard, from low or not applicable to high. These ratings were determined using subject matter expertise through a series of discussion group and interview consultations with Central Hudson staff and can be found in Appendix B: Sensitivity Scores.

The sensitivity ratings are defined as follows:

- Assets, operations, or systems considered to have **low sensitivity** experience no or minimal adverse impact when exposed to a given climate hazard.
- Assets, operations, or systems considered to have **medium/moderate sensitivity** risk being adversely affected by high thresholds of exposure, such as very high temperatures or water levels. Sensitivity also may be considered moderate if potential impacts are more accurately characterized as chronic/controlled rather than sudden/acute (e.g., accelerated degradation rather than catastrophic failure).
- **Highly sensitive** assets, operations, or systems may be subject to an increased risk of major or sudden failure in the event of exposure to a given climate hazard. Existing protection or adaptation measures of assets or operations considered to be highly sensitive are typically limited or nonexistent (e.g., electrical substations without flood protection walls).

Consequence is defined as the potential for impacts to sensitive assets to result in negative outcomes for Central Hudson's system, customers, or staff. Consequence incorporates the criticality of assets, as well as any existing ability to cope with impacts (known as *adaptive capacity*).

Importantly, asset consequence scores are independent of exposure to climate hazards. Consequence scores focus strictly on the outcomes that may occur if asset or asset groups were to have its operational status and functionality impeded. Accordingly, consequence levels are generalized across natural hazards, with differences in hazards captured in sensitivity scores. Considerations important to scoring consequence include likelihood to interrupt energy delivery to customers, environmental impact, public and employee safety, and component number and complexity (e.g., there are relatively few substation transformers connected to the network, and they are complex and have long lead-times for replacement). Consequence scores of all assets can be found in Appendix C: Consequence Scores. The consequence ratings are defined as follows:

- Assets or operations are considered to have a **low consequence** rating if the potential for hazards to affect sensitive assets could result in minor or minimal adverse outcomes.
- Assets or operations are considered to have a **moderate consequence** rating if the potential for hazards to affect sensitive assets could result in significant adverse outcomes, including sustained outages in localized areas, safety risks to the public or utility personnel, and/or costly repairs.
- One factor which influences whether an asset is assigned a moderate or **high consequence** rating is how widespread or extreme outcomes are. Assets or operations are considered to have a high consequence rating if the potential for hazards to affect sensitive assets could result in widespread or long duration outages, numerous injuries, and/or major financial impacts. High

consequence ratings should be representative of outcomes equivalent to or greater than the most severe adverse events Central Hudson has faced in the past.

After sensitivity and consequence scores are assigned to each asset or asset-hazard combination, the numerical scores associated with rankings are *multiplied* together. The product, potential impact, is a valuable indicator which communicates not just if an asset could be impacted by a given climate hazard, but the implications and criticality of impact. Like sensitivity and consequence, potential impact is also categorized and ranked from high (red), to medium (yellow), to low (green), as shown in Table 8. High potential impact scores indicate an increased likelihood for negative outcomes to occur in the event of asset exposure, while low scores suggest minimal likelihood for negative outcomes. The potential impact scores of all assets in this Study can be found in Appendix D: Potential Impact Scores.

Potential Impact Score

Consequence Score				
3 (High)	NA	3	6	9
2 (Moderate)	NA	2	4	6
1 (Low)	NA	1	2	3
Sensitivity Score	0 (NA)	1 (Low)	2 (Moderate)	3 (High)

Table 8. Potential impact scores rubric.

Vulnerability

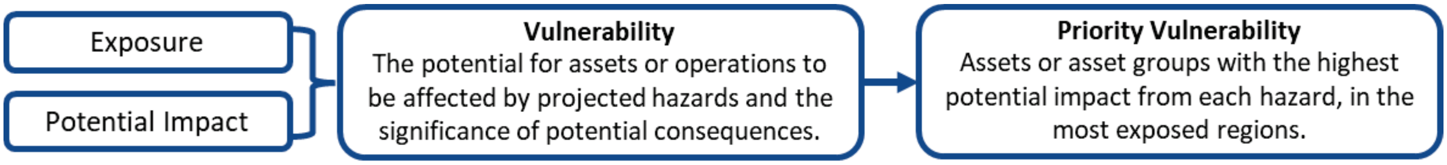
After all asset-hazard combinations have been considered and associated with a potential impact score, they are evaluated in tandem with exposure to establish **vulnerability**. Priority vulnerabilities are asset types with the highest sensitivity from each hazard, in the most exposed areas for each relevant hazard.

The Study team developed vulnerability scores by multiplying exposure scores by potential impact scores. The Study team then assigned these numerical scores a vulnerability rating of high (orange), moderate (yellow), or low (green) using the rubric found in Table 9.

Vulnerability Score

Potential Impact Score			
9	9	18	27
6	6	12	18
4	4	8	12
3	3	6	9
2	2	4	6
1	1	2	3
NA	NA	NA	NA
Exposure Score	1	2	3

Table 9. Vulnerability scoring rubric.



Vulnerability
The potential for assets or operations to be affected by projected hazards and the significance of potential consequences.

Priority Vulnerability
Assets or asset groups with the highest potential impact from each hazard, in the most exposed regions.

Figure 18. Process for identifying priority vulnerabilities.

RESULTS

The section below presents the vulnerability scores for all asset types and hazards, as summarized in Table 10. Vulnerability scores are presented by climate hazard for the SSP5-8.5 50th percentile scenario (chosen as the planning scenario) for the 2050 timeframe. Within each climate hazard, vulnerability results are organized by asset family (transmission, distribution, and substation) with reference to specific high-ranking sub-assets. Sub-assets for each asset family are listed with corresponding high, medium, low, or NA vulnerability ranking.

Note that the color-coding (i.e., scoring high, medium, or low) **differs by variable**—that is, vulnerability scores have different "buckets" for high, medium, and low compared to the scores for sensitivity, consequence, and exposure. This is based on the differences in the range of possible scores for each variable.

Asset Types	Extreme Heat	Extreme Cold and Ice	Flooding	Extreme Precipitation	Extreme Wind
Transmission					
Line structures (poles/towers)	NA	6	6	6	**12**
Conductors (overhead)	**12**	9	6	**12**	**12**
Conductors (underground)	6	NA	6	6	NA
Switching devices	NA	4	4	4	4
Distribution					
Structures (overhead)	NA	6	**12**	**12**	**18**
Conductors (underground)	6	NA	**12**	**12**	NA
Conductors (overhead)	8	6	4	4	**12**
Transformers (overhead)	4	2	2	2	4
Transformers (padmount)	4	1	6	6	2
Regulators (pole mounted)	8	4	4	4	8
Capacitors (pole mounted)	2	1	2	2	4
Switching devices	4	6	4	4	8
Surge arrestors	2	2	NA	4	4
Reclosers	4	NA	4	4	8
Manholes	4	2	8	8	NA
Substations					
Substation transformers/ voltage regulators	**12**	3	6	6	6
Circuit breakers	**12**	3	**18**	**18**	6
Instrument transformers	8	NA	4	4	4
Substation reactors	**12**	3	6	6	6
Controllers	8	2	4	4	4
Switching devices	6	6	6	6	6
Surge arrestors	4	2	NA	8	4

Table 10. Vulnerability scores for all asset types and hazards. Orange = high, yellow = moderate, green = low, and gray = not applicable.

Extreme Heat

Overall, assets in Central Hudson's service territory are projected to have **moderate** exposure to extreme heat in 2050. This is expected to increase by late-century (2080s), with assets having high exposure to extreme heat.

Transmission

Overall, transmission assets have varying degrees of vulnerability to extreme heat, with overhead conductors having the highest vulnerability. Overhead conductors' high vulnerability score is driven by a high consequence score, since a circuit outage could occur if conductors are damaged. Some assets, such as line structures and switching devices, are not sensitive to extreme heat, and therefore do not have any vulnerability to the hazard.

Extreme Heat

	Potential Impact			
Asset Type	**Sensitivity**	**Consequence**	**Exposure**	**Vulnerability**
Transmission				
Line structures (poles/towers)	NA	3	2	NA
Conductors (overhead)	2	3	2	12
Conductors (underground)	1	3	2	6
Switching devices	NA	2	2	NA

Overhead conductors are sensitive to extreme heat, as the hazard reduces the ability of the conductor to dissipate heat in extreme scenarios. High ambient temperatures along with high humidity are also often associated with higher demand due to customers' use of air conditioning; such high demand can increase conductor temperature, which can impact the conductor's ability to dissipate heat. For the New York Control Area (NYCA), following implementation of Federal Energy Regulatory Commission (FERC) Order 881 on Ambient Adjusted Ratings (AAR), summer ambient temperatures exceeding 95°F (35°C) will result in overhead conductor ratings that are less than currently established static ratings; similarly, winter ambient temperatures exceeding 50°F (10°C) also will result in overhead conductor ratings that are less than currently established static ratings. This, however, does not in itself alter the maximum allowable conductor temperatures. A long-term trend of rising ambient temperatures may result in a change to the ambient temperature assumptions used in NYCA's rating methodology; this may result in a reduction in static ratings. If lines are not operated to their AAR, excessive conductor sagging may occur and may increase the risk of vegetation contact, post-contingency. Higher conductor temperatures (maximum and average) will also impact material strength over time.

Distribution

Overall, distribution assets show lower vulnerability to extreme heat. Overhead and underground conductors and regulators are moderately vulnerable to extreme heat driven by their projected exposure in 2050.

Extreme Heat

	Potential Impact			
Asset Type	**Sensitivity**	**Consequence**	**Exposure**	**Vulnerability**
Distribution				
Poles (overhead)	NA	3	2	NA
Conductors (underground)	1	3	2	6
Conductors (overhead)	2	2	2	8
Transformers (overhead)	2	1	2	4
Transformers (padmount)	2	1	2	4
Voltage regulators (pole mounted)	2	2	2	8
Shunt capacitors (pole mounted)	1	1	2	2
Switching devices	1	2	2	4
Surge arrestors	1	1	2	2
Reclosers	1	2	2	4
Manholes	1	2	2	4

Underground conductors are moderately vulnerable to extreme heat. This score is driven by a high consequence score, and moderate projected exposure in 2050. Even though underground conductors have low sensitivity to extreme heat due to being located underground where temperatures are stable, there is a high level of impact if the asset fails, resulting in a moderate vulnerability.

Substation

Substation assets overall have high vulnerability to extreme heat, specifically transformers/voltage regulators, circuit breakers, and substation reactors. A high vulnerability score for these assets is driven by a high consequence score and moderate sensitivities, along with moderate exposure to extreme heat. Substation assets are highly critical and, depending on system design and operating conditions at the time, could result in customer outages if they become unavailable.

Extreme Heat				
	Potential Impact			
Asset Type	**Sensitivity**	**Consequence**	**Exposure**	**Vulnerability**
Substation				
Substation transformers/ voltage regulators	2	3	2	12
Circuit breakers	2	3	2	12
Instrument transformers (current transformers [CTs] and potential transformers [PTs])	2	2	2	8
Substation reactor	2	3	2	12
Controllers—regulators and LTCs	2	2	2	8
Switching devices	1	3	2	6
Surge arrestors	1	2	2	4

Transformers are complex devices with long lead times for replacement, making them critical for proper system functionality. High temperatures lower the effective capacity of transformers/voltage regulators by approximately 1% per 1°C increase in average daily temperature above 30°C.[40] High heat conditions also have the potential to accelerate aging by elevating temperatures of the transformer insulation system and may result in higher risk of failure. Increasing Central Hudson's standard summer ambient temperature cycle by 1°C for each hour, however, could result in a reduction in rating of approximately 0.6% and a 0.023% increase in loss of insulation life (for a fully loaded, post-contingency, long-term emergency [LTE] event).[41] Central Hudson's distribution substations are typically designed for the loss of only one substation transformer. With both transformers in service, therefore, each transformer would not be loaded to its normal rating and a reduction in rating under these conditions would not be consequential.

Circuit breakers are vulnerable to extreme temperature and are not able to dissipate heat as effectively when temperatures increase. High ambient temperatures may increase the aging rate and marginally increase the risk of failure.

Substation reactors are typically rated to operate in ambient temperatures of up to an average of 30°C and maximum of 40°C. At temperatures above assumed ambient, accelerated aging and a slightly higher risk failure may occur.

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[40] IEEE Std C57.91, *IEEE Guide for Loading Mineral-Oil-Immersed Transformers and Step-Voltage Regulators*, March 2012.

[41] Calculations performed by Central Hudson using the Electric Power Research Institute's PT-Load Ver 6.2 Software.

Extreme Cold and Ice

Assets in Central Hudson's service territory are expected to have **low** exposure to extreme cold across the 2050s and 2080s. As temperatures warm through the 21st century, the frequency of freezing and extreme cold temperatures is projected to decrease, and a smaller proportion of Central Hudson's service territory could be exposed to extreme cold temperatures.

Transmission

Although transmission assets have low exposure to extreme cold and ice, their sensitivity and consequence is moderate to high, resulting in a moderate vulnerability to extreme cold. Overhead conductors and line structures have moderate vulnerability, especially when coated with ice, and could result in a circuit outage if damaged. No transmission assets have a high vulnerability to the hazard.

Extreme Cold and Ice

Asset Type	Potential Impact			
	Sensitivity	Consequence	Exposure	Vulnerability
Transmission				
Line structures (poles/towers)	2	3	1	6
Conductors (overhead)	3	3	1	9
Conductors (underground)	NA	3	1	NA
Switching devices	2	2	1	4

Distribution

Distribution assets overall have low-to-moderate vulnerability to extreme cold and ice, with no assets having a high vulnerability to the hazard. Poles, conductors, and switching devices have moderate vulnerability to extreme cold and ice, primarily driven by moderate-to-high sensitivity and consequence scores. Pole failures and damaged overhead conductors can lead to circuit outages. Damaged regulators and switching devices will not necessarily lead to circuit outages but could still impact power quality and utility operations such as switching associated with routine maintenance.

Extreme Cold and Ice

Asset Type	Potential Impact			
	Sensitivity	Consequence	Exposure	Vulnerability
Distribution				
Poles (overhead)	2	3	1	6
Conductors (underground)	NA	3	1	NA
Conductors (overhead)	3	2	1	6
Transformers (overhead)	2	1	1	2
Transformers (pad mount)	1	1	1	1
Regulators (pole mounted) [Voltage regulator]	2	2	1	4
Capacitors (pole mounted) [Shunt capacitors]	1	1	1	1
Switching devices	3	2	1	6
Surge arrestors	2	1	1	2
Reclosers	NA	2	1	NA
Manholes	1	2	1	2

Substation

Altogether, substation assets have low vulnerability to extreme cold and ice due to low sensitivity and exposure scores. Switching devices are moderately vulnerable, especially if ice forms on the asset. Since substation assets are highly critical, their moderate to high consequence score has greater influence on their vulnerability score, although no substation assets have high vulnerability to the hazard.

Extreme Cold and Ice

	Potential Impact			
Asset Type	**Sensitivity**	**Consequence**	**Exposure**	**Vulnerability**
Substation				
Substation transformers/voltage regulators	1	3	1	3
Circuit breakers	1	3	1	3
Instrument transformers (CTs and PTs)	NA	2	1	NA
Substation reactor	1	3	1	3
Controllers—regulators and LTCs	1	2	1	2
Switching devices	2	3	1	6
Surge arrestors	1	2	1	2

Flooding

Assets within the Central Hudson service territory are expected to have **moderate** exposure to coastal and inland flooding during the 2050s. This is expected to remain at moderate exposure into the 2080s.

Transmission

As an asset family, transmission assets have moderate vulnerability to flooding, with the exception of switching devices. Transmission structures and underground and overhead conductors have a moderate vulnerability score to flooding due to a high consequence score and moderate exposure. However, their low sensitivity scores make them only moderately vulnerable, instead of highly vulnerable. If transmission structures and overhead/underground conductors were to be damaged by flooding, it would likely result in a circuit outage.

Flooding (coastal and inland flooding)

	Potential Impact			
Asset Type	**Sensitivity**	**Consequence**	**Exposure**	**Vulnerability**
Transmission				
Line structures (towers)	1	3	2	6
Conductors (overhead)	1	3	2	6
Conductors (underground)	1	3	2	6
Switching devices	1	2	2	4

Distribution

Two distribution assets, distribution poles and underground conductors, are highly vulnerable to flooding while the rest of the assets have low vulnerability to the hazard. These assets are particularly vulnerable because they are moderately sensitive to flooding, and failure of either would likely result in a power outage. All other assets have a lower consequence score and would not necessarily lead to an outage if damaged.

Flooding (coastal and inland flooding)

	Potential Impact			
Asset Type	**Sensitivity**	**Consequence**	**Exposure**	**Vulnerability**
Distribution				
Poles (overhead)	2	3	2	12
Conductors (underground)	2	3	2	12
Conductors (overhead)	1	2	2	4
Transformers (overhead)	1	1	2	2
Transformers (pad mount)	3	1	2	6
Voltage regulators (pole mounted)	1	2	2	4
Shunt capacitors (pole mounted)	1	1	2	2
Switching devices	1	2	2	4
Surge arrestors	NA	1	2	NA
Reclosers	1	2	2	4
Manholes	2	2	2	8

Distribution poles are highly vulnerable to flooding, specifically the base of the pole. Erosion, scouring of the ground near pole bases, and saline water exposure from higher water tables associated with flooding can compromise structural integrity, or similarly cause trees to uproot, potentially colliding with poles and leading to damage. When inundation is long term, standing water can damage poles; however, the greatest impacts are from moving water.

Underground distribution conductors are also highly vulnerable to flooding. Underground assets are typically designed to be submersible. However, in some cases, conductors and associated structures could be subject to corrosion, particularly in the case of existing damage or incomplete sealing. Maintenance can be restricted if floodwaters block access.

Substation

Switchgear-style circuit breakers are the only asset that is highly vulnerable to flooding, primarily driven by a high sensitivity and consequence score. Substation transformers/voltage regulators, instrument transformers, and substation reactors typically are highly sensitive to flooding; however, Central Hudson employs a combination of waterproofing and elevation to protect these assets, making them less sensitive and subsequently less vulnerable. Most substation assets have a high consequence score; if substation assets are damaged, it could lead to line outages, system faults, and even fires and electric shocks in switchgear.

Flooding (coastal and inland flooding)				
	Potential Impact			
Asset Type	**Sensitivity**	**Consequence**	**Exposure**	**Vulnerability**
Substation				
Substation transformers/ voltage regulators	1	3	2	6
Circuit breakers	3	3	2	18
Instrument transformers (CTs and PTs)	1	2	2	4
Substation reactor	1	3	2	6
Controllers—regulators and LTCs	1	2	2	4
Switching devices	1	3	2	6
Surge arrestors	NA	2	2	NA

Circuit breakers and instrument transformers, including current transformers (CTs) and potential transformers (PTs), are highly vulnerable to flooding if they are not installed above potential flood levels and equipment is exposed to floodwaters.

Extreme Precipitation

Assets throughout Central Hudson's service region are projected to have **moderate** exposure to extreme precipitation events by both mid- and late-century. The intensity of the most extreme precipitation events is expected to increase slightly compared to present day.

Transmission

The overall vulnerability of transmission assets to extreme precipitation in Central Hudson's service region ranges from low to high. Overhead conductors' high vulnerability to the hazard is driven by moderate exposure paired with moderate sensitivity. Heavy precipitation events may marginally increase the risk of flashovers.[42]

Extreme Precipitation				
	Potential Impact			
Asset Type	**Sensitivity**	**Consequence**	**Exposure**	**Vulnerability**
Transmission				
Line structures (poles/towers)	1	3	2	6
Conductors (overhead)	2	3	2	12
Conductors (underground)	1	3	2	6
Switching devices	1	2	2	4

Distribution

Many of the distribution assets in Central Hudson's service territory have a low vulnerability to extreme precipitation. However, poles and underground conductors are highly vulnerable to the hazard, due to moderate sensitivity and high consequence scores. If poles and underground conductors are damaged, circuit outages may result. All other assets have low-to-moderate sensitivity and

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[42] A flashover is a continuous electrical discharge of high current that flows through an air gap between conductors.

consequence pairing and result in a low vulnerability score.

Extreme Precipitation				
	Potential Impact			
Asset Type	**Sensitivity**	**Consequence**	**Exposure**	**Vulnerability**
Distribution				
Poles (overhead)	2	3	2	12
Conductors (underground)	2	3	2	12
Conductors (overhead)	1	2	2	4
Transformers (overhead)	1	1	2	2
Transformers (padmount)	3	1	2	6
Voltage Regulators (pole mounted)	1	2	2	4
Shunt Capacitors (pole mounted)	1	1	2	2
Switching devices	1	2	2	4
Surge arrestors	2	1	2	4
Reclosers	1	2	2	4
Manholes	2	2	2	8

Extreme precipitation events can lead to rain-induced flooding, which can compromise ground structure and place overhead structures and poles at an increased risk of damage. However, risk of damage through ground softening and disruption is greatest from moving water; standing water impacts are expected only when inundation is long term. Ground softening can also cause trees to uproot and collide with poles, leading to damage.

Underground distribution conductors are typically designed to be submersible. However, in some cases conductors and associated structures could experience corrosion, particularly in the case of existing damage or incomplete sealing. Maintenance can also be impeded due to rain-induced floodwaters.

Substation

The majority of substation assets are moderately vulnerable to extreme precipitation and rain-induced flood events. Only switchgear-style circuit breakers are highly vulnerable, driven by a high sensitivity and consequence score, in addition to moderate exposure. Other assets have lower consequence scores or sensitivity scores that result in moderate vulnerability. Similar to coastal and riverine flooding, substation transformers/voltage regulators, instrument transformers, and substation reactors typically are highly sensitive to flooding; however, Central Hudson employs a combination of waterproofing and elevation to protect these assets, making them less sensitive and subsequently less vulnerable.

Extreme Precipitation				
	Potential Impact			
Asset Type	**Sensitivity**	**Consequence**	**Exposure**	**Vulnerability**
Substation				
Substation transformers/ voltage regulators	1	3	2	6
Circuit breakers	3	3	2	18
Instrument transformers (CTs and PTs)	1	2	2	4
Substation reactor	1	3	2	6
Controllers—regulators and LTCs	1	2	2	4
Switching devices	1	3	2	6
Surge arrestors	2	2	2	8

Circuit breakers and associated components within switchgear can experience damage by precipitation-induced flooding over time, which could impact substation operations and potentially lead to outage events. Controllers are also at risk of damage and may corrode when exposed to floodwaters over time. Occasionally, debris carried by floodwaters can be deposited in component enclosures and cause asset failure. Surge arrestors are unlikely to be damaged by heavy rain alone, but increasing frequency and intensity of precipitation events or humid conditions may increase surge arrestor failure rates.

Extreme Wind

Assets throughout Central Hudson's service region are projected to have **moderate** exposure to increasing extreme wind events. While average wind speed is projected to change minimally across the service territory, extreme wind speeds are projected to increase in both frequency and intensity by mid- through late-century. Several asset types have high consequence and moderate-to-high sensitivity scores and could be damaged by fallen trees that are a result of high winds if exposure increases. These vulnerable asset types include overhead transmission line structures and conductors as well as distribution poles.

Transmission

Transmission assets have varying degrees of vulnerability to wind, with overhead line structures and conductors having the highest vulnerability to extreme wind events.

Extreme Wind				
	Potential Impact			
Asset Type	Sensitivity	Consequence	Exposure	Vulnerability
Transmission				
Line structures (poles/towers)	2	3	2	12
Conductors (overhead)	2	3	2	12
Conductors (underground)	NA	3	2	NA
Switching devices	1	2	2	4

Overhead transmission line structures and conductors are highly vulnerable to wind events. Although direct sensitivity for overhead transmission conductors due to wind is typically considered low, high wind speeds can cause surrounding vegetation to damage transmission lines and lead to structural failure.

Distribution

Most overhead distribution assets have a moderate to high vulnerability to wind, with distribution poles and overhead conductors being most vulnerable to the hazard. High wind events can cause surrounding vegetation to make contact with overhead assets and cause poles and the assets that are mounted to them to break. A large number of poles can potentially be damaged during a severe wind event from this type of contact with vegetation.

Extreme Wind				
	Potential Impact			
Asset Type	Sensitivity	Consequence	Exposure	Vulnerability
Distribution				
Poles (overhead)	3	3	2	18
Conductors (underground)	NA	3	2	NA
Conductors (overhead)	3	2	2	12
Transformers (overhead)	2	1	2	4
Transformers (padmount)	1	1	2	2
Voltage Regulators (pole mounted)	2	2	2	8
Shunt Capacitors (pole mounted)	2	1	2	4
Switching devices	2	2	2	8
Surge arrestors	2	1	2	4
Reclosers	2	2	2	8
Manholes	NA	2	2	NA

Substation

Substation assets have low-to-moderate vulnerability to wind, driven largely by the low wind loading of sub-assets. Vulnerability scores are mostly driven by assets' high consequence scores and moderate exposure to wind.

Extreme Wind

	Potential Impact			
Asset Type	**Sensitivity**	**Consequence**	**Exposure**	**Vulnerability**
Substation				
Substation transformers/ voltage regulators	1	3	2	6
Circuit breakers	1	3	2	6
Instrument transformers (CTs and PTs)	1	2	2	4
Substation reactor	1	3	2	6
Controllers—regulators and LTCs	1	2	2	4
Switching devices	1	3	2	6
Surge arrestors	1	2	2	4

OPERATIONAL VULNERABILITIES

In addition to assessing the climate vulnerability of Central Hudson's assets, the Study team also conducted a series of interviews with Central Hudson SMEs to assess the climate vulnerability of six distinct operational processes. This analysis is more qualitative in nature and is meant to help identify general trends and relevant climate risks that may impact the current procedures of each distinct operational group.

Load Forecasting

Relevant Hazards: Extreme Heat

Description of Operational Risk: The load forecasting team at Central Hudson forecasts system peak energy demand and consumption for future periods. The peak demand forecasting process uses historical "peak producing days"; that is, days upon which prior system peak demands occurred, to develop a relationship between weather and peak demand. The process uses a weather variable that is a blend of max and mean dry bulb temperatures for the peak day and mean dry bulb temperatures for the prior day. This weather variable is computed for the prior 30 years for a "normal" day, defined as the 30-year average, and an "extreme" day, defined as the upper 95th percentile over the 30-year period. The load forecasting process also considers electrification-based demand adjustments to account for electric vehicles, heat pumps, and other demand drivers. Central Hudson derives weather variable data from temperature readings obtained from Dutchess County Airport.

Central Hudson's current use of historical weather data in the load forecasting processes may fail to capture changes in climate that may impact peak demand. Forecasting solely based on historical experience could result in equipment overloads, which could impact reliability and revenue forecasting. Incorrect load forecasting and relief planning due to heat waves and chronic increases in average temperature may result in assets operating at decreased capacity while experiencing higher-than-usual demand. Prolonged extreme temperatures combined with unmitigated demand could lead to load shedding to prevent asset damage.

Asset Management

Relevant Hazards: Extreme heat, flooding, precipitation, extreme cold/ice, extreme wind

Description of Operational Risk: Asset management includes the processes of monitoring and maintaining T&D assets and systems to ensure that they meet performance standards. It includes engineering and design standards as well as inspections, monitoring, maintenance, and asset replacement programs. Failure to account for the impact of climate change on asset management processes may result in higher capital costs and/or impact service reliability.

Central Hudson currently uses Cascade as its asset management system. Cascade includes information on asset age, health, quantity, and location. Most transmission and substation assets are in the Cascade system, while most distribution assets reside within a geographic information system (GIS) or the internal mainframe, field operating system (FOS), with the exception of distribution devices associated with the Company's Distribution Automation initiative, which have been migrated to Cascade. Central Hudson is working toward consolidating additional asset data into the Cascade system. Central Hudson captures failure data for larger assets such as circuit breakers, transformers, and switches but has less robust failure data for smaller grid components nearer to the grid edge.

Over the last few years, Central Hudson has made design standard changes toward a more resilient system. Some of those changes include upgrading to the National Electrical Safety Code (NESC) Grade B construction standard and upgrading from wood to fiberglass crossarms on overhead distribution new mainline construction.

While only substation transformers have distinct asset health indices (which include information on oil quality, dissolved gas analysis, power factor tests, inspection results, and transformer leaks), the asset management team is working on developing health scores for substation batteries; the team also is evaluating including distribution transformers in the Cascade system. Central Hudson has a substation evaluation report that includes information on the condition of major substation assets and combines that condition information into an overall station evaluation measure. However, neither the Cascade system nor the substation evaluation report account for potential climate impacts to the fleet of assets. **Because of this, current asset management processes may be vulnerable to climate change if they do not have the capability to model the impact of projected changes of climate on asset aging and failure rates.**

The ability to determine the real-time asset status of substation assets varies by substation age. Newer substations have temperature alarms for each transformer, while in older substations, the temperature alarms are category alarms that require an operator to visit the station to determine that the alarm was a temperature alarm.

Central Hudson faces substantial challenges in its supply chain that will likely worsen with increasing climate risk. Lead times for assets such as breakers, transformers, voltage regulators, insulators, and conductors have increased substantially. The utility has also faced challenges in the quality of assets; many parts arrive damaged or malfunctioning. These procurement issues have forced the utility to accept less robust asset upgrades than desired, such as upgrading to class 4 utility poles rather than class 2, because of lack of availability of class 2 poles. Additionally, these supply chain issues have forced Central Hudson to delay some capital improvement projects because of the lack of available components. The increasing risk and severity of extreme climate events have the potential to increase asset damage and failure rates, which may require Central Hudson to increase asset replacement rates. Given the ongoing issues with supply chains, and potential future climate-hazard related disruptions of supply chains, this risk is particularly acute.

Central Hudson has already implemented some resilience measures for storm hardening that will better equip the system to face climate hazards. These include use of fiberglass crossarms on distribution poles in strategic areas to preserve pole integrity during storm events, upgrading pole classes where/when deemed necessary, and various design changes that allow for better mechanical coordination between system components.

Capacity Planning (Equipment Ratings)

Relevant Hazards: Extreme heat

Description of Operational Risk: The primary objectives of capacity planning are to quantify the delivery capabilities of assets, identify areas of the grid where demand growth could exceed asset ratings, and plan necessary investments to meet expected customer demand.

Climate change may affect the frequency, severity, and duration of heat waves as well as increase average daily temperatures. The Central Hudson system is currently not thermally constrained, having sufficient capacity to meet anticipated peak demand. The system peak occurred in 2006 and load has declined slightly since then. In addition, Central Hudson designs and operates its system relatively conservatively. For example, the Company has historically used a 75°C operating temperature for distribution system aluminum conductors, as opposed to 90°C, which is typical in the industry. Also, the design rating of distribution feeders is below the thermal capacity, with the standard distribution feeder design rating ranging from approximately 6 MW to 9 MW, while the feeder thermal capacity is typically 9 MW to 14 MW. Finally, Central Hudson distribution substations are typically designed with two transformers but loaded only to the post-contingency capability of one transformer.

At a system level, Central Hudson has experienced some constraints on the transmission system in isolated regions, such as in Western Ellenville, where planned load growth may bring the local system near capacity limits.

For the distribution system, the distribution system design standards are typically below the equipment thermal ratings, which allows sufficient margin for the high demands and lower equipment capacities expected during extreme heat events.

However, while there is currently latent capacity to handle additional demand from various sources, including electrification, longer term trends in climate may drive increasing demand while also reducing the delivery capacity of components that rely on air for cooling, such as overhead transmission and distribution conductors, transformers, and switches.

The ratings for Central Hudson's substation transformers are determined using the Electric Power Research Institute (EPRI) PT Load software with a load cycle that has 24 individual hourly temperatures, which were in turn derived from historical temperatures in Poughkeepsie approximately 20 to 30 years ago. While the 24-hour load cycle used in the PT Load program has a maximum ambient temperature of 93.9°F (34.4°C), since 1990, the maximum temperature at Poughkeepsie has exceeded 93.9°F 26 times, or 8 out of 10 years**. Consequently, the current load cycle used for rating transformers does not reflect recent historical weather.** Accordingly, a re-evaluation of the load cycle for the PT Load software to better reflect actual temperature conditions, incorporate temperature projections, and consider temperatures from around the service territory would position Central Hudson to develop revised transformer ratings, given projected changes in climate.

For transmission line ratings, Central Hudson assumes a summer ambient temperature of 35°C, consistent with the 2019 New York Transmission Owners Task Force on Tie-Line Ratings Final Report.[43] Central Hudson will be moving to ambient adjusted ratings to comply with FERC order 881, which requires public utility transmission providers to: 1) implement AAR on the transmission lines over which they provide transmission service; 2) use uniquely determined emergency ratings; and 3) maintain a database of transmission line ratings.[44] **This change to incorporate ambient adjusted ratings will provide a better linkage between near-term projected ambient temperatures and transmission line ratings and loading but will not**

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[43] New York Transmission Owners Task Force on Tie-Line Ratings, *Final Report*, 2019, accessed August 11, 2023, https://www.nyiso.com/documents/20142/1402024/NYTO-2019-Tie-Line-Report-V01-2020-January-9.pdf/7029e9e9-3f76-5355-5646-8b1f18699750.

[44] Homepage, Federal Energy Regulatory Commission, https://www.ferc.gov, accessed August 11, 2023.

provide insight into longer-term temperature trends and how transmission line ratings may need to change to address those trends.

For pole-top distribution transformers, Central Hudson currently estimates loading based on historical data and how many homes are connected to the transformer. This load estimation method was verified using a sample set of AMI meter data. For commercial customers, which have demand meters, loading is estimated based on actual historical peak data.

The company currently does not have Advanced Metering Infrastructure (AMI), but AMI data would provide better insight into the loading on individual transformers and support better alignment between transformer capability and loading.

Emergency Response

Relevant Hazards: Precipitation, extreme cold/ice, flooding

Description of Operational Risk: Climate change may increase the frequency and severity of extreme events which require emergency response, increasing the importance of Central Hudson's emergency response activities and activation capabilities. Central Hudson has already experienced some impacts of climate change that have affected emergency response teams and protocols. The increasing frequency and severity of storms has triggered emergency response activities more frequently than in previous years, straining operating budgets and blue-sky staff capacity.[45] The rise of invasive species, such as the Emerald Ash Borer, which is only expected to increase with a warming climate, has also led to far more downed trees, especially during storm events.

Other factors such as the increasing cost of outside contractors, high turnover rates in the industry, declining quality of contractor work and shifts in mutual assistance practices have and will continue to compound the impacts of climate change on the ability of Central Hudson to respond to events.

Central Hudson’s current set of disparate electronic systems, including functions such as damage assessment, tracking wires down, and updating municipalities, do not optimally support storm operations. The disparate nature of these systems presents a challenge for Central Hudson’s storm response. Integration of these disparate systems, as well as deployment of AMI, would help improve storm response.

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[45] Blue-sky capacity is the capacity to operate non-emergency roles within the utility during normal operating times.

Reliability Planning

Relevant Hazards: Extreme wind, extreme heat, precipitation, extreme cold/ice, flooding

Description of Operational Risk: Reliability planning strives to meet electric system reliability performance targets by understanding the impact of weather and component failure rates on reliability and identifying investments and operating process improvements to achieve target performance.

Weather is a significant driver of customer interruptions, and a strong understanding of the vulnerability of assets to failure from weather events is crucial to ensure proper and informed reliability planning. For example, the increased frequency and severity of storms can greatly increase outage rates. Central Hudson's electric reliability interruption index, SAIFI,[46] increased over the period from 2012 to 2021 (from 1.0 to 1.43) and the Company's electric reliability duration index, CAIDI,[47] also increased slightly (from 2.3 hours to 2.5 hours) over that same period of time.[48] Central Hudson's Kingston district has been particularly affected by outages due to storms, particularly those with high winds, as there is particularly high tree density in the region.

Central Hudson's design philosophy of using two transformers in most distribution substations and keeping loading levels within the capability of one transformer, as well as designing their distribution feeders to less than the thermal capability, provides a strong foundation for reliability.

Central Hudson has also implemented various capital projects to improve reliability, including adding distribution feeder ties, upgrading poles and distribution wire, converting older 4.8 kV distribution infrastructure to 13.2 kV and completing some dedicated "storm hardening" projects in the first protective zones of distribution circuits. While these programs may help improve some aspects of resilience of the system, they do not explicitly consider the impacts of climate change. Failure to consider climate change in reliability planning could result in system performance falling below target levels in the future.

Central Hudson conducts regular infrared thermal scanning of transmission, substation and distribution assets, performs in-depth investigations on non-storm outages affecting greater than 300 customers, and regularly evaluates worst-performing distribution circuits to examine options to improve reliability of the 5% of circuits with the worst reliability performance. The Company's grid modernization program includes investments that have the potential to improve reliability, including added visibility and control of electronic devices and Fault Location, Isolation, and Service Restoration (FLISR) schemes.

Central Hudson is currently partnering with the University of Albany to develop a new outage prediction model (OPM) that forecasts weather to better predict service disruptions.[49] Projects similar to this should be continued to further understand the impact of weather events and strengthen reliability planning across the service territory.

Vegetation Management

Relevant Hazards: Extreme heat, precipitation, extreme cold/ice

Description of Operational Risk: The main objectives of vegetation management are to track and maintain vegetation as an effort to reduce the risk of vegetation caused outages and utility caused

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[46] System Average Interruption Frequency Index.
[47] Customer Average Interruption Duration Index.
[48] New York State Department of Public Service Electric Reliability Performance Report(s); date excludes major storms.
[49] University of Albany, "UAlbany Partners on New Outage Prediction System to Enhance Storm Preparedness and Response Efforts," 2021, accessed August 13 2023, https://www.albany.edu/news-center/news/2021-ualbany-partners-new-outage-prediction-system-enhance-storm-preparedness-and

wildfires. Vegetation can pose a great risk to utilities, especially those that operate in rural areas, such as Central Hudson; 46% of all outages in the Central Hudson system are tree related.

Climate change may impact vegetation growth rates and cycles due to temperature changes, greater atmospheric CO_2, and longer growing seasons. Such changes may enhance annual vegetative growth, requiring trim cycles to be updated in order to maintain safe levels of reliability performance. Additionally, changes in climate can introduce or proliferate invasive species. Invasive insects, such as the Emerald Ash Borer, and invasive fungi have already greatly increased rates of tree death in the Central Hudson service territory. Dead trees pose a particularly high risk to overhead distribution infrastructure. Invasive plant species proliferate quickly and have already caused issues in the service territory, and they require additional resources to manage growth and protect transmission and distribution assets. Additionally, expected increases in the frequency and length of dry spells shrink tree roots, and when met with flood or storm events, which also are expected to increase due to climate change, can easily uproot trees and pose a hazard to overhead assets.[50,51]

While Central Hudson has already increased its storm hardening and tree trimming efforts to adapt to these changing conditions, as climate hazards continue to worsen in frequency and severity, vegetation management practices will likely become more strained.

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[50] Katharine Hayhoe et al., “Past and Future Changes in Climate and Hydrological Indicators in the U.S. Northeast,” *Climate Dynamics* 28, (2006):381–407, https://doi:10.1007/s00382-006-0187-8.

[51] Sharon Douglas, “Drought Stress, Tree Health, and Management Implications,” *The Connecticut Agricultural Experiment Station*, https://portal.ct.gov/CAES/Fact-Sheets/Plant-Pathology/Drought-Stress-Tree-Health-and-Management-Implications.

Potential Adaptation Measures

The goal of this Study is to describe priority climate vulnerabilities of Central Hudson's assets and operations. Based on these findings, Central Hudson will then develop a Climate Change Resilience Plan (CCRP) to address the priority vulnerabilities. The goal of the CCRP is to provide adaptation measures that will ensure that the utility can continue to provide safe and reliable power to its customers by increasing physical and operational resilience to climate hazards.

Effective resilience measures should strive to accomplish one or more of the objectives below, which provide a framework for resilience before, during, and after climate events, as shown in Figure 19:

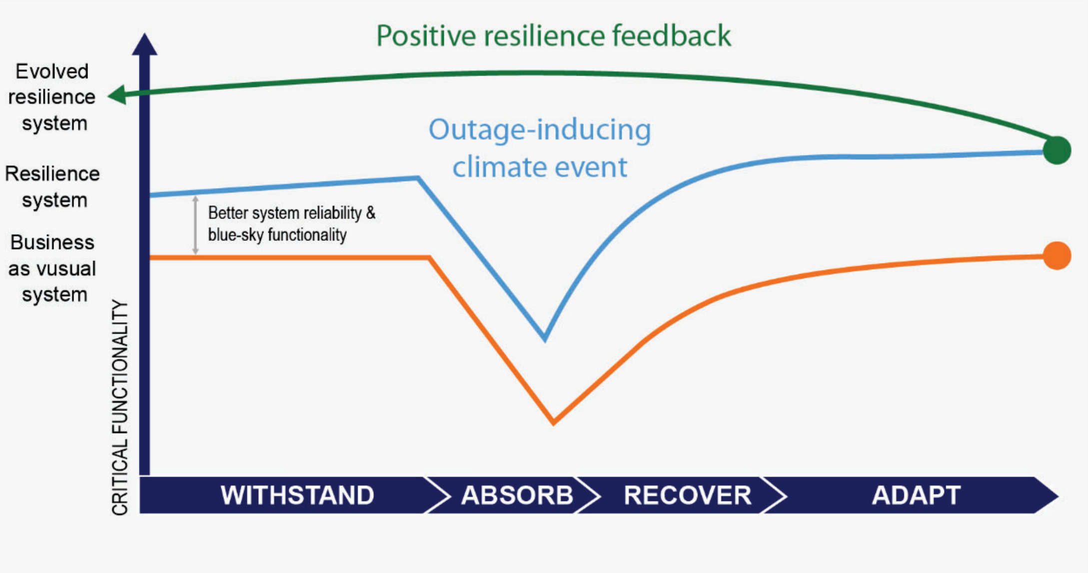
1. **Strengthen** assets and operations to **resist** the adverse impacts of a climate hazard event. (Withstand)
2. Increase the system's ability to **anticipate** when a climate hazard event may occur **and absorb** its effects. (Absorb)
3. Bolster the system's ability to quickly **respond and recover** in the aftermath of a climate hazard event. (Recover)
4. **Advance and adapt** the system to address a continuously changing threat landscape and perpetually improve resilience. (Adapt)

These objectives can be applied to both operational procedures and physical assets and infrastructure. Developing adaptation strategies that address risk for both operations and assets is critical to improve system-wide resilience to the climate hazards analyzed in this report.

Examples of adaptation measures that **strengthen** the Central Hudson system and help it **resist** the impacts of climate change include but are not limited to:

- Installing storm hardening measures, such as flood gates
- Increasing the temperature ratings of conductors
- Installing additional cooling for substation transformers
- Increasing the wind rating of distribution poles

Figure 19. Resilience Framework



Increase resilience throughout the **life cycle** of outage-inducing climate events

- Withstand
- Absorb
- Recover
- Adapt

Examples of adaptation measures that increase the system's ability to **anticipate and absorb** climate hazards include but are not limited to:

- Using Advanced Metering Infrastructure to measure demand in real time
- Increasing energy efficiency to lower demand and allow for increases in load and decreases in capacity during heat events
- Creating microgrids within the system to support continuous access to energy services and contain the impact of outages to localized areas
- Ensuring substations have sufficient spare capacity to allow for asset failure while maintaining reliability

Examples of adaptation measures that improve the system's ability to **respond and recover** after being impacted by climate hazards include but are not limited to:

- Expanding the operating capacity and training of emergency response teams
- Providing additional communication and support services to customers during outage events
- Increasing stocks of portable assets (substations, generators, etc.)
- Increasing stocks of spare assets and parts to avoid supply chain lead times in replacing damaged or destroyed assets

Examples of adaptation measures that further the system's overall ability to **advance and adapt** to the changing threat landscape of climate change include but are not limited to:

- Integrating climate change risk into investment decision making and risk management tools
- Periodically reevaluating climate risk scenarios as new data become available
- Explicitly integrating climate considerations across operating procedures including load forecasting, asset management, vegetation management, capacity planning, reliability planning, and emergency response.

Conclusion and Next Steps

The climate vulnerabilities identified in this report have potentially profound implications for Central Hudson's ability to deliver electricity safely and reliably to its customers if not addressed. As assets will face a variety of climate extremes, rates of asset failure may increase, causing outages and decreasing the system's reliability. Central Hudson has the potential to face an increasingly large financial burden through increased expenses to replace failed equipment or equipment that has prematurely aged from exposure to climate hazards. Operational expenses are also likely to increase to manage resources to repair and replace equipment and respond to increasingly frequent and severe storm events. Additionally, safety will become a larger concern to both Central Hudson and its customers. Increasingly extreme weather will amplify workers' and customers' exposure to hazardous conditions, potentially resulting in both direct and indirect casualties caused by outages. The CCRP that follows this CCVS will use expertise and industry-preferred practices, paired with input from Central Hudson SMEs and multiple data sources to further characterize and quantify the potential consequences of climate change on the utility's assets and operations. The CCRP will also examine implications of equity as it relates to reliability and resilience within the service territory and explore methods to incorporate equity into resilience investments and decision-making.

Appendix A: Energy Demand

Climate change is likely to cause increases in cooling demand and decreases in heating demand in the Central Hudson service territory in the coming decades. Cooling degree days (CDD), heating degree days (HDD),[52] and cumulative temperature-humidity index (CTHI)[53] are used to forecast energy consumption and peak load for the Central Hudson service territory.

As average temperatures rise with climate change, CDD and HDD are projected to increase and decrease, respectively. At Mohonk, CDD in July, the warmest month of the year, are projected to increase from less than 250 degree days per month to as many as 500 degree days by mid-century under the SSP5-8.5 90th percentile scenario (Figure 20). Conversely, HDD in January, the coldest month of the year, are projected to decrease from less than 1,250 degree days to as little as 900 degree days per month by mid-century under the SSP5-8.5 90th percentile scenario. Notably, the highest number of CDD may begin to shift away from July towards August by mid-century under the SSP5-8.5 90th percentile scenario (Figure 20).

CTHI combines the effects of ambient dry-bulb temperature and humidity, both of which can increase energy demand. Climate change is likely to cause the warmest ambient temperatures to increase, driving up summer maximum CTHI and peak energy load during the summer months. By late-century, peak summer CTHI could increase from 85.5 to as much as 100.2 (an increase of nearly 15) under the SSP5 8.5 90th percentile scenario (Table 11). Similar to the projections for CDD, this projected increase in CTHI indicates that peak load from cooling could increase by mid-century.

Summer Maximum CTHI at Mohonk Station

Decade	Historical	SSP2-4.5 50th Percentile	SSP5-8.5 50th Percentile	SSP5-8.5 90th Percentile
2030s	85.5	88.8	89.1	91.7
2050s	85.5	90.3	91.4	94.3
2080s	85.5	91.4	95.6	100.2

Table 11. Historical and future projected maximum summer CTHI at the Mohonk Weather Station.

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[52] Degree days are defined as cumulative sum in a given period (e.g., a month or year) of the difference between the daily average ambient temperature and a standard temperature – in this case, 65°F. For example, two days in a row with daily average temperatures of 56°F and 58°F represents 16 heating degree days, and two days in a row with daily average temperatures of 70°F and 72°F represents 12 cooling degree days. https://www.eia.gov/energyexplained/units-and-calculators/degree-days.php

[53] Central Hudson uses CTHI to inform energy demand and load forecasting. CTHI combines hourly temperature and humidity data to create a 3-day cumulative heat index.

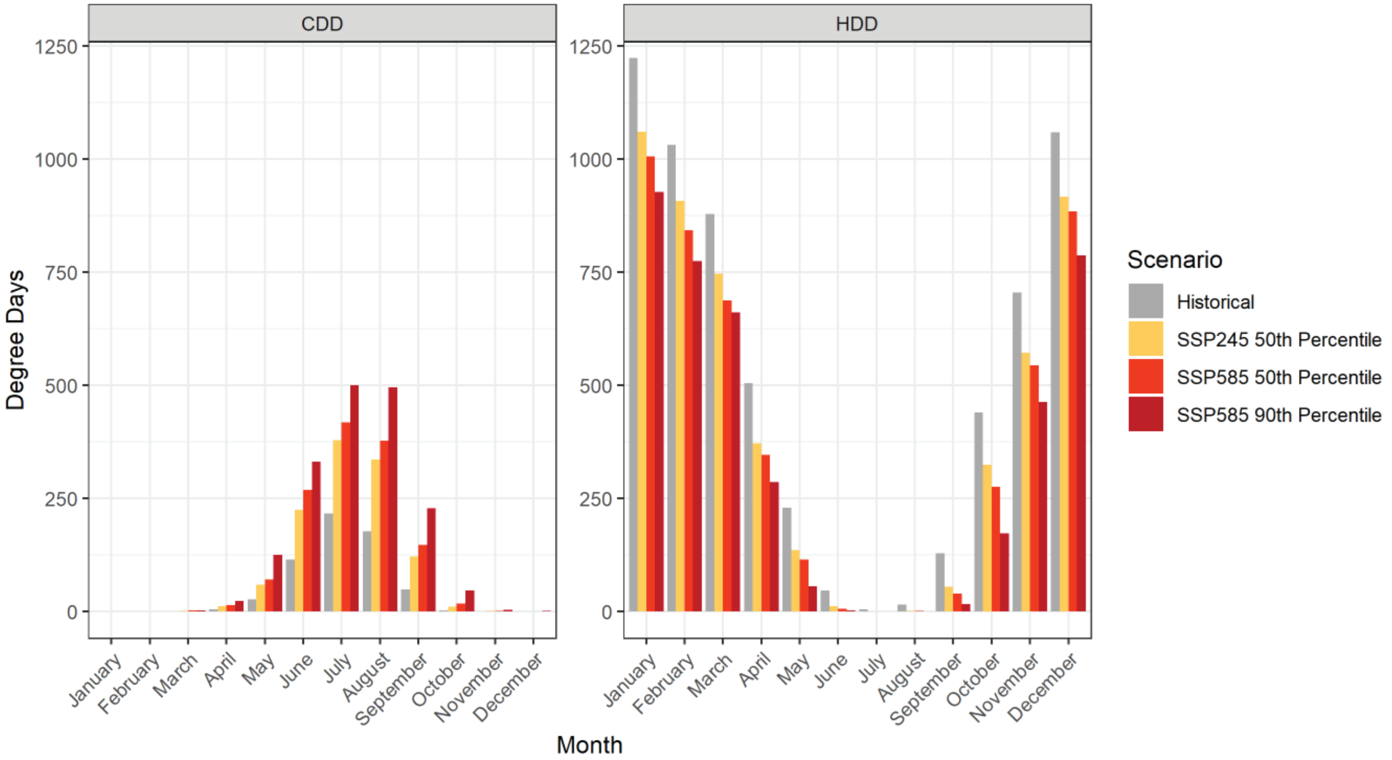

Figure 20. Historical and 2050 projected monthly cooling degree days (CDD) and heating degree days (HDD) at Mohonk Weather Station.

Appendix B: Sensitivity Scores

Table 12 below provides the sensitivity scores used in the analysis (and provided in the results section).

	Extreme Heat	Extreme Cold/Ice	Extreme Wind	Flooding	Extreme Precipitation
Transmission					
Line structures (poles/towers)	NA	2	2	1	1
Conductors (overhead)	2	3	2	1	2
Conductors (underground)	1	NA	NA	1	1
Switching devices	NA	2	1	1	1
Distribution					
Structures (overhead)	NA	2	3	2	2
Conductors (underground)	1	NA	NA	2	2
Conductors (overhead)	2	3	3	1	1
Transformers (overhead)	2	2	2	1	1
Transformers (pad mount)	2	1	1	3	3
Regulators	2	2	2	1	1
Capacitors	1	1	2	1	1
Switching devices	1	3	2	1	1
Surge arrestors	1	2	2	NA	2
Reclosers	1	NA	2	1	1
Manholes	1	1	NA	2	2
Substations					
Substation transformers/voltage regulators	2	1	1	1	1
Circuit breakers	2	1	1	3	3
Instrument transformers	2	NA	1	1	1
Substation reactor	2	1	1	1	1
Controllers	2	1	1	1	1
Switching devices	1	2	1	1	1
Surge arrestors	1	1	1	NA	2

Table 12. Sensitivity scores.

Appendix C: Consequence Scores

Table 13 below provides the consequence scores used in the analysis (and provided in the results section).

Transmission	Score
Line structures (poles/towers)	3
Conductors (overhead)	3
Conductors (underground)	3
Switching devices	2
Distribution	
Structures (overhead)	3
Conductors (underground)	3
Conductors (overhead)	2
Transformers (overhead)	1
Transformers (pad mount)	1
Regulators (pole mounted)	2
Capacitors (pole mounted)	1
Switching devices	2
Surge arrestors	1
Reclosers	2
Manholes	2
Substations	
Substation transformers/voltage regulators	3
Circuit breakers	3
Instrument transformers	2
Substation reactor	3
Controllers—regulators and LTCs	2
Switching devices	3
Surge arrestors	2

Table 13. Potential consequence scores.

Appendix D: Potential Impact Scores

Table 14 below provides the potential impact scores used in the analysis (and provided in the results section).

Assets	Extreme Heat	Extreme Ice and Cold	Extreme Wind	Flooding	Extreme Precipitation
Transmission					
Line structures (poles/towers)	NA	6	6	3	3
Conductors (overhead)	6	9	6	3	6
Conductors (underground)	3	NA	NA	3	3
Switching devices	NA	4	2	2	2
Distribution					
Structures (overhead)	NA	6	9	6	6
Conductors (underground)	3	NA	NA	6	6
Conductors (overhead)	4	6	6	2	2
Transformers (overhead)	2	2	2	1	1
Transformers (pad mount)	2	1	1	3	3
Regulators (pole mounted)	4	4	4	2	2
Capacitors (pole mounted)	1	1	2	1	1
Switching devices	2	6	4	2	2
Surge arrestors	1	2	2	NA	2
Reclosers	2	NA	4	2	2
Manholes	2	2	NA	4	4
Substations					
Substation transformers/ voltage regulators	6	3	3	3	3
Circuit breakers	6	3	3	9	9
Instrument transformers	4	NA	2	2	2
Substation reactor	6	3	3	3	3
Controllers	4	2	2	2	2
Switching devices	3	6	3	3	3
Surge arrestors	2	2	2	NA	4

Table 14. Potential impact scores.