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September 30, 2022

VIA ELECTRONIC FILING

Ms. A. Shonta Dunston, Chief Clerk
North Carolina Utilities Commission
4325 Mail Service Center
Raleigh, North Carolina 27699-4300

RE: Duke Energy Carolinas, LLC and Duke Energy Progress, LLC's Joint Climate Risk and Resilience Study – Interim Report Docket Nos. E-7, Subs 1213, 1214 and 1187 and E-2, Subs 1219 and 1193

Dear Ms. Dunston:

Pursuant to the North Carolina Utilities Commission's ("Commission") March 31, 2021 *Order Accepting Stipulations, Granting Partial Rate Increase, and Requiring Customer Notice* in Docket Nos. E-7, Subs 1213, 1214, and 1187, and the Commission's April 16, 2021 *Order Accepting Stipulations, Granting Partial Rate Increase, and Requiring Customer Notice* in Docket Nos. E-2, Subs 1219 and 1193 ("2019 Rate Case Orders"), enclosed for filing in the above-referenced dockets is the Joint Climate Risk and Resilience Study Interim Report of Duke Energy Carolinas, LLC ("DEC"), and Duke Energy Progress, LLC ("DEP," together, "the Companies") ("CRRS Interim Report").

As part of the Companies' 2019 Rate Case Orders, the Companies entered into a settlement agreement with Vote Solar to initiate a Climate Risk and Resilience Study ("CRRS") in North Carolina to study physical adaption risks to climate change in the Companies' Transmission and Distribution ("T&D") systems. Such study was to be conducted through an external stakeholder process and run by a third-party consultant. ICF Incorporated, LLC ("ICF") was selected as the third party consultant to lead this research and analysis.

The Companies established a Technical Working Group ("TWG") for the purpose of conducting and reporting on this study and stakeholder process. The CRRS study's scope includes: 1) assessing the vulnerability of the Companies' T&D assets and operations to current and projected physical impacts of climate change and 2) developing a flexible framework to improve the Carolinas' T&D system's resilience. The Companies in their scope with ICF included an optional Interim Report after assessing the vulnerabilities. Throughout the process, the Companies' subject matter experts from across the company provided detailed input and feedback through ongoing discussions, interviews, workshops and comments. This CRRS Interim Report has been shared with the external TWG stakeholders during the last TWG meeting held on August 10, 2022.

The Companies are providing this CRRS Interim Report as an informational filing, which includes climate projections for the Carolinas, the vulnerability assessment of T&D systems without mitigation, and a summary of stakeholder engagement and feedback. The upcoming CRRS Final Report, to be filed in 2024, will include details related to developing an adaptation framework.

The Companies plan to reference this CRRS Interim Report in their upcoming 2022 Climate Report. This CRRS Interim Report will also be published on the Companies' website at www.duke-energy.com on or after October 4, 2022

Thank you for your attention to this matter. If you have any questions, please let me know.

Sincerely,

Jack E. Jirak

Enclosure

cc: Parties of Record

CERTIFICATE OF SERVICE

I certify that a copy of Duke Energy Carolinas, LLC's and Duke Energy Progress, LLC's Joint Climate Risk and Resilience Study – Interim Report, filed today in Docket Nos. E-7, Subs 1213, 1214, and 1187 and E-2, Subs 1219 and 1193, has been served by electronic mail, hand delivery or by depositing a copy in the United States mail, postage prepaid to parties of record.

This the 30th day of September, 2022.

Jack E. Jirak
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Climate Risk and Resilience Study

Interim Report

September 2022

DUKE ENERGY®

BUILDING A SMARTER ENERGY FUTURE®

Climate Risk and Resilience Study

Interim Report

Prepared by:

DUKE ENERGY®

ICF

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Executive Summary

Duke Energy initiated this Climate Risk and Resilience Study (CRRS) of the Carolinas transmission and distribution (T&D) system to 1) assess the vulnerability of its Transmission and Distribution ("T&D") assets and operations to current and projected physical impacts of climate change and 2) to develop a flexible framework to improve the Carolinas T&D system's resilience. ICF led the research and analysis, and throughout the process, Duke Energy subject matter experts from across the company provided detailed input and feedback through ongoing discussions, interviews, workshops and comments.

The study reviewed exposure and vulnerability to physical impacts of climate change at the individual asset level (discrete, existing physical T&D assets) and provided granular data to support Duke Energy's assessment of adaptation options that would improve the system's resilience amid future potential risks. The study's findings are organized by asset type (e.g., functional components such as transformers or conductors), by asset group (i.e., transmission, substations, distribution), and by planning and operations process areas (e.g., asset management, workforce safety). The **vulnerability ratings** are summarized throughout as **low**, **medium** or **high**, with supporting documentation. Importantly, these ratings reflect incremental risk associated with plausible climate change effects, focusing on the 2050 time frame, and are not intended to indicate current or cumulative risk levels. Figure 1 illustrates the framework for assessing and characterizing vulnerability.

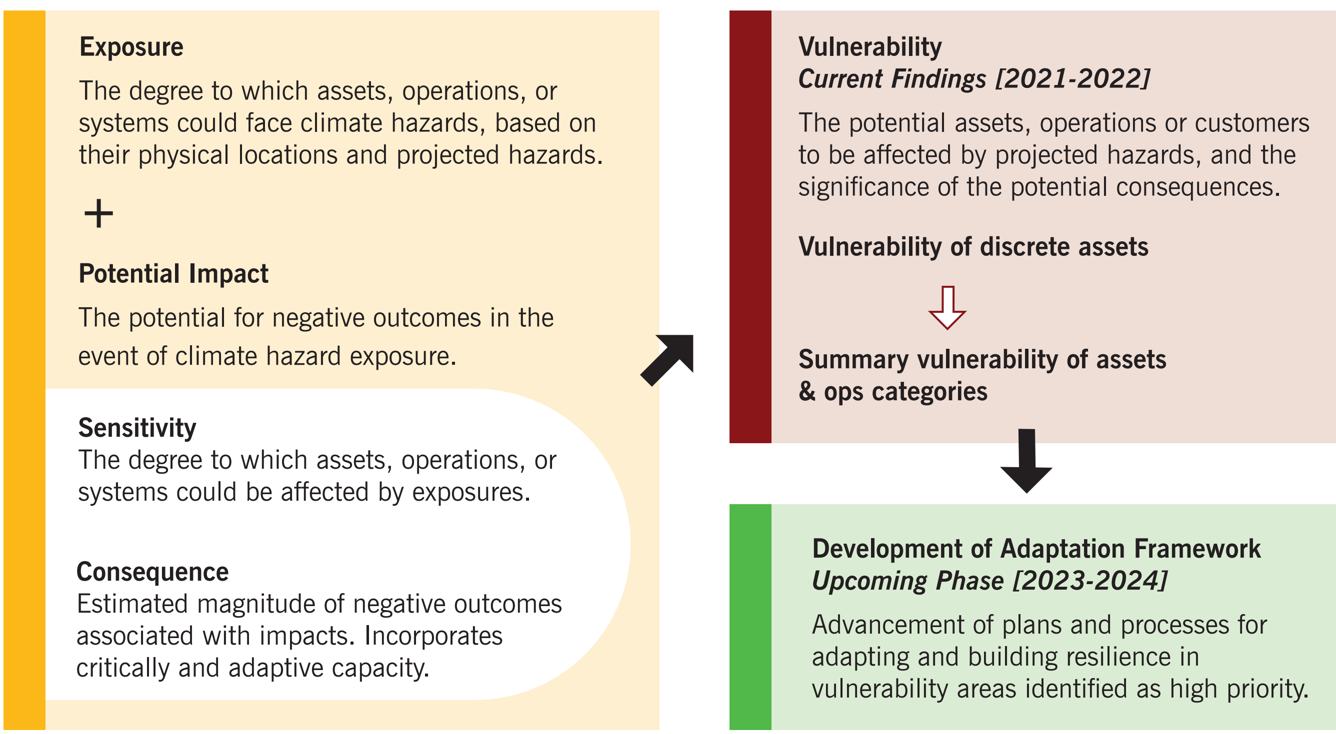


Figure 1: Vulnerability assessment framework.

Stakeholder Engagement

At the request of Duke Energy, ICF convened a panel of stakeholders to serve on the CRRS Technical Working Group (TWG) that consisted of a wide range of stakeholders, including customers, state regulatory staff, environmental advocates, industry organizations, academia, cooperative/ municipal power providers, government/agency representatives and others. ICF has engaged TWG members through multiple channels, including interviews, multiparty discussions, email updates and surveys. The valuable input shared by stakeholders informed the vulnerability assessment methodology, shaped the assessment goals and objectives, and contributed to findings. Stakeholder feedback will also inform the development of the flexible adaptation framework in the next phase of the project.

Climate Change Projections

The study focuses on the range of plausible climate change futures for five climate hazard categories: 1) high temperatures and extreme heat; 2) extreme cold and ice; 3) flooding and precipitation; 4) wind; and 5) wildfire.

The analytical focus is on plausible upper and lower bounds of climate scenario projections, using the Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathway (RCP) 4.5 (50th percentile) and RCP8.5 (90th percentile) scenarios. The range between these scenarios represents uncertainty in global emissions, scientific modeling, and our understanding of Earth systems. The study provides exposure and impact analysis for both scenarios. The RCP 8.5 90th percentile scenario represents a complete failure of global emissions reduction efforts and high-end climate sensitivity, thus reflecting an extremely conservative approach or a "worst-case" understanding of risks. RCP 4.5 50th percentile projections represent a scenario that is more likely and better aligned with current and pledged emissions policies than RCP 8.5. However, while future anthropogenic emissions following RCP 8.5 are considered unlikely, realization of warming similar to RCP 8.5 may be possible even under lower emissions scenarios due to carbon cycle feedbacks that may be underconsidered in climate models (e.g., methane released from permafrost or ocean sinks decrease), resulting in a greater buildup of greenhouse gases in the atmosphere. Separately, new climate modeling suggests that climate sensitivity (the response of the atmosphere to cumulative greenhouse gases) may be underrepresented in some models, resulting in greater warming under lower emissions scenarios.

Table 1 provides a summary of projected changes in 2050 for each climate hazard and vulnerability ratings for all hazard and asset group combinations under RCP 4.5 50th percentile and RCP 8.5 90th percentile scenarios. Without adaptation planning, under both scenarios, substations are at the highest potential risk, with extreme heat and flooding being the greatest concerns for existing assets. The transmission system faces medium- or low-scoring risks for most climate hazards (depending on scenario, with lower risks under RCP 4.5).

Table 1. Summary of vulnerability ratings for all hazards and asset groups (transmission, substations, distribution) under RCP 4.5 50th percentile and RCP 8.5 90th percentile under the 2050 time frame.

Climate Hazard	RCP	Trans.	Subs.	Dist.	2050 Projected Change and Impact
High Temperature and Extreme Heat	8.5	Med.	High	Med.	Temperatures and extreme heat are projected to increase across the Carolinas over the coming decades. For example, 1-in-10-year daily maximum temperatures (temperatures with a 10% annual probability of occurrence) are projected to increase approximately 4-9°F (from a baseline of 91-106°F). Such an event would feature widespread exceedances of 110°F, the hottest temperature ever recorded at any location in North Carolina. Heat-related impacts to substation equipment (accelerated aging, need for additional capacity during heat waves, or, in the worst case, load shedding) represent the greatest potential climate related risks for Duke Energy, with capacity and degradation impacts to transmission and distribution equipment also possible.
	4.5	Low	Med.	Low	Under RCP 4.5, very few assets will be exposed to 1-in-10 maximum temperatures of 110°F or higher. While 1-in-10 maximum temperatures of over 104°F are projected in this scenario, a typical year will see few to no days above this threshold, depending on location. This means that the capacity of the system will be reduced on the hottest days of the year, but it is unlikely that temperatures will result in exceptional levels of accelerated aging or require load shedding.
Extreme Cold and Ice	8.5	Low	Low	Low	Projections show that climate change will drive overall warmer temperatures in the Carolinas, although cold snaps and winter storms are still expected to occur. A warmer climate does not preclude severe winter weather or extreme cold temperatures (i.e., polar vortex events). Future winters in the Carolinas will likely see less total snowfall and fewer heavy snowstorms and icing events. Based on low certainty of any detrimental effects as well as Duke Energy's existing standards, these changes present relatively low incremental vulnerability across asset types.
	4.5	Low	Low	Low	Under RCP 4.5, winters are anticipated to warm, though not as much as under RCP 8.5. As under RCP 8.5, severe winter weather and cold temperatures will still occasionally occur. Overall, the incremental risk of extreme cold and ice will decrease over time.
Coastal Flooding	8.5	Med.	Med.	Low	Rising sea levels and projected increases in hurricane intensity may result in increased flood risk for coastal infrastructure, on a permanent basis and/or an increase in the degree and duration of storm surge events. Impacts to transmission assets are more likely to be chronic, while impacts to substations, which are highly sensitive to flooding, may be more likely at a limited number of locations, where storm surge coupled with rising sea levels could exceed flooding thresholds, resulting in severe impacts. Substation flooding analysis may be updated as modeling improvements are made.
	4.5	Med.	Med.	Low	Under both RCP 8.5 and 4.5 hurricane intensity is anticipated to increase over time. Since increasing intensity of hurricanes is a major driver of the coastal flooding vulnerability scores, the ratings remain the same under both future scenarios.
Precipitation and Inland Flooding	8.5	Med.	High	Low	Over the coming decades, higher atmospheric moisture content and other factors may increase the amount of rainfall during periodic heavy downpours, increasing the potential for flash flooding and resulting in destructive landslides and debris flows. These changes could affect many of the 124 (5% of Duke Energy's total) substations located in existing FEMA 500-year flood plains (which can be considered a proxy for future 100-year flood plains), as well as the 38% of total substations and 21% of total transmission structures that are located in regions of high landslide incidence or susceptibility. Note that these ratings may be considered conservative, given the territorywide analysis does not identify severity of potential flood exposure, and that subsequent site-specific analysis may narrow the list of at-risk sites.
	4.5	Low	Med.	Low	Under RCP 4.5, projected increases in the average annual maximum five-day precipitation ranges from approximately 5% to 20% across the service area. While certainly an increase, it is much less than the up to 35% increase under RCP 8.5. Substations within existing flood plains will be at elevated risk of flooding compared to today, but overall there is a lower likelihood of significant, repeated flooding when compared to RCP 8.5, especially given changes in Duke Energy's design standards and recent investments in substation flood protection.
Wind	8.5	Med.	Low	Med.	Projections show small changes in average wind speeds across the Carolinas through 2050. However, extreme wind speeds from hurricanes and storms may increase over the coming decades with increasing storm intensity. While Duke Energy's assets are generally built to be resilient to high wind conditions, extreme winds – as well as the indirect effects of wind-driven vegetation and debris impacts – may result in damage to or collapse of T&D overhead structures, resulting in a medium rating for transmission and distribution.
	4.5	Med.	Low	Med.	Under both RCP 8.5 and 4.5 hurricane and storm intensity is anticipated to increase over time. Since increasing intensity of hurricanes and other storms is a major driver of the wind vulnerability scores, the ratings are the same under both future scenarios.
Wildfire	8.5	Med.	Med.	Med.	Projections under RCP 8.5 indicate a moderate increase in the frequency of conditions conducive to wildfires within the Carolinas (e.g., dryness, temperature, wind, lightning, forest density).
	4.5	Low	Low	Low	Projections under RCP 4.5 demonstrate a more moderate increase in wildfire risk than under RCP 8.5. In addition, projections of wildfire are subject to uncertainty, and some evidence suggests mitigating development trends and improved wildfire control measures may reduce the degree to which climate change increases this risk.

Potential Climate Change Implications for Planning and Operations

In addition to assessing the climate change vulnerabilities of Duke Energy's Carolina T&D infrastructure, the study team also reviewed potential risks to Duke Energy's planning processes and operations. Table 2 shows the priority ratings assigned to each planning and operation area. These ratings reflect the potential magnitude of changes that may need to occur within Duke Energy's planning and operational processes to account for climate change, regardless of the realized RCP scenario.

Table 2. 2050 projected vulnerability priority ratings for asset and operations planning groups, agnostic of scenario.

Process Area	Risk Score
Asset Management	High
Load Forecasting	Medium
Capacity Planning	Medium
Reliability Planning	Medium
Emergency Response	Low
Workforce Safety	Low
Vegetation Management	Low

Asset management, or Duke Energy's processes to monitor, repair, replace, and augment equipment and systems, is the only process area receiving a high priority vulnerability rating. Risks to Duke Energy's asset management include accelerated equipment aging; a potential need to adjust design criteria to address the risk of changing precipitation, flooding and heat patterns; an incomplete understanding of the pole fleet's weather readiness; and limited insight into failure data and impact of climate on failure rates. Without adaptation, these risks could result in higher capital costs and reduced service reliability for customers. Load forecasting, capacity planning, and reliability planning all received medium priority vulnerability ratings since only one or two process components would need to be updated to account for climate change for each of those process areas. Across these process areas, Duke Energy could benefit from incorporating local variations in temperature and projected future changes in temperature and extreme weather events, which could enhance Duke Energy's system reliability, avoid accelerated equipment aging or equipment failure, and ensure that Duke Energy continues to avoid the need for implementing load shedding. While emergency response, workforce safety, and vegetation management will all be impacted by climate change, their existing processes were found to be flexible and robust enough to address future changes in climate through 2050.

Social Vulnerability Analysis

Communities with socioeconomic or physical disadvantage may be disproportionately affected by climate change-driven natural hazard events due to higher levels of exposure and lower capacity to adapt. Power system malfunctions can worsen the impacts of climate hazards to vulnerable communities. This study includes a preliminary analysis of potential overlaps between climate-related hazards that could affect Duke Energy infrastructure (i.e., heat, flooding, landslides) and vulnerable communities. For example, out of the total 124 Duke Energy substations that are within today's FEMA 500-year flood plain, 53 are also located in high or extremely high social vulnerability census tracts.

Workshop Discussion – Sequential Events

To address high-impact, low-frequency events in the Carolinas, ICF developed two highly unlikely, yet still plausible, event scenarios: (1) a Category 5 hurricane making landfall in the service area followed by an intense heat wave where maximum temperatures would exceed 120°F for a single day and 115°F for three days in some parts of the territory, and (2) an intense winter storm with ice accumulation of up to 1.25 inches followed by a severe cold snap where temperature minimums during the coldest night reach 0°F in Central North Carolina and -8°F in the western areas (and even lower at high elevations). Through a workshop, ICF and the Duke Energy CRRS team validated the notion that some high-impact, low likelihood weather events exceed electric utilities' economic capacity to reasonably prepare or "harden" all system elements against extreme events. Infrastructure damage could occur across asset types and customers could experience impacts including widespread and extended outages, which could lead to public safety risks, especially for low-income, elderly, and customers with disabilities, and customers that reside in homes with limited insulation or indoor air temperature control. Discussion of these scenario events included consideration of Duke Energy's robust existing emergency communication protocols, storm preparation procedures, and restoration priority procedures, in addition to potential additional hardening and planning measures that could be beneficial in preparing for future extreme events. Considerations identified in this discussion will further inform Duke Energy's ongoing climate change adaptation planning.

Next Steps: Adaptation Planning

- In the next phase of this project, which will focus on flexible adaptation planning, ICF will collaborate with Duke Energy and the TWG to discuss possible approaches to increase the Carolinas T&D system's preparedness for the effects of climate change. The preliminary objective for the adaptation planning phase of the project is to identify opportunities to improve Duke Energy's ability to meet or exceed expectations for performance with future investments and existing systems over their useful life despite changes in climate. This will be accomplished by:
- Selecting an initial climate change scenario for use in Duke Energy planning and design.
- Identifying existing Duke Energy guidance documents that should be updated to incorporate climate change projections.
- Identifying adaptation strategies and signposts that would prompt their implementation, particularly for assets ranked highly vulnerable.
- Identifying potential adaptation strategies for extreme events, including options for partnership with local communities.
- Establishing key considerations for implementation of strategies such as mutual community resilience objectives.

I. Introduction

Overview of Duke Energy Climate Resilience Study

Through the Climate Risk and Resilience Study (CRRS), Duke Energy aims to develop an improved understanding of the physical vulnerabilities and risks that climate change could pose to its transmission and distribution assets, operations, and customers, and to develop a flexible framework to improve the company's resilience.[1] Duke Energy selected ICF's climate adaptation and resilience experts to conduct the technical analysis supporting the study. ICF's experts, along with Duke Energy internal subject matter experts, make up the project team for the CRRS. This Interim Report summarizes the vulnerability assessment findings and is the first major deliverable in the overarching study. Next, the project team will begin developing the flexible adaptation strategy. The goals of the vulnerability assessment were to:

- Develop a clear and detailed understanding of potential climate change vulnerabilities to Duke Energy's transmission and distribution (T&D) assets and operations across a range of climate change scenarios.
- Identify Duke Energy's highest priority climate vulnerabilities for further adaptation planning, based on reasonably bounding potential exposures and system-level impacts.
- Enhance Duke Energy's capacity to analyze climate change projections and impacts to inform ongoing adaptation planning.
- Implement a transparent methodology and robust opportunities for stakeholder feedback throughout the process to ensure that study results are accessible and useful to stakeholders and the public.
- Affirm Duke Energy's commitment to providing reliable and resilient energy in the face of changing weather and climate conditions. This work is complementary to Duke Energy's existing efforts to enhance the present-day resiliency of its T&D system.

The objectives of the vulnerability assessment were to:

- Consolidate the knowledge base describing relevant sensitivities and potential system consequences by T&D asset type.
- Provide a robust collection of tailored climate change data to support Duke Energy's ongoing climate change analysis and adaptation planning.
- Support transparent public reporting and provide stakeholder data access to share study findings in formats that can inform community resilience planning.
- Enhance understanding of relevant community vulnerabilities and stakeholder priorities with respect to adaptation planning.

The ICF study team led the analysis of climate change projections and findings of potential Duke Energy vulnerabilities. Throughout the process, Duke Energy subject matter experts provided detailed input and feedback through interviews, meetings and workshops. The study team also received feedback and guidance from

[1] This report fulfills, in part, the terms of a settlement agreement that the company reached with Vote Solar and filed on July 9, 2020, in NCUC Docket No. E-2, Sub 1219.

the study's Technical Working Group (TWG), comprised of representatives form external stakeholders, with respect to the study's scope, methodology and findings.

Introduction to Duke Energy's System and Prior Resilience Activities

Duke Energy's service area in North Carolina and South Carolina is comprised of Duke Energy Carolinas (DEC) and Duke Energy Progress (DEP), which deliver electricity to customers through a grid of transmission lines, distribution lines and substations. This study focuses on these portions of Duke Energy's assets and operations. It does not include Duke Energy's generation assets. Figure 2 depicts Duke Energy's service area for DEC and DEP.

Infrastructure in the DEC service area serves approximately 2.7 million industrial, commercial, and residential customer accounts, and spans nearly 24,000 square miles. The DEP service area serves nearly 1.6 million industrial, commercial, and residential customer accounts, and spans nearly 32,000 square miles.

Within Duke Energy's service territory, approximately 1.5 million customer accounts are served by local distribution cooperatives or municipal utilities. Both resell energy (supplied wholesale electricity generators, such as Duke Energy) to end-use customers using distribution assets owned and operated by the cooperative or municipal utility. These non-Duke Energy assets are considered out of scope for the current study, though the climate analysis in this study does encompass those utilities' service territories. As such, many of the vulnerabilities for non-Duke Energy assets may be like those identified for Duke Energy's T&D system.

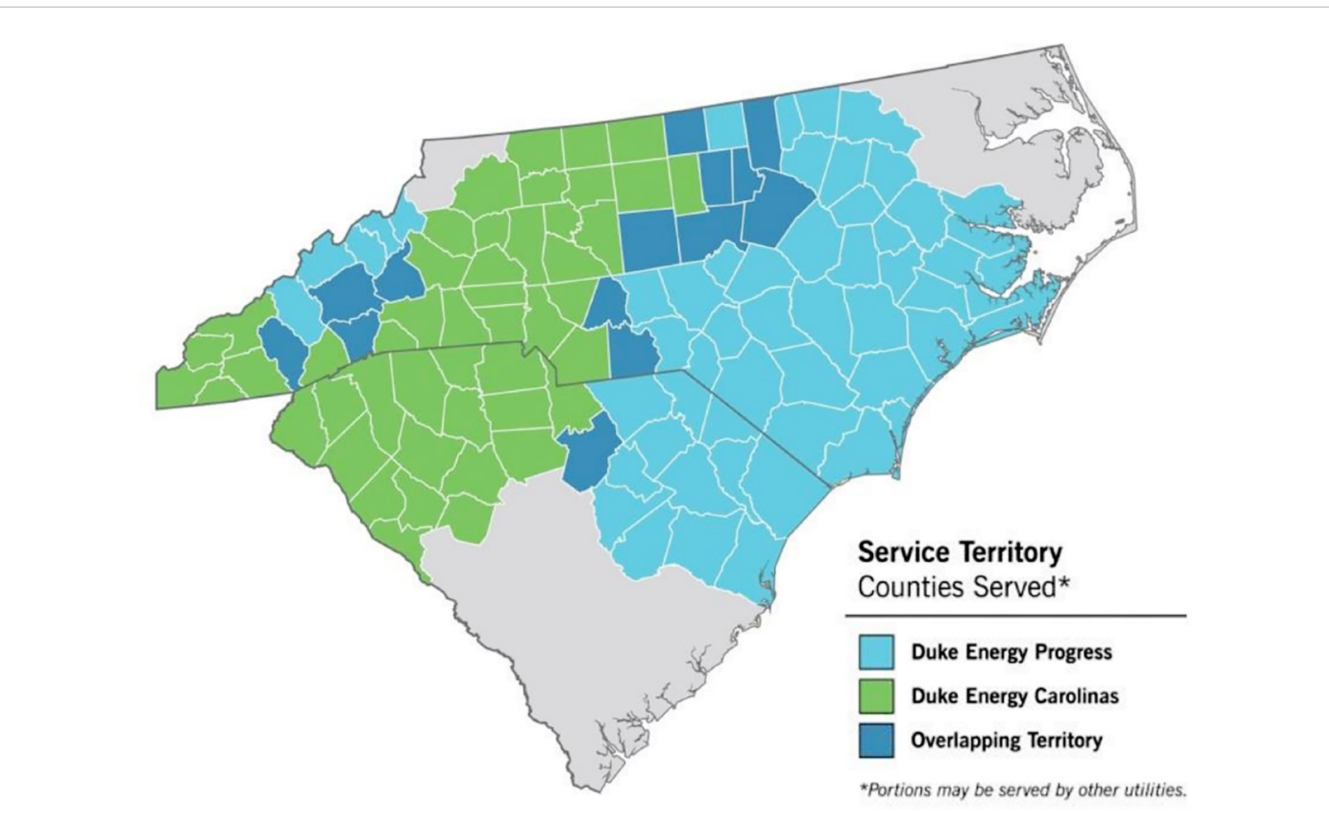


Figure 2. Map of DEC & DEP service territory.

Methodology

The vulnerability assessment methodological framework produces an understanding of the nature, extent, and priority of the vulnerabilities that Duke Energy may face as a result of climate change. This is a refined methodology based on ICF's professional experience, but it draws from many established and widely adopted frameworks, including the guidance from the U.S. Department of Energy.[2] Figure 3, below, summarizes this framework. At the most basic level, **vulnerability** is defined as the potential for assets or operations (and, by extension, customers) to be affected by climate change, and the significance of the potential consequences. This incorporates the degree to which assets may be **exposed** to climate hazards, as well as the **potential impacts** of those exposures, which in turn are assessed based on the infrastructure **sensitivity** to the hazard and the **consequence** of impact.

For each major asset group (i.e., transmission, substations, distribution) and climate hazard (i.e., extreme heat, extreme cold and ice, sea level rise and precipitation, wind, wildfire) combination, the **vulnerability rating** is summarized as **low**, **medium**, or **high** (see Table 4 for definitions). These ratings reflect the overall priority level of potential vulnerabilities under plausible and reasonably bounding future climate change conditions. Importantly, the rating reflects incremental risk associated with plausible climate change effects, focusing on the 2050 time frame, and are not intended to indicate current or cumulative risk levels. This summary is supported by quantitative and qualitative asset-level analysis of exposure, sensitivity, and potential consequence. Additionally, definitions of specific assets referred to within the vulnerability assessment are provided in Table 3.

[2] U.S. Department of Energy Office of Energy Policy and Systems Analysis. "Climate Change and the Electricity Sector: Guide for Assessing Vulnerabilities and Developing Resilience Solutions to Sea Level Rise." 2016.

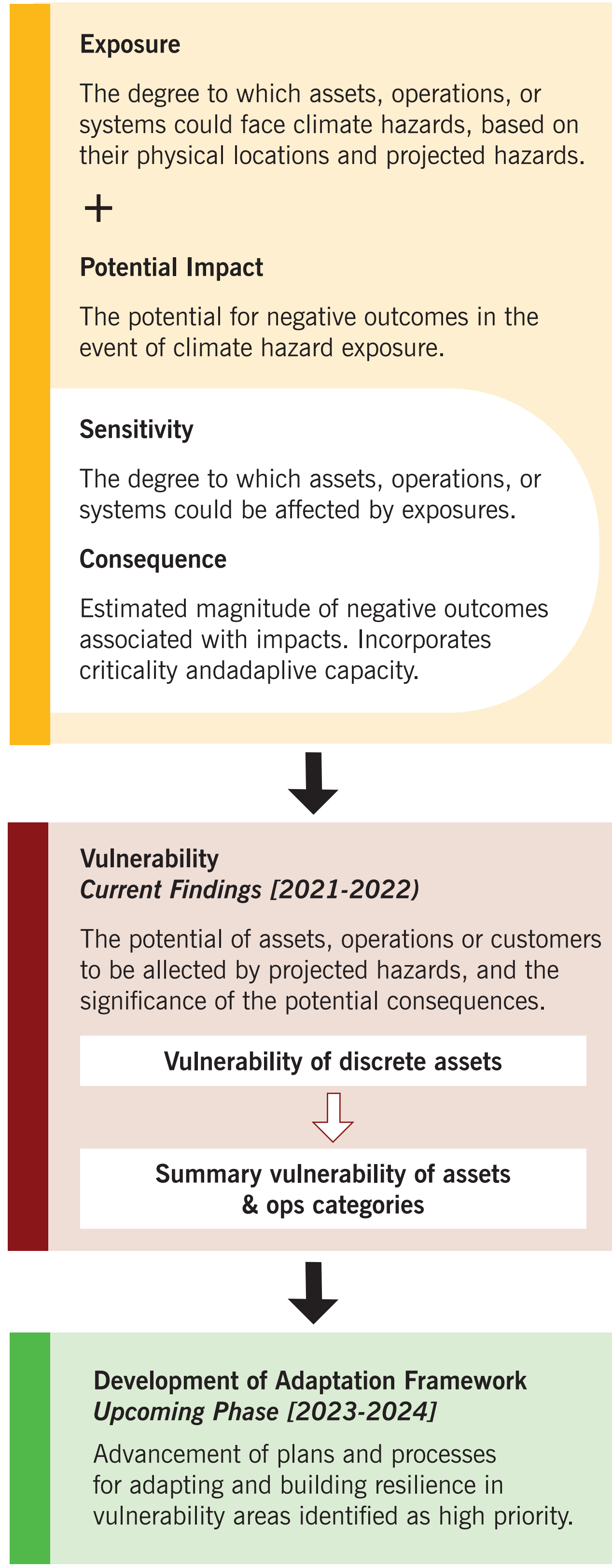


Figure 3. Vulnerability assessment framework.

Table 3. In-scope assets for the climate vulnerability study.

Transmission Assets	Asset Description
Line structures (poles/towers)	Transmission-scale poles and towers, which may be steel lattice, concrete, or wood.
Conductors (overhead)	Transmission-voltage overhead wire.
Conductors (underground)	Transmission-voltage underground wire.
Open-air current carrying components (e.g., switches, jumpers)	Non-conductor current-carrying components that are exposed to the air outside the substation physical plant.
Substation Assets	**Asset Description**
Substation transformers/regulators	Large power transformers and regulators within substations.
Circuit breakers	Substation circuit breakers designed to interrupt short circuits or overloads.
Open-air current carrying components (e.g., switches, jumpers)	Non-conductor current-carrying components that are exposed to the air within a substation.
Protection & control devices	Equipment such as protective relays and control systems that manage substation operation.
Instrument Transformers (Control Transformers and Potential Transformers)	Transformers that reduce current from high voltage for the purposes of measurement and control.
Distribution Assets	**Asset Description**
Structures (overhead) [including poles]	Distribution-scale utility poles, typically wood. Also includes crossarms and overhead support structures.
Structures (underground)	Vaults and underground infrastructure to support electric distribution equipment.
Conductors (underground)	Buried distribution wire.
Conductors (overhead)	Overhead distribution wire.
Transformers (overhead)	Overhead distribution transformers.
Transformers (padmount)	Enclosed ground-level distribution transformers mounted on concrete or fiberglass pads.
Regulators (pole mounted)	Distribution-scale voltage regulators mounted on poles throughout the system.
Reclosers	Automatic electric switch designed to detect and interrupt faults.
Capacitors	Devices to adjust distribution power factor, located overhead.
Open-air current carrying components (e.g., switches, jumpers)	Non-conductor current-carrying components that are exposed to the air outside the substation physical plant, located overhead.
Batteries (overhead)	Rechargeable batteries that are integrated into distribution equipment such as overhead reclosers.

Similarly, a **low**, **medium**, and **high climate risk score** was assigned to Duke Energy's planning and operations processes (i.e., vegetation management, workforce safety, asset management, load forecasting, capacity planning, reliability planning, emergency response) based on the number of internal processes that that do not include climate change and pose a risk to Duke Energy's system and customers.

Table 4: Vulnerability priority category rating scale for infrastructure assets and planning & operational processes.

Vulnerability Category		
	Assets	**Planning & Operational**
Low	Limited sensitivity to projected levels of change in exposure, accounting for existing risk mitigations.	No process vulnerabilities to climate change are identified.
Medium	Potential for increased impacts that could result in reliability, cost, or other consequences. Moderated by existing adaptive capacity or risk mitigations, concentration of risks in high-end climate scenarios only, or other factors.	Vulnerabilities to climate change are identified in one or two process components.
High	High sensitivity/consequence associated with potential change in exposure. Could result in increased potential for highly significant outages, risks, and/or costs.	Vulnerabilities to climate change are identified in several process components.

The product of this vulnerability assessment is an understanding of the priority vulnerabilities (based on the relative level of overall potential impact) to address in the flexible adaptation framework.

II. Stakeholder Engagement

For Duke Energy's climate resilience planning to be effective, it must include the perspectives of a broad range of stakeholders, including the communities that DEP and DEC serve, and leverage expertise beyond Duke Energy's own staff. Partnering with community representatives and other experts helps ensure Duke Energy's resilience planning is informed by a broad range of perspectives and fulfills the utilities' ultimate purpose of serving communities' and customers' energy needs into the future. Therefore, this project includes a robust stakeholder engagement effort designed to:

- Identify stakeholders' key goals, challenges and concerns
- Collect and consider best practices and expertise offered from third-party expert resources
- Integrate stakeholder feedback, to the extent possible, in Duke Energy's evolving resilience planning
- Provide transparency on the climate study process and outcomes

ICF convened a wide-ranging panel of stakeholders to serve as the CRRS Technical Working Group (TWG). The purpose of the TWG is to provide input and feedback to the study team throughout the study process, and to review interim study results ahead of key milestones. The TWG includes a wide range of stakeholder segments. A full list of TWG organizations that participated in the vulnerability assessment work is listed in Table 5.

Table 5: TWG Member Organizations

Organization Type	TWG Member Organization
Clean Energy/ Environmental Organizations	Advanced Energy
	Interfaith Power & Light, NC
	NC Sustainable Energy Association
	Sierra Club
	Southern Alliance for Clean Energy
	Southern Environmental Law Center
	Vote Solar
Customers – Large	CIGFUR
	Corning Incorporated
	Gerdau
	Google
	Walmart
Energy Industry Association	Electric Power Research Institute
	Research Triangle Cleantech Cluster
	Smart Electric Power Alliance
Governmental	City of Asheville
	Durham County
	NC Department of Environmental Quality
	NC Department of Justice
	NC Utilities Commission Public Staff
	New Hanover County
	SC Department of Natural Resources
	SC Office of Regulatory Staff
	SC Office of Resilience
	Town of Chapel Hill
Low-Income Advocates	NC Justice Center
Universities & Other Educational Organizations	Clemson University
	Duke University
	Institute for Policy Integrity NYU Law School
	Nicholas Institute for Policy Solutions (Duke University)
	North Carolina State University/NC State Climate Office
	UNCC EPIC Center
	NC Clean Energy Technology Center
	NC Institute for Climate Studies
Utilities & Related Organizations	Dominion
	Dominion SC
	ElectriCities of NC, Inc.
	Lockhart Power Company
	NC Electric Membership Corporation

Engagement Activities to Date

ICF has engaged TWG members in the Climate Study through multiple channels, including interviews, meetings, email updates and surveys. Much of the feedback received to date will inform the development of the flexible adaptation framework in the next phase of the project.

Interviews

To inform the study plan, ICF interviewed 12 individuals across 11 organizations in fall 2021 to gain insights into stakeholders' key climate resilience priorities. The concept of "community resilience" emerged as the top concern voiced by stakeholders. More specifically, stakeholders urged the study to:

- Consider the disproportionate impact of climate stressors on certain communities (particularly disadvantaged communities)
- Take into consideration non-climate stressors, such as population growth and social equity when prioritizing resilience-related actions
- Work collaboratively with local governments and communities on wholistic locally specific solutions and incorporate actions beyond Duke Energy (e.g., supporting local flood protection that would protect a substation as well as the local community)

TWG meetings

ICF has convened three virtual TWG meetings thus far and plans to hold one more over the course of the project, in addition to two more presentations to Duke Energy's broader Integrated Systems and Operations Planning (ISOP) stakeholder group.

TWG Meeting #1 was held on Sept. 21, 2021 and included the following presentations:

- Introduction & Purpose (ICF)
- Overview of NC Climate Risk Assessment and Resilience Plan (NC Dept. of Environmental Quality)
- Stakeholder Panel: Local Resilience Planning
    - City of Asheville
    - Durham County
    - New Hanover County
- Climate Vulnerability Assessment Framework for T&D (ICF)

TWG Meeting #2 was held on Feb. 17, 2022, and included the following presentations:

- Welcome and Feedback Received to Date (ICF)
- Climate Data/Exposure Update (ICF)
- Vulnerability Assessment Update (ICF)
- Adaptation Planning (Duke Energy & ICF) + Adaptation Brainstorming
- Next Steps (ICF)

TWG Meeting #3 was held on Aug. 10, 2022, and included the following presentations:

- Welcome and Introduction (ICF)
- Vulnerability Assessment Findings and Feedback (ICF)
- Adaptation Planning Scoping (ICF)
    - Panel on TWG-Recommended Adaptation Strategies
- Next Steps (ICF)

During the second TWG meeting, members provided input on adaptation planning ideas via a virtual whiteboard. TWG members highlighted opportunities for Duke Energy to participate alongside communities in solutions that are preventive, holistic and go beyond infrastructure hardening. The recommendations are summarized below.

- Collaborate in assessing risks, planning solutions, and investing in adaptations that have mutual benefit

- Enhance support of vulnerable customers (restoration priority, resilience, bill hardships, weatherization, shelters/cooling centers, etc.)
- Consider decentralized and distributed resources (behind the meter resilience solutions, Demand Response, etc.), as appropriate in planning process
- Share more information with communities (climate change information, specific risks of power outages, etc.)
- Consider climate change scenario projections in planning and building the system
- Protect power infrastructure
- Invest in resilient T&D solutions, especially for critical customers (e.g., hospitals, first responders, water systems)
- Explore new technologies to help understand and manage risk
- Enhance storm response planning

Dedicated mailbox and bimonthly email updates

ICF maintains an email inbox for the project that TWG members can reach out to with questions or comments about the study.

In addition, stakeholders receive email updates about the project every other month, to allow stakeholders to remain engaged during the interim periods between TWG meetings.

Surveys

ICF distributed a survey to stakeholders following the first TWG meeting held on Sept. 21, 2021, to seek input on ICF's proposed climate science scenarios and vulnerability assessment framework, and how ICF should engage stakeholders throughout the two-year study process. Survey respondents emphasized the need for transparency and meaningful, interactive engagement with stakeholders early in the study process. They also recommended the vulnerability assessment consider community impacts, equity, and future clean energy growth.

Stakeholder Input

Table 6 below summarizes TWG feedback to date and how ICF has incorporated or plans to incorporate this feedback into the study.

Table 6. TWG feedback summary and actions taken or recommended by ICF.

TWG Feedback	Actions Taken/Recommendation by ICF
Goals and Scope of Vulnerability Assessment TWG members underscored the importance of the study outcomes being accessible and readily usable by communities to inform their own resilience planning. TWG members also recommended additional assets for consideration and adjustments to the study time horizon.	• Established Vulnerability Assessment Goals. • Adjustments to framing of asset scope and time-period focus.
Social Equity Social equity is a top concern amongst TWG members. The CRRS should consider how equity issues impact the climate vulnerability of the communities served by Duke Energy's grid.	• Incorporating the U.S. Center for Disease Control (CDC) Social Vulnerability Index (SVI) into the Vulnerability Assessment based on recommendations from the TWG and its strong reputation as an accurate and geographically refined dataset.
Engagement Process TWG members want to be engaged early and often throughout the study. The more interaction and information the better.	• Interviewed stakeholders early in the process. • Established bimonthly email update to keep TWG informed on progress and how feedback is being incorporated. • Added TWG #2 meeting to the schedule; leveraging interactive whiteboard software.
Exploring Climate Adaptation Solutions TWG members have recommended many approaches that Duke Energy should consider to mitigate climate risks to its T&D system. E.g., enhanced local government coordination, undergrounding, vegetation management, community microgrids, incentives for distributed generation, etc.	• Kicking off Adaptation Planning discussion at TWG #2 meeting. [February 2022] • Will use this feedback to seed Adaptation Planning phase of the study later in 2022-2023.

III. Overview of Future Climate Projections for the Carolinas

To support the Vulnerability Assessment, the study team synthesized best available climate and extreme weather projections into metrics of plausible impacts of climate change. First, the study team worked with Duke Energy subject matter experts (including experts from meteorology, transmission, distribution, etc.) to identify and tailor climate projection variables, specific to the Carolinas, based on the constraints of the T&D system related to climate and extreme weather. This approach, grounded in climate science, enabled the team to develop assessment criteria and focus its attention on decision-relevant climate projections. Ultimately, the study team identified a suite of variables related to a range of climate and extreme weather hazards including, temperature, precipitation, humidity, sea level rise and coastal flooding, wildfire, wind, winter precipitation, tropical cyclones, thunderstorms and drought. Temperature, precipitation, and sea level rise projections for Duke Energy's territory can be seen at this interactive GIS-based web map, which was developed specifically for this study.

As displayed in Figure 4, this study refers to the three major geographic regions of North Carolina: coastal plain, Piedmont, and western mountains to capture the range of changes in climate projected for the region.

Climate science indicates that multiple different climate change futures are possible, driven by uncertainties in both future global greenhouse gas concentration trajectories and complex climate system sensitivities. To account for this range of potential futures, this study developed climate

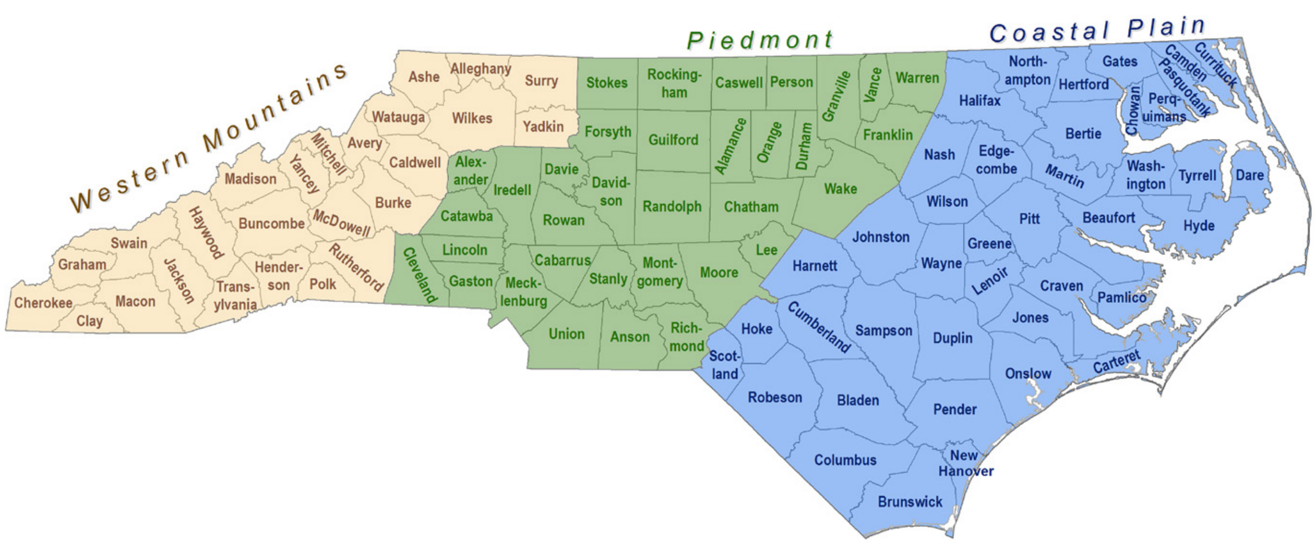


Figure 4. The three major geographic regions in North Carolina: coastal plain, Piedmont and western mountains. (Source: North Carolina Climate Science Report, 2020.)

projections drawn from a large ensemble of Global Climate Models and multiple greenhouse gas concentration trajectories.

To distill this complexity for the purposes of reporting and analysis, this report focuses on projections for plausible lower and upper bounds of the range of potential climate futures that Duke Energy may consider in the evaluation of system vulnerability and for planning. For atmospheric projections, these have been selected as:

- **Representative Concentration Pathway (RCP) 4.5 50th percentile scenario (lower bound):[3]** Reflecting significant global emissions reductions and middle-of-the-road assumptions on climate system sensitivity.
- **RCP 8.5 90th percentile scenario (upper bound):** Reflecting failure of global emissions reduction efforts and high-end climate sensitivity.[4] New modeling suggests warming similar to RCP 8.5 may be possible even under lower emissions scenarios.

The study uses a similar approach for sea level rise by bracketing the range of plausible future change using the National Oceanic and Atmospheric Association (NOAA) intermediate-low and intermediate-high sea level rise projection scenarios.[5]

Recognizing that many possible futures are possible between these two bounding scenarios, this study generally takes a risk-averse approach by stress testing the T&D system's vulnerabilities under the most aggressive plausible climate change scenarios. While this approach is appropriate for the screening of potential risks, it is not necessarily the approach that the company will or should take when planning the future T&D system.

Where applicable, climate projections were developed at decadal time horizons and for a high-resolution grid (e.g., 6 km x 6 km) across the service territory. For the purposes of this study, analysis focuses **on near-term (2030)**, **medium-term (2050)**, and **long-term (2080)** time frames to capture potential change over the course of the century.

High Temperatures and Extreme Heat

Temperatures and extreme heat are projected to increase within the Carolinas over the coming decades. Hotter summertime temperatures are particularly relevant to heat-sensitive T&D assets. Historically, the warmest parts of the Duke Energy service territory are within the coastal plain and southern Piedmont, with temperatures generally decreasing toward the west and mountainous areas.

Projections for both average and extreme temperatures show increases in the Carolinas under both RCP 4.5 and RCP 8.5. For example, in 2030 average July temperatures are projected to increase between approximately 1.9°F and 3.4°F across the territory under RCP 4.5 50th and RCP 8.5 90th percentiles, respectively. In comparison, by 2080 July average temperatures are projected to increase between approximately 3.9°F and 9.6°F under RCP4.5 50th and RCP 8.5 90th percentiles. Looking forward, significant increases in average summertime temperatures are

[3] IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3-32. In order to enable and encourage consistent comparison across climate studies globally, the IPCC identified five Representative Concentration Pathways (RCPs) for use by policymakers and scientists. The pathways describe five different climate futures, all of which are considered plausible, each of which varies by emissions rates, socioeconomic assumptions, levels of climate change mitigation and, for aerosols and non-methane ozone precursors, air pollution controls, as defined by climate scientists. Scenarios and climate data used in this study represent results from the Coupled Model Intercomparison Project Phase 5 (CMIP-5) – the most recent set of validated global climate model projects with fully developed data products available at the time of this project.

[4] The scenarios do not reflect a selection of specific climate resilience planning scenarios by Duke Energy, nor do they reflect Duke Energy's climate change mitigation ambitions or preferences on greenhouse gas emissions policies.

[5] Sweet, William, Robert Kopp, Christopher Weaver, Jayantha Obeysekera, Radley Horton, E. Robert Thieler, and Chris Zervas. "Global and Regional Sea Level Rise Scenarios for the United States." *NOAA Technical Report* NOS CO-OPS 083. Silver Spring, MD: National Oceanic and Atmospheric Administration, National Ocean Service, 2017 https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf.

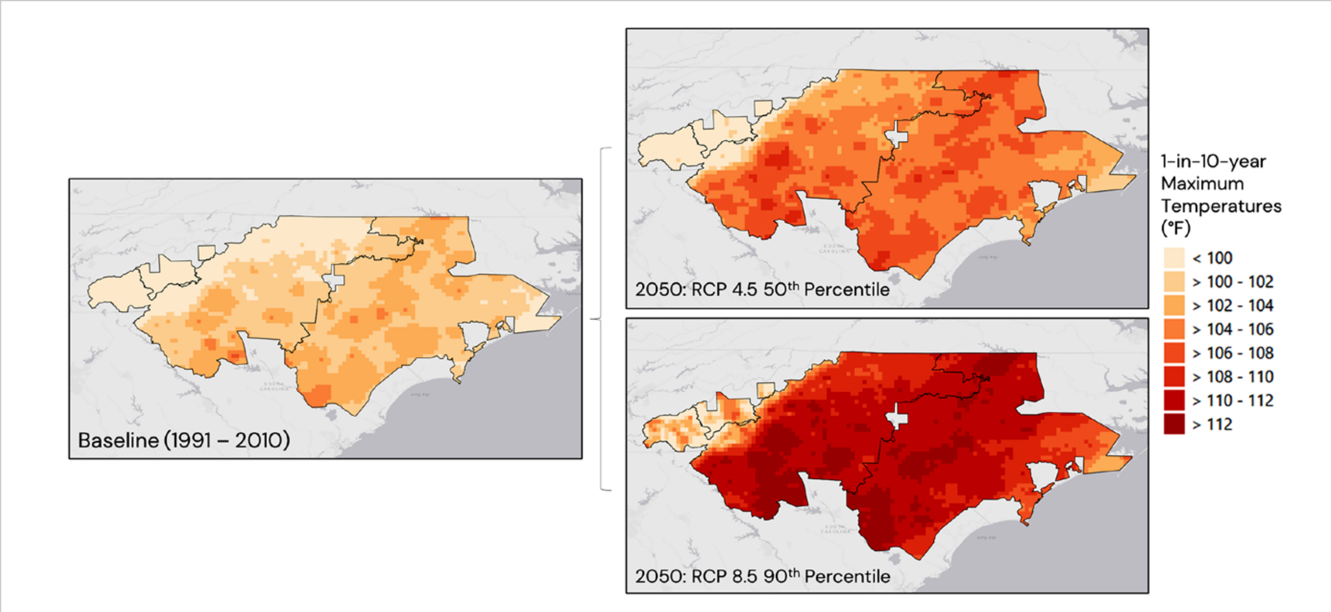


Figure 5. 1-in-10-year maximum temperatures across Duke Energy territory, showing baseline temperatures (left) and projected temperatures in 2050, under RCP 4.5 50th percentile scenario (top right) and RCP 8.5 90th percentile scenario (bottom right).

projected for many cities within the service territory such as Charlotte, Wilmington and Asheville, N.C. Average July temperatures in Charlotte could reach approximately 90°F by 2080 under RCP 8.5 90th percentile, compared to the historical baseline value of approximately 79.5°F.

Extreme hot temperatures are also projected to increase across the Carolinas. The 1-in-10-year daily maximum temperatures (temperatures with a 10% annual probability of occurrence) ranged from approximately 91°F to 106°F across the service territory during the 1991-2010 historical baseline period. These values are projected to increase approximately 4°F to 9°F by 2050, and approximately 5°F to 15°F by 2080 based on RCP 4.5 50th percentile and RCP 8.5 90th percentile projections (Figure 6). To date, the hottest recorded temperature in North Carolina was 110°F in Fayetteville, N.C., in 1983.[6] Under a severe climate change scenario (RCP 8.5 90th percentile), projections show that 1-in-10-year daily maximum temperatures could exceed 110°F in approximately 40% of the service territory by 2050. Since coastal cities may be moderated by the Atlantic Ocean to some degree, projected increases in extreme temperatures are smaller in coastal cities compared to inland regions. Figure 6, above, shows projected changes in the 1-in-10-year maximum temperature in three representative cities across the Duke Energy service area: Wilmington, Charlotte and Asheville.

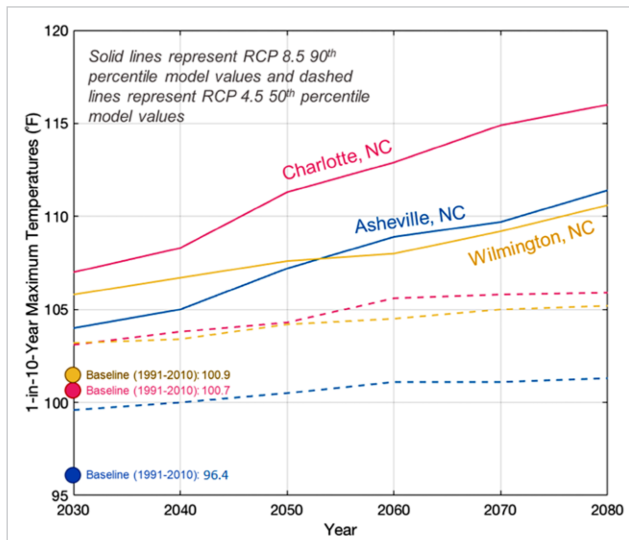


Figure 6. Projected change in 1-in-10-year maximum temperatures in Wilmington, Charlotte and Asheville.

[6] Armstrong, Tim, "Historic Heat waves in the Carolinas," National Weather Service, June 2017, https://www.weather.gov/ilm/heatwaves.

Extreme Cold and Winter Storms

Projections show that specific climate change scenarios will drive, in general, warmer temperatures in the Carolinas. Warming temperatures have a range of implications for the Duke Energy service area, including, on average, warmer winters and a decrease in the frequency of cold weather. For example, Charlotte, N.C., could experience between 20 and 40 fewer days with minimum temperatures below 32°F by 2080 relative to the historical baseline, corresponding to RCP 4.5 50th percentile and RCP 8.5 90th percentile, respectively (Figure 7). Other areas of the service territory are projected to experience similar decreases in cold weather.

Warming winter air temperatures also have implications for future winter precipitation. Projections show that precipitation is more likely to fall as rain than snow or ice in a warmer climate. This means that, overall, future winters in the Carolinas will likely experience reduced total snowfall, and a reduction in the frequency of heavy snowstorms and icing events.[7]

However, climate change does not preclude the potential for cold snaps and winter storms in the future. Difficult-to-model climate change dynamics could increase the likelihood for some future winter extremes, such as polar vortex events and destructive winter storms. For example, winter storms may become 5% to 25% wetter by the late-21st century compared to present day over the U.S. east coast, meaning that snow and potentially icing events could worsen when temperatures are cold enough to support frozen precipitation.[8]

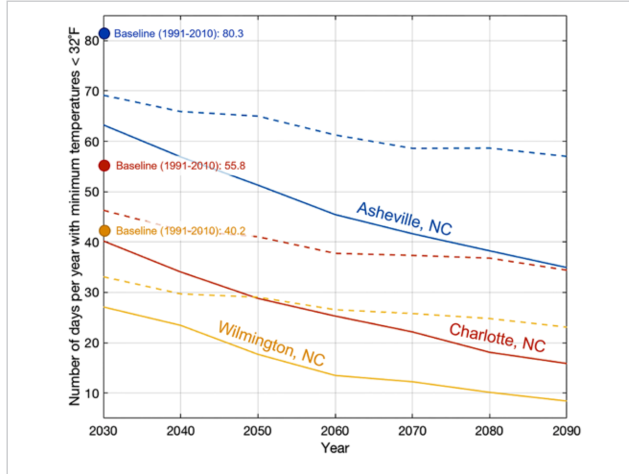


Figure 7: Projected average annual number of days with minimum temperatures less than 32°F for three locations within the Carolinas (Asheville, Charlotte and Wilmington). The baseline value (1991-2010) is shown as the dot on the left-hand side of the figure. The dotted lines represent RCP4.5 50th percentile projections; the solid lines represent RCP 8.5 90th percentile projections.

Sea Level Rise and Coastal Flooding

Projections show that sea level rise (SLR) will continue along the coast of the Carolinas through the 21st century. For example, relative SLR at Beaufort, N.C., could increase between approximately 1 to 2.2 feet by 2050 and 1.6 and 4.5 feet by 2080 relative to 1991-2009 water levels under NOAA's

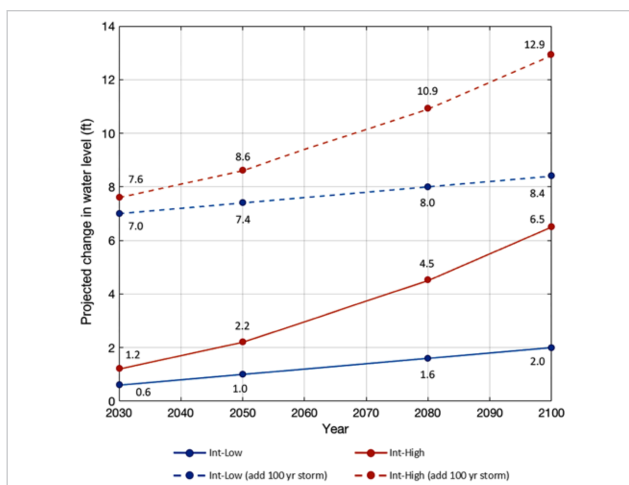


Figure 8: Projected change in water levels at the Beaufort, N.C., tide gauge through the 21st century relative to a 1991-2009 baseline. The solid lines show projected change in water levels from sea level rise under NOAA's intermediate-low and intermediate-high sea level rise scenarios. The dashed lines show projected changes in water levels resulting from sea level rise under the NOAA scenarios plus the historical 100-year extreme water level at the tide gauge.

[7] Kunkel, Kenneth, David Easterling, Andrew Ballinger, Solomon Bililign, Sarah Champion, D. Reide Corbett, Kathie Dello, Jenny Dissen, Gary Lackmann, Richard Luettich, L. Baker Perry, Walter Robinson, Laura Stevens, Brooke Stewart, and Adam Terando. *North Carolina Climate Science Report*. Asheville, N.C.: North Carolina Institute for Climate Studies, 2020. https://ncics.org/nccsr.

[8] Zhang, Zhenhai, and Brian A. Colle, "Changes in Extratropical Cyclone Precipitation and Associated Processes During the Twenty-First Century Over Eastern North America and the Western Atlantic Using a Cyclone-Relative Approach," *Journal of Climate* 30, No. 21 (2017): 8633-8656, accessed May 4, 2022, https://doi.org/10.1175/JCLI-D-16-0906.1.

intermediate-low and intermediate-high scenarios, respectively (Figure 8).

Projected SLR will also exacerbate coastal storm surge in the future. Water levels combining projected SLR with the historical 100-year storm at the Beaufort, N.C., tide gauge could reach approximately 8.4 and 12.9 feet above mean 1991-2009 levels by 2100 under intermediate-low and intermediate-high scenarios, respectively (Figure 8). Other coastal areas of the service territory are projected to experience similar increases.

Precipitation

While SLR drives coastal flooding, precipitation strongly influences patterns of inland flooding. Climate change is projected to drive heavier precipitation in the service area. In addition, warmer sea surface temperatures can increase the intensity of coastal storms, including hurricanes, and increase the amount of precipitation that they produce.

One of the key precipitation variables developed for this study was the maximum amount of precipitation falling during a five-day period, which represents longer-duration heavy precipitation events relevant to inland flooding. Historically, average annual maximum five-day precipitation in the service area has been greatest within the coastal plain and western mountains where events have exceeded approximately 6 inches on average. Projections show potentially significant increases in average annual maximum five-day precipitation, with increases ranging from approximately 5% to 20% averaged across the service area under RCP 4.5 50th percentile and RCP 8.5 90th percentile, respectively (see Figure 9). Increases are projected to exceed 30% in some western mountainous areas under RCP 8.5 90th percentile. Increases commensurate with this level could significantly increase the potential for riverine and pluvial flooding, as well as precipitation-driven landslides and debris flows.

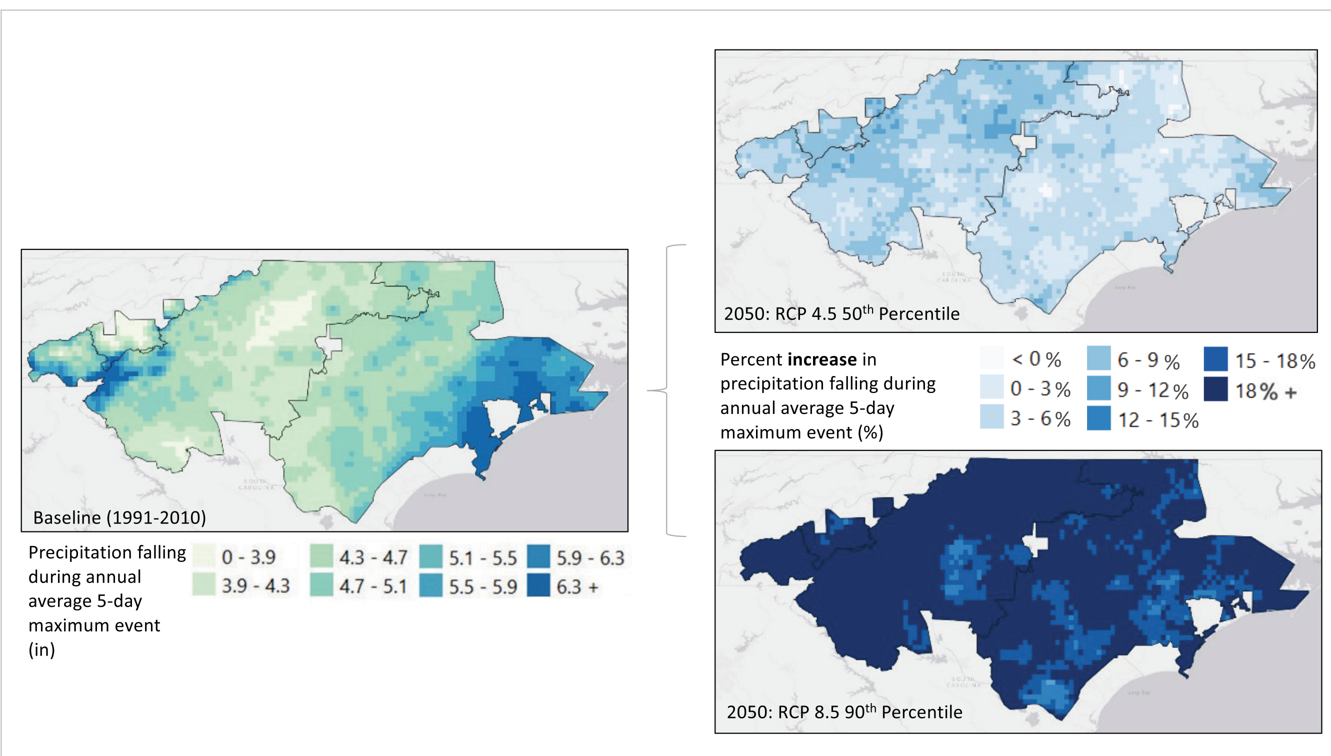


Figure 9. Annual average five-day precipitation events across Duke Energy territory, showing baseline precipitation amounts (left), projected change by 2050, under RCP 4.5 50th percentile scenario (top right) and RCP 8.5 90th percentile scenario (bottom right).

Wind

Projections developed for this study reveal small future changes in average daily wind speeds across the Carolinas relative to baseline conditions. This finding applies to both annual average wind speeds and the 98th percentile of daily average wind speeds, which represents the average daily wind speeds occurring during the seven windiest days of the year. For example, projections show increases in the 98th percentile wind speeds of approximately 0.5% to 3% through 2050 in the western and mountainous region of the service area, where 98th percentile wind speeds have historically reached up to nearly 12 meters per second, or 26.8 miles per hour.

While these projections inform our understanding of potential changes in average daily wind speeds in the service area, they do not completely resolve subdaily wind gusts or sustained winds from storms that are often most impactful to infrastructure and system performance. To address this, this study supplemented downscaled climate projections with a broad review of peer-reviewed scientific literature to better understand the influence of climate change on storm systems in the service area and, in turn, implications for future wind gusts.

Overall, the review determined that climate change will likely increase the frequency and intensity of some extreme wind events in the service area. For example, there is medium to high confidence that the intensity of stronger hurricanes (i.e., Category 3 and above) will increase under climate change, which could further increase maximum speeds and radii of hurricane-force winds during these storm events.[9,10] In addition, warming atmospheric temperatures are projected to more frequently create unstable atmospheric conditions that, in turn, could drive more frequent severe thunderstorms and storm-driven wind gusts throughout the Carolinas.[11] Stronger or more frequent thunderstorms could also have implications for tornadoes in the service area, however additional study is needed by the broader research community on this topic. Historical changes in tornado activity are similarly complex. For example, the number of days per year on which tornadoes occur has decreased, while the number of tornadoes that form on such days and the length of the tornado season has increased since the 1970s across the United States.[12,13]

Wildfire

As discussed in the NC Climate Science Report, climate change is projected to moderately increase the frequency of conditions that could lead to wildfires within the Carolinas as well as the size of wildfires. Factors including dryness, temperature, wind, forest density, development patterns, and lightning-influenced ignition.[14] Climate change may drive a range of physical factors that increase wildfire risk within the Carolinas, including changing vegetation type, increased evapotranspiration, drying of vegetation from higher temperatures, and prolonged periods of drought. However, future wildfire projections are characterized by a high degree of uncertainty given the complex interactions between climate-driven factors. Additionally,

9 Kunkel, Kenneth, David Easterling, Andrew Ballinger, Solomon Bililign, Sarah Champion, D. Reide Corbett, Kathie Dello, Jenny Dissen, Gary Lackmann, Richard Luettich, L. Baker Perry, Walter Robinson, Laura Stevens, Brooke Stewart, and Adam Terando. *North Carolina Climate Science Report*. Asheville, N.C.: North Carolina Institute for Climate Studies, 2020. https://ncics.org/nccsr.

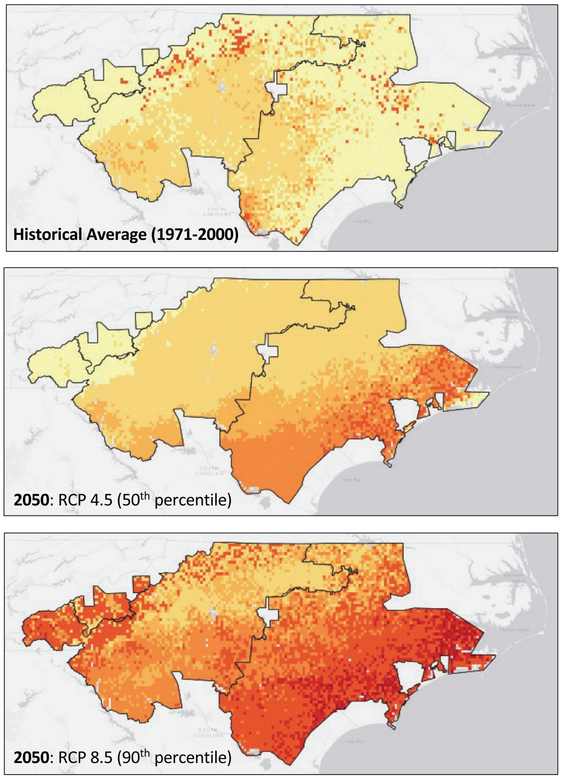
10 Mudd, Lauren, Yue Wang, Chris Letchford, and David Rosowsky, "Assessing Climate Change Impact on the U.S. East Coast Hurricane Hazard: Temperature, Frequency, and Track," *Natural Hazards Review* 15, No. 3 (2014): https://ascelibrary.org/doi/abs/10.1061/%28ASCE%29NH.1527-6996.0000128.

11 Diffenbaugh, Noah, Martin Scherer, and Robert Trapp. "Robust Increases in Severe Thunderstorm Environments in Response to Greenhouse Forcing," *National Academy of Sciences* 110, No. 41 (2013): 16361-16366, https://doi.org/10.1073/pnas.1307758110.

12 Kunkel, Kenneth, David Easterling, Andrew Ballinger, Solomon Bililign, Sarah Champion, D. Reide Corbett, Kathie Dello, Jenny Dissen, Gary Lackmann, Richard Luettich, L. Baker Perry, Walter Robinson, Laura Stevens, Brooke Stewart, and Adam Terando. *North Carolina Climate Science Report*. Asheville, N.C.: North Carolina Institute for Climate Studies, 2020. https://ncics.org/nccsr.

13 Mudd, Lauren, Yue Wang, Chris Letchford, and David Rosowsky, "Assessing Climate Change Impact on the U.S. East Coast Hurricane Hazard: Temperature, Frequency, and Track," *Natural Hazards Review* 15, No. 3 (2014): https://ascelibrary.org/doi/abs/10.1061/%28ASCE%29NH.1527-6996.0000128.

14 Environmental Protection Agency. "Climate Change Indicators: Wildfires," *Environmental Protection Agency*, accessed April 2022, https://www.epa.gov/climate-indicators/climate-change-indicators-wildfires.



Average percent area burned per grid cell

Historical Average (1971-200)	2050 RCP 4.5 50th percentile	2050 RCP 8.5 90th percentile
0.38 %	1.04 %	2.66 %

Average Annual Percent Area Burned per Grid Cell (%): 0; 0-1; 1-2; 2-3; 3-4; 4-5; >5

Figure 10: Wildfire projections for Duke Energy service territory, under historical and future climate scenario conditions.

mitigating social factors and improved wildfire control measures may reduce the degree to which climate change increases risk, meaning projections that consider the influence of climate change alone could overstate the amount by which wildfire risk will increase.[15]

When considering physical factors of climate change, wildfire risk in the Carolinas may increase due to higher temperatures and greater regional dryness, although this is characterized by significant uncertainty. Throughout the service territory, quantitative projections show increases in the average annual percent area burned by wildfire. Wildfire projections for the Duke Energy service territory under historical and future climate scenario conditions are shown in Figure 10, with the greatest increases within the coastal plain and, under the high-end climate change scenario, the western Carolinas. Other studies have also shown that projections indicate significantly greater increases for the coastal plain compared to the western mountains.[16]

Several factors suggest a case for future change in wildfire risk being more moderate than high-end projections suggest. For example, relative to the more fire-prone western United States, the Carolinas comparatively lower baseline wildfire risk, lower historical wildfire activity, and absence of “megafires” are due to generally consistent precipitation, denser canopies that allow forest floors to remain moist for longer, and fewer wildfire-inducing wind patterns.[17] While the number

[15] Kunkel, Kenneth, David Easterling, Andrew Ballinger, Solomon Bililign, Sarah Champion, D. Reide Corbett, Kathie Dello, Jenny Dissen, Gary Lackmann, Richard Luettich, L. Baker Perry, Walter Robinson, Laura Stevens, Brooke Stewart, and Adam Terando. *North Carolina Climate Science Report*. Asheville, N.C.: North Carolina Institute for Climate Studies, 2020. https://ncics.org/nccsr.

[16] Barbero R., J. Abatzoglou, N. Larkin, C. Kolden, and B. Stocks, “Climate Change Presents Increased Potential for Very Large Fires in the Contiguous United States,” *International Journal of Wildland* Fire 24, No. 7 (2015): 892-899, https://doi.org/10.1071/WF15083.

[17] Current Results. “Summer Rainfall Averages for Every State,” *Current Results*, accessed April 2022. https://www.currentresults.com/Weather/US/average-state-precipitation-in-summer.php.

of fires across North Carolina has stayed largely consistent over the last century, the number of acres burned has dramatically decreased since mid-20th century, suggesting significant factors driving a trend away from large-area fires (Figure 11).[18] Potential drivers of this phenomenon include stronger wildfire control measures such as prescribed burns, and land use change trends such as increasingly developed areas resulting in less contiguous burnable forest area.[19] From a forward-looking perspective, the one study available that includes wildfire control measures suggest a much more limited increase in wildfire, even under a high-end climate change scenario.[20]

Overall, while forward-looking modeling show increases in atmospheric conditions and other physical factors conducive to wildfires through the 21st century, wildfires may not experience commensurate increases in scope and impact due to the range of mitigation efforts and social factors described above.

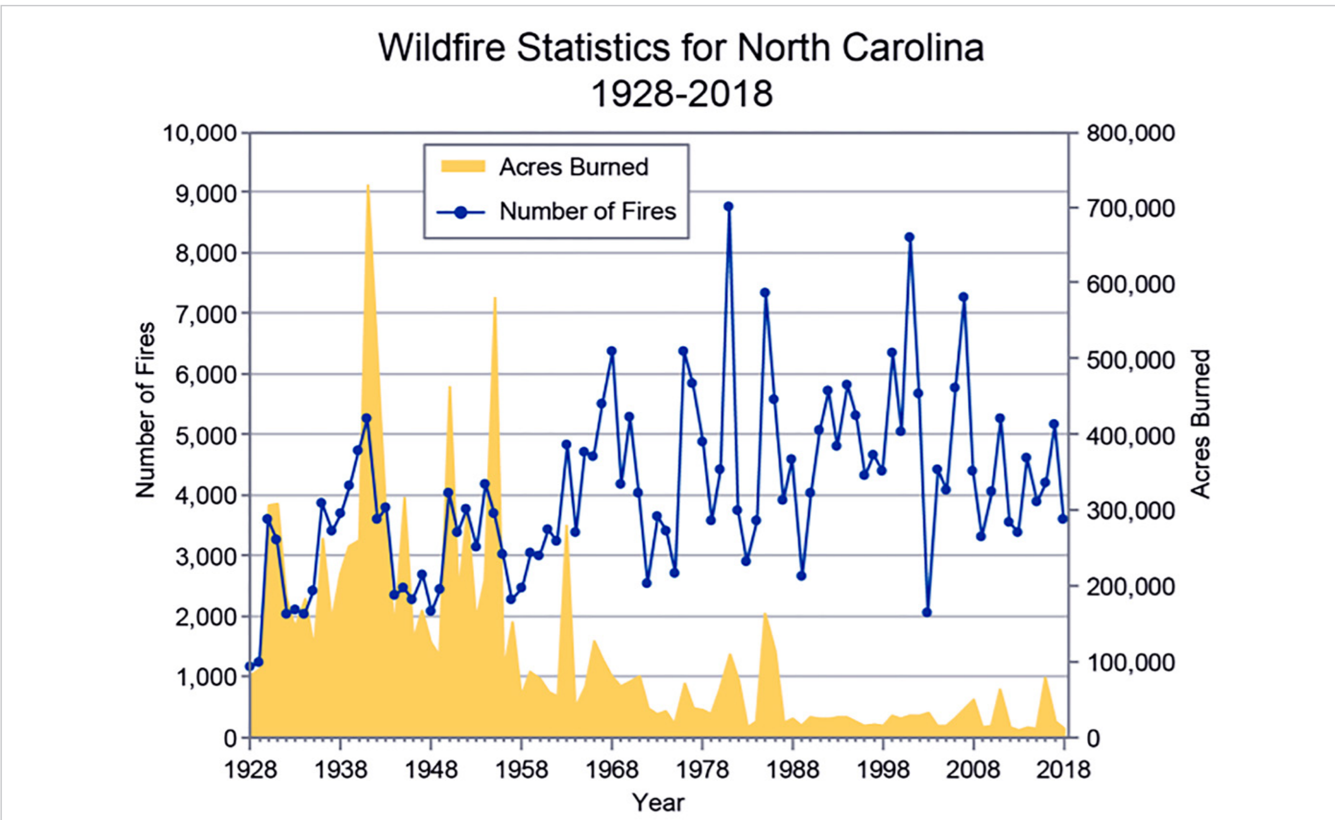


Figure 11: Year-to-year variations in the number of forest fires and acreage burned in North Carolina. (Source: North Carolina Climate Science Report, 2020).

[18] Kunkel, Kenneth, David Easterling, Andrew Ballinger, Solomon Bililign, Sarah Champion, D. Reide Corbett, Kathie Dello, Jenny Dissen, Gary Lackmann, Richard Luettich, L. Baker Perry, Walter Robinson, Laura Stevens, Brooke Stewart, and Adam Terando. *North Carolina Climate Science Report*. Asheville, N.C.: North Carolina Institute for Climate Studies, 2020. https://ncics.org/nccsr.

[19] Prestemon, Jeffrey, Uma Shankar, Aijun Xiu, K. Talgo, D. Yang, Ernest Dixon, Donald McKenzie, and Karen Abt. "Projecting Wildfire Area Burned in the Southeastern United States, 2011-60," *International Journal of Wildland* 25 No. 7 (2016): 715-729, https://doi.org/10.1071/WF15124.

[20] Prestemon, Jeffrey, Uma Shankar, Aijun Xiu, K. Talgo, D. Yang, Ernest Dixon, Donald McKenzie, and Karen Abt. "Projecting Wildfire Area Burned in the Southeastern United States, 2011-60," *International Journal of Wildland* 25 No. 7 (2016): 715-729, https://doi.org/10.1071/WF15124.

IV. Vulnerability Assessment

This section identifies the physical vulnerabilities of Duke Energy's T&D assets due to climate change by 2050. The section is divided into projections and vulnerabilities for five distinct categories of climate-related hazard (extreme heat, cold and ice, flooding and precipitation, wind and wildfire). It also includes summarized insights from a scenario-driven workshop on extreme sequential event impacts and a review of potential risks to Duke Energy's T&D planning processes and operations.

Summary of Infrastructure Vulnerability Findings

This section identifies the physical vulnerabilities of Duke Energy's assets that could emerge as a result of climate change and is divided into vulnerabilities for five distinct categories of climate-related hazards (extreme heat, cold and ice, flooding and precipitation, wind and wildfire).

High Temperatures and Extreme Heat

Analysis of extreme heat projections and potential impacts to assets suggests that potential future extreme heat presents a moderate-to-high vulnerability for Duke Energy assets, especially under a high climate change scenario. Figure 12 shows overall vulnerability ratings and summaries for transmission, substation, and distribution asset groups. Vulnerability priority is summarized on a low, medium, high scale, which indicates the relative level of overall potential impact and exposure of assets, with emphasis on 2050.

Transmission

The 2050 vulnerability priority of Duke Energy transmission assets, under the RCP 8.5 90th percentile scenario, to extreme heat hazards is rated as **medium**. Under the RCP 4.5 50th percentile scenario, future vulnerability of transmission assets is rated as **low.** Most transmission assets (e.g., poles/towers, switches) are not sensitive to heat, and underground conductors are not exposed since ground temperatures are relatively stable and remain cooler than air temperatures during hot periods. The transmission asset with the greatest potential impact from increases in temperature are overhead conductors.

However, as temperatures warm over the coming decades, overhead transmission conductors (e.g., transmission lines) are projected to be exposed to increased frequency of extreme heat events. See Figure 13 for the projected amount of days per average year that Duke Energy transmission line miles could experience temperature exceedence of 104°F (the ambient temperature reference value that Duke Energy and IEEE standards use for many electric T&D assets) under the respective assumed scenarios. Additionally, under a high climate change scenario, 1,960 miles (10%) of overhead transmission conductor are projected to see temperatures exceeding 110°F on more than one day per year on average.

While a conductor itself can tolerate high temperature conditions exceeding 200°F, a conductor is vulnerable to elevated ambient temperatures. High ambient temperatures can result in the need for derating of equipment (e.g., operating equipment below normal operating limits) to reduce additional heat generated by electrical load, which itself may be increased significantly by air conditioning demand during periods of high temperature. Derating means that the amount of

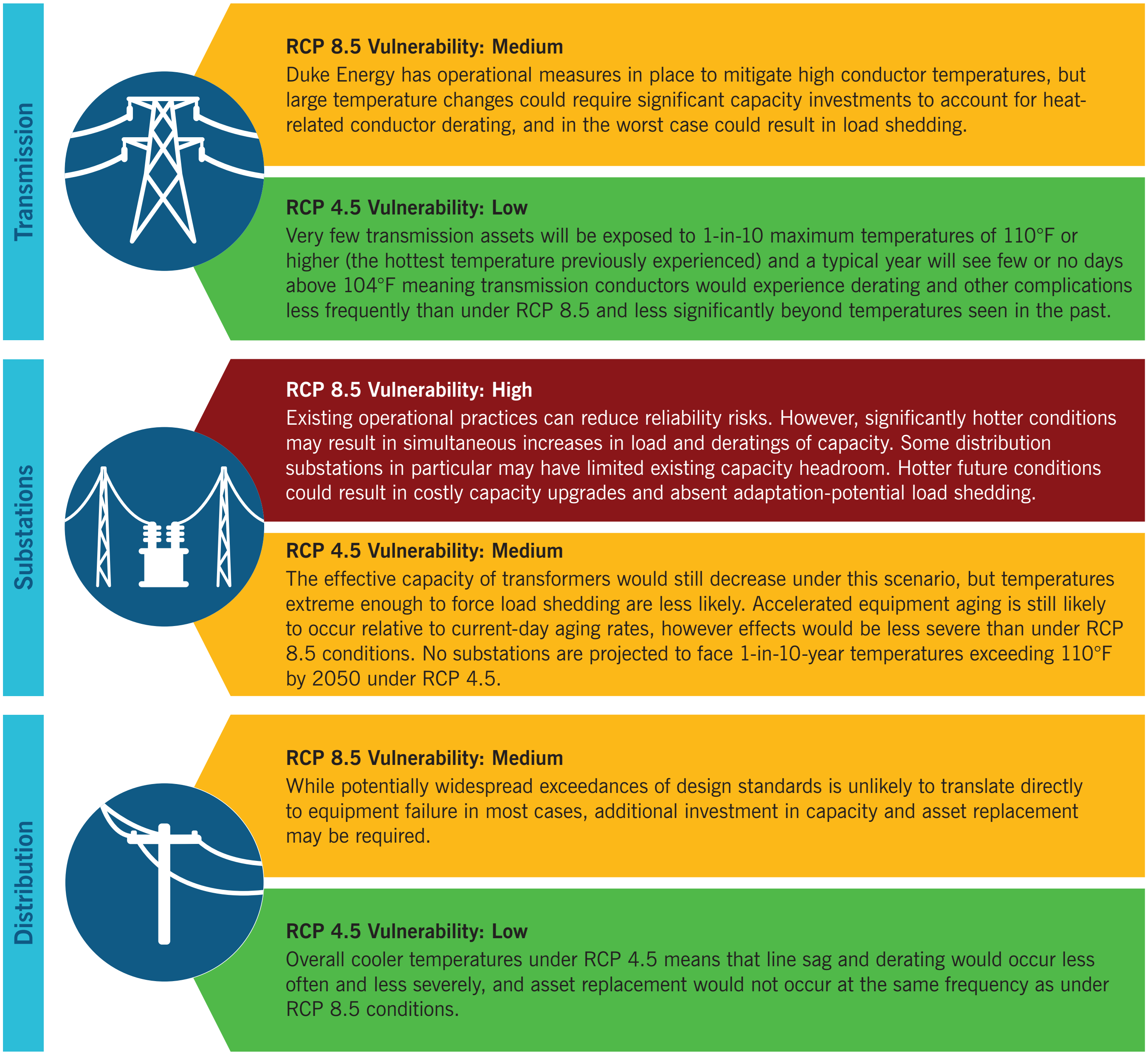


Figure 12. High temperatures and extreme heat asset group vulnerability ratings and explanations.

power that can be delivered on a particular line, without risk of damage or failure, is reduced. Today, Duke Energy's transmission operating procedures are designed to prevent excessive loading and maintain conductor temperature within design limits.

However, absent adaptation, under worst-case extreme temperatures and high demand conditions, load shedding (also referred to as rolling blackouts) could occur as the company would operate the transmission system to prioritize safety, avoid severe damage, uncontrolled outages, and/or line failure. Load shedding is the controlled dropping of intentionally selected loads in order to prevent cascading system impacts and minimize overall outages in an emergency capacity shortfall scenario. Historically, Duke Energy has not had to deploy capacity-driven T&D load shedding to mitigate the impacts of extreme heat. Procedures are in place to minimize the potential for such a scenario, including forward-looking capacity planning processes and demand response initiatives.

In general, avoiding extreme conductor loading conditions also helps reduce risks associated with exogenous failures and stressors, such as the software error that contributed to the Northeast Blackout of 2003.[21] Duke Energy's capacity planning process (discussed in greater detail in the Planning and Operations Vulnerabilities section of this report) is the primary venue for mitigating this vulnerability. Investing in adaptation for this hazard could require substantial capacity investments.

Substations

The overall 2050 vulnerability priority of Duke Energy substations to extreme heat hazards under the RCP 8.5 90th percentile scenario is **high**. Under the RCP 4.5 50th percentile scenario, future vulnerability of substations is rated as **medium.** Several substation assets (e.g., transformers and regulators, circuit breakers, batteries, protection and control devices) could face disruption, or in severe cases failure, due to high heat conditions. Open air components efficiently reject internal heat to the air and are therefore not sensitive to heat.

As temperatures warm over the coming decades, Duke Energy substations are projected to be exposed to increased frequency of extreme heat events. Figure 14 provides a sense of the territorywide potential for annual days over 110°F by midcentury under a high climate change scenario. 110°F is the historical record high temperature in North Carolina, recorded at Fayetteville in 1983. Substations in the southern Piedmont region are projected to experience the greatest annual average days over 110°F under high climate change. Notably, substation exposure is projected to differ dramatically depending on the future climate scenario. For example:

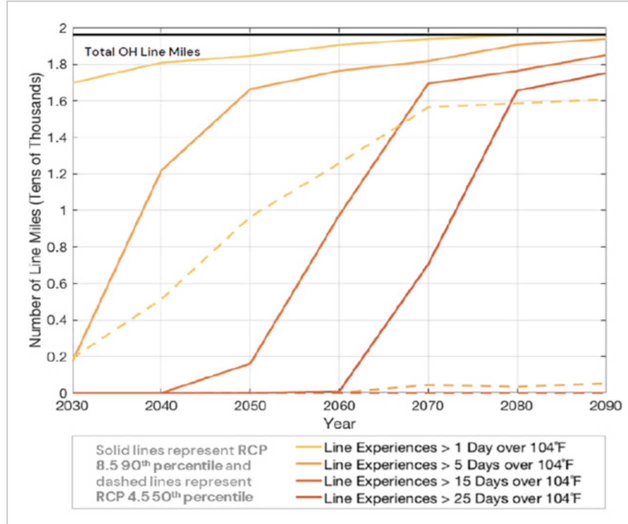


Figure 13: Projected future days per average year of Duke Energy overhead (OH) transmission line miles with ambient temperature exceedance of 104°F.

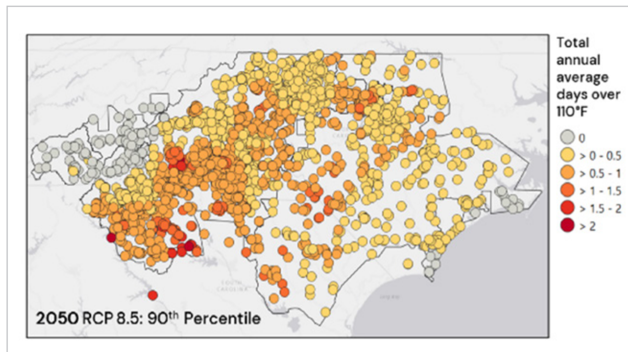


Figure 14: Substations by number of average annual days with temperatures exceeding 110°F in 2050 consistent with a high climate change scenario.

- Under the RCP 4.5 50th percentile scenario, no substations are projected to face temperatures exceeding 110°F by 2050.
- Under the RCP 8.5 90th percentile scenario several substations are projected to annually experience more than two days with temperatures exceeding 110°F by 2050.

Within the substation, transformers and regulators (which are functionally similar to transformers) face the most serious potential for disruptions due to heat. As temperatures rise, the effective capacity of transformers decreases, meaning the amount of power a transformer can deliver without risk of damage

[21] Minkel, J.R., "The 2003 Northeast Blackout – Five Years Later," *Scientific American*, August 2008, https://www.scientificamerican.com/article/2003-blackout-five-years-later/.

or failure is reduced.[22] This is frequently coupled with elevated load from air conditioning demand. Industry standards for transformers assume daily maximum temperatures of 104°F and daily average temperatures of 86°F, both of which may be exceeded with increasing frequency, although even under very high temperatures transformers can avoid failure due to their protection system that trips offline before reaching catastrophic failure. Absent adaptation, under worst-case extreme temperatures and unmitigated high demand conditions at substations, load shedding could occur in order to prevent more severe damage and uncontrolled outage scenarios.

Under high heat conditions generally, there is potential for significantly accelerated transformer aging as the equipment is subjected to elevated average and extreme temperatures. Today, full replacement of a transformer is costly and cannot typically occur quickly. Moreover, substations are currently designed to withstand the loss of one transformer. If multiple transformers at a substation, or at multiple substations, were inoperable simultaneously due to heat, then customer outage risk increases. While Duke Energy has the capability to deploy mobile transformers and substations in the event of failure, those resources are currently limited.

Circuit breakers, batteries, regulators, and protection and control equipment may also face elevated risks of degradation (or, in rare cases, failure) as a result of temperatures exceeding their design basis of 104°F. Failure of these devices could also result in customer outages.

Duke Energy should monitor substation vulnerability to heat, particularly power transformers, and prioritize asset maintenance, adjustment of design standards, and appropriate adjustment of load planning. These procedures can reduce the likelihood of equipment failure and the number and duration of customer outages.

Distribution

The overall 2050 vulnerability priority of Duke Energy distribution assets for extreme heat hazards under the RCP 8.5 90th percentile scenario is **medium**. Under the RCP 4.5 50th percentile scenario, 2050 vulnerability of distribution assets is rated as **low.** Extreme heat that exceeds equipment design standards could cause impacts to distribution assets including reduced distribution transformer capacity, reduced equipment life span, accelerated equipment aging, and, in extreme cases, equipment failure.

As temperatures warm over the coming decades, distribution assets are projected to be exposed to increased frequency of extreme heat events, which could cause potential costs and disruptions, absent adaptation. Figure 15 shows the projected length of overhead primary distribution line miles that could experience 1-in-10-year temperature exceedance of 104°F (a common equipment reference temperature) over low-end and high-end climate change scenarios:

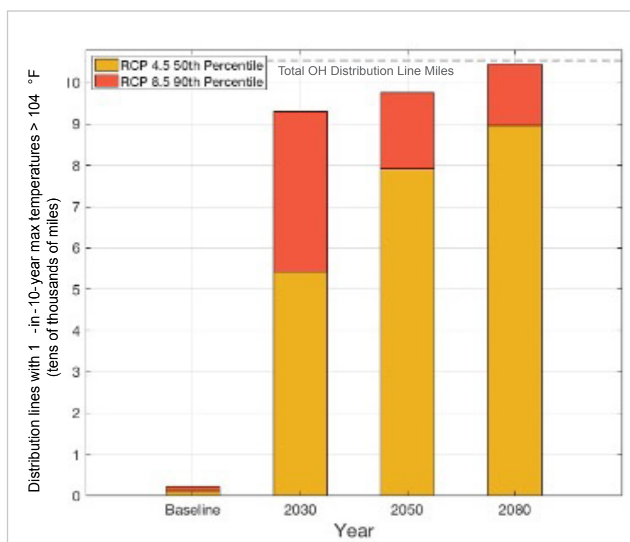


Figure 15*: Overhead distribution line miles experiencing 1-in-10-year maximum temperatures over 104°F, under RCP 4.5 50th percentile and RCP 8.5 90th percentile scenarios, across time periods. (Methodological note: Total line miles count multiphase conductor segments as multiple lines, as reflected in Duke Energy's GIS database).*

[22] For example, see: Burillo, Daniel, Mikhail Chester, Stephanie Pincetl, Eric Fournier, Daniel Walton, Fengpeng Sun, Marla Schwartz, Katharine Reich, and Alex Hall, "Climate Change in Los Angeles County: Grid Vulnerability to Extreme Heat," *California's Fourth Climate Change Assessment*. Sacramento, CA: California Energy Commission, 2018. https://www.energy.ca.gov/sites/default/files/2019-11/Energy_CCCA4-CEC-2018-013_ADA.pdf.

- Under a low-end climate future (RCP 4.5 50th percentile) 79,142 (75%) miles of Duke Energy overhead distribution conductors in the territory would be exposed to this level of extreme heat by 2050.
- Under a high climate change scenario (RCP 8.5 90th percentile) 97,617 miles of overhead distribution conductors, or 93% of distribution conductors in the territory, would be exposed to 1-in-10-year maximum temperatures exceeding 104°F by 2050.

The impact of occasional exceedances above 104°F depends upon a range of factors and equipment may often be able to withstand such temperatures. However, the possibility of impact increases based on the magnitude and frequency of temperatures exceeding this threshold, as well as based on the associated loading conditions, which themselves are linked to temperature. Notably, the low-end versus high-end climate scenarios differ significantly when comparing higher-end temperature thresholds, such as 1-in-10-year temperature exceedance of 110°F. By 2050, under the RCP 8.5 90th percentile scenario, 69% of distribution lines will face 1-in-10 temperatures over 110°F, compared to 0% of distribution lines under the RCP 4.5 50th percentile scenario.

These temperature increases – especially under high-end change – represent significant increases over the historical baseline with respect to these temperature thresholds. Other distribution equipment faces similar exposure trends with the hottest temperatures projected in the southern and central Piedmont and coastal plain.

Specific impacts and vulnerabilities to heat vary by asset. Accelerated equipment aging can occur in all distribution assets, apart from structures and open-air current carrying components, which are not sensitive to heat. Overhead distribution conductors, especially those that have not been updated to recent standards, may thermally expand during hot periods and under high electricity demand, exacerbating “line sag” and increasing potential interaction with trees and surrounding objects, which presents elevated risk of conductor arcing and potential line failures. This is particularly relevant in areas of Duke Energy’s system where capacity upgrades have not occurred in recent years.

Distribution transformers and regulators are also subject to operating at reduced capacity during high temperature periods. Transformer fuses may also be triggered under high heat and load conditions or transformers may otherwise fail, resulting in customer outages. Outages per distribution transformer are limited in number, but transformer outages could be relatively widespread during an extreme heat wave event, given the broad exposure of Duke Energy assets to high temperatures. Extreme heat exceeding design temperature can also significantly lower the life expectancy of distribution capacitors and control batteries.

Under a high climate change scenario, additional investment in capacity and asset replacement may be required to mitigate impacts of widespread exceedances in design standards, while under a lesser climate change scenario, conditions are less likely to exceed the historical rare hottest conditions and impacts would likely be less severe.

Extreme Cold and Ice

Analysis of extreme cold and ice projections and potential impacts to assets suggests that projected future changes in extreme cold and ice conditions present relatively low incremental vulnerability to Duke Energy assets. This assessment is primarily based on the low certainty of projected extreme winter changes and Duke Energy’s existing design standards. Figure 16 provides overall vulnerability ratings for transmission, substations and distribution asset groups. Vulnerability priority is summarized on a low, medium, high scale, which indicates the

Transmission

RCP 8.5 Vulnerability: Low

Duke Energy's transmission system faces low relative vulnerability to climate-related changes in cold and ice hazards, particularly given Duke Energy's adherence to NESC design criteria and the significant uncertainty in projected changes in icing.

RCP 4.5 Vulnerability: Low

Under RCP 4.5, winters are anticipated to warm, though not as much as under RCP 8.5. As under RCP 8.5, severe winter weather and cold temperatures will still occasionally occur. Overall, the incremental risk of extreme cold and ice will decrease over time.

Substations

RCP 8.5 Vulnerability: Low

Overall, Duke Energy substations face low relative vulnerability to climate-related changes in cold and ice hazards, given low substation sensitivity and lack of clear evidence for major changes in extreme cold and ice exposure.

RCP 4.5 Vulnerability: Low

Under RCP 4.5, winters are anticipated to warm, though not as much as under RCP 8.5. As under RCP 8.5, severe winter weather and cold temperatures will still occasionally occur. Overall, the incremental risk of extreme cold and ice will decrease over time.

Distribution

RCP 8.5 Vulnerability: Low

Duke Energy's distribution assets face low relative vulnerability to future cold and ice related hazards, particularly given Duke Energy's adherence to NESC design criteria and the significant uncertainty in projected changes in icing.

RCP 4.5 Vulnerability: Low

Under RCP 4.5, winters are anticipated to warm, though not as much as under RCP 8.5. As under RCP 8.5, severe winter weather and cold temperatures will still occasionally occur. Overall, the incremental risk of extreme cold and ice will decrease over time.

Figure 16. Extreme cold and ice asset group vulnerability ratings and explanations.

relative level of overall potential impact and exposure of assets, with emphasis on 2050.

As described earlier in this report, winter temperatures and conditions are expected to be increasingly warm, with a lower possibility of extreme cold and ice events. Historically, the coastal plain experiences winter precipitation as rainfall. eastern North Carolina, and mountainous regions of the Carolinas region experience colder temperatures on average compared to the Piedmont.[23] Generally, winter temperatures throughout the Carolinas are expected to increase over time, and precipitation is expected to trend away from snowfall and toward rainfall for the entire region. While some low-confidence climate dynamics point to potential factors driving increased rare and severe

[23] Kunkel, Kenneth, David Easterling, Andrew Ballinger, Solomon Bililign, Sarah Champion, D. Reide Corbett, Kathie Dello, Jenny Dissen, Gary Lackmann, Richard Luettich, L. Baker Perry, Walter Robinson, Laura Stevens, Brooke Stewart, and Adam Terando. *North Carolina Climate Science Report*. Asheville, N.C.: North Carolina Institute for Climate Studies, 2020. https://ncics.org/nccsr.

events, these are against the backdrop of a clear countervailing trend toward warming winters. Extreme cold and ice events are considered in greater detail in the Workshop Discussion Summary – Sequential Events section.

Transmission

The overall 2050 vulnerability priority of Duke Energy transmission assets to climate-related changes in extreme cold and ice events under both the RCP 8.5 90th percentile and RCP 4.5 50th percentile scenarios is **low**. While extreme cold absent ice is not a concern to transmission assets, some assets (e.g., line structures and overhead conductors) are highly sensitive to ice, which in significantly colder regions (e.g., Canada, New York) has resulted in transmission tower failure.

Duke Energy transmission assets are projected to be exposed to warmer winter temperatures on average and are thereby not likely to experience increased incidence of disruption due to cold and ice. However, if a significant ice event does occur and overhead conductors and line structures experience damage, this would be a high consequence event that could disrupt energy delivery and system resilience. Open air current carrying components (e.g., switches jumpers) and underground conductors are less sensitive to icing and, given projected warming winter temperatures, are not projected to face significant impacts due to cold and ice.

Unrelated to climate change, the South Carolina Office of Regulatory Staff produced a 2021 report on present-day risks to T&D systems from extreme cold weather.[24] This report notes that winter peak loads, heightened by increasing electrification of heat, may increase strain on the grid during extreme cold weather events. Again, however, future winter temperatures are likely to warm on average, potentially mitigating but not necessarily eliminating this item of concern.

Furthermore, as stated earlier in the report, Duke Energy's overhead transmission system is constructed to meet or exceed NESC standards for combined wind and ice loading (250D). DEP transmission structures are designed to tolerate 0.75 inches of ice accumulation with 30 mph winds, or 1 inch of heavy ice with no wind. DEC structures are designed to tolerate 0.75 inches of ice with 44 mph winds. These standards reflect a high tolerance for ice loading, amidst a projected climate of generally decreasing extreme cold.

Substations

The overall 2050 vulnerability priority of Duke Energy substation assets to climate-driven changes in extreme cold and ice under both the RCP 8.5 90th percentile and RCP 4.5 50th percentile scenarios is **low,** given low substation sensitivity and lack of clear evidence for major increases in extreme cold and ice exposure. Specifically, projections indicate warming winter temperatures over the coming decades and frequency and severity of ice events do not result in strong evidence for increased exposure and present relatively low incremental potential for negative outcomes to substation equipment.

As noted, research suggests that climate change could make cold snaps associated with "polar vortex" events more common in the future, but with a low level of certainty that this will increase actual icing, which poses a greater risk to substations than cold alone. Severe icing may cause operating problems with mechanical devices such as transformer tap changers and disconnect switch mechanisms, however, this is more likely to be a nuisance than to impact energy delivery in any significant way. Ice accumulation is generally well tolerated by substation equipment bushings and insulators. In isolate cases, flashover (discharge of current to nearby material, potentially resulting in

[24] South Carolina Office of Regulatory Staff. 2021. *Final Report on the Resiliency of South Carolina's Electric and Natural Gas Infrastructure Against Extreme Winter Storm Events*. Columbia, SC: 2021. https://ors.sc.gov/sites/default/files/Documents/Regulatory/electricNaturalGas/Resiliency%20of%20SC%20Electric%20and%20Natural%20Gas%20Infrastructure%202021-66-A.pdf.

ignition) can occur, particularly at higher voltages on contaminated insulators.

The most extreme cold (-10°F to -30°F) can cause impacts via lowered internal pressures, but these temperatures are historically extremely rare in the Carolinas, and climate change will result in further moderation of winter temperatures.

Distribution

The overall 2050 vulnerability priority of Duke Energy distribution assets to climate-driven change in extreme cold and ice events under both the RCP 8.5 90th percentile and RCP 4.5 50th percentile scenarios is **low**. Risks exist today: extreme icing may cause damage to distribution infrastructure, particularly for overhead components in highly vegetated areas where trees may be susceptible to icing, and may fall or snap, damaging distribution components. However, as with other asset groups, distribution is not anticipated to see major incremental increases in risk associated with climate change and winter weather events. A 2021 report commissioned by the South Carolina Office of Regulatory Staff characterized South Carolina's large electric utilities, including Duke Energy, as "leading" (the second-highest level of maturity) on all 11 indicators of winter storm preparedness and response.

Extreme cold ambient temperatures can have minor detrimental impacts to some types of equipment (e.g., regulators and batteries), but generally have minimal potential impacts on the overall distribution system. Ice events, on the other hand, can have high impacts to overhead conductors and may lead to moderate impacts to other overhead and open-air distribution assets. Overhead conductors, structures, and transformers are susceptible to ice accumulation, which can result in physical and mechanical failures in system components. The operating mechanism of reclosers, batteries, pad-mounted transformers, and capacitors is typically enclosed and sealed, so that ice accumulation will have minimal, if any, impact on their operation.

Duke Energy's ongoing efforts to design system components up to NESC design standards (250B), have increased systemwide resilience to icing events and further contribute to generally low systemwide vulnerability to these climate hazards. NESC standards for the medium loading region (encompassing Duke Energy's territory) require equipment to be able to withstand 0.25 inches of ice with 40 mph winds. As discussed further in the wind section, these standards may be less consistently applied to low load-growth areas where the system has not been updated in recent years, but the proportion of the system meeting up-to-date code will continue to increase over time. Overall, given the uncertainty related to the impact of climate change on the potential for rare extreme cold conditions and icing, a high-confidence overall trend toward winter warming, and Duke Energy's adherence to industry design practices, incremental climate-driven vulnerability to cold and ice remains low.

Flooding and Precipitation

Overall coastal and inland flooding vulnerability ratings were assessed for transmission, substation, and distribution asset groups. This section presents 1) coastal flooding and 2) inland flooding/precipitation as separate overall ratings and discussions, given the differing hazard profile. Vulnerability priority is summarized on a low, medium, high scale, which indicates the relative level of overall potential impact and exposure of assets, with emphasis on 2050.

Coastal Flooding

Rising sea levels and changes in hurricane intensity have potential to affect Duke Energy's coastal infrastructure. Sea level rise may result in increased flood risk for of coastal infrastructure, either on a permanent ("blue-sky") basis or through greater extents and depths of flooding during storm surge events. Projections suggest that the frequency of the strongest storms (categories 3-5) may increase in the Carolinas, potentially resulting in more severe flooding from the combination of precipitation and wind-driven storm surge. Figure 17 provides overall vulnerability ratings for transmission, substation, and distribution asset groups for coastal flooding.

Transmission

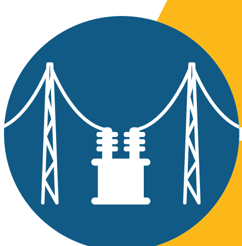
The overall vulnerability priority of Duke Energy transmission assets to climate-driven changes in coastal flooding across both the 2050 RCP 4.5 50th percentile scenario and RCP 8.5 90th percentile scenario is **medium**. Since increasing intensity of hurricanes is a major driver of the coastal flooding vulnerability scores, the ratings remain the same under both future scenarios.

Transmission

RCP 8.5 Vulnerability: Medium
Impacts from flooding on transmission infrastructure are more likely to be chronic than acute, and a relatively small number of transmission structures are projected to face new inundation. However, given the high criticality of transmission equipment, Duke Energy should prioritize ensuring the resilience of potentially affected structures.

RCP 4.5 Vulnerability: Medium
Sea level rise under RCP 4.5 is projected to expose a somewhat lesser (relative to RCP 8.5) but still meaningful number of transmission structures to more frequent flooding. Under both RCP 8.5 and 4.5 hurricane intensity is anticipated to increase over time, meaning that storm-driven exposure of transmission structures may be similar under both scenarios.

Substations



RCP 8.5 Vulnerability: Medium
Sea level rise alone presents minor incremental risks even considering the highest historical water levels on top of sea level rise. However, potentially more severe hurricanes coupled with rising sea levels could increase the risk of storm surge affecting up to 36 coastal substations, which are highly sensitive to flood conditions.

RCP 4.5 Vulnerability: Medium
Under both RCP 8.5 and 4.5 hurricane intensity is anticipated to increase over time. Since increasing intensity of hurricanes is a major driver of the coastal flooding vulnerability scores, the ratings remain the same under both future scenarios.

Distribution

RCP 8.5 Vulnerability: Low
Sea level rise is projected to result in fairly limited increases in exposure of the most sensitive Duke Energy distribution assets, especially relative to assets that would already be affected by a 100-year flood. However, increased potential frequency and depth of flooding, including during hurricanes, may warrant waterproofing of select poles and padmounts. Vulnerabilities are concentrated primarily in New Hanover and Carteret counties.

RCP 4.5 Vulnerability: Low
Under both RCP 8.5 and 4.5 hurricane intensity is anticipated to increase over time. Since increasing intensity of hurricanes is a major driver of the coastal flooding vulnerability scores, the ratings remain the same under both future scenarios.

Figure 17. Coastal flooding asset group vulnerability ratings and explanations.

Line structures (poles/towers) are the most likely transmission asset to face negative consequences from flooding, given their exposure at ground level. Impacts from flooding on transmission infrastructure are more likely to be chronic than acute, and a relatively small number of transmission structures are projected to face new inundation. By midcentury less than 1% of Duke Energy's transmission system (transmission poles, towers and structures) is projected to face exposure to sea level rise impacts, including under the historical-equivalent 100-year coastal storm exacerbated by sea level rise, although exposure is projected to increase later in the century. Relative to 2010 sea levels, by 2050 an additional 289 transmission structures may be exposed to blue-sky inundation, under an upper bound climate change scenario (399 total). Structures that are flagged as already exposed to present-day blue-sky inundation are generally located within wetlands or water crossings. During a 100-year storm, an additional 195 structures may be inundated (990 total). Towers currently exposed to inundation (located in coastal flood zones or existing bodies of water) may see as much as 1 foot of additional inundation by 2030 and 2 feet by 2050.

As seen in Figure 18, most of the exposed poles and towers, both in the baseline exposures and the climate-driven increases, are located in Carteret and New Hanover counties, primarily in the Wilmington area, as well as Morehead City and Jacksonville areas. By 2050, under a high climate change scenario, Carteret County could see nearly 50% of its transmission structures inundated under the 100-year storm, and Brunswick and New Hanover could see 10% to 20%.

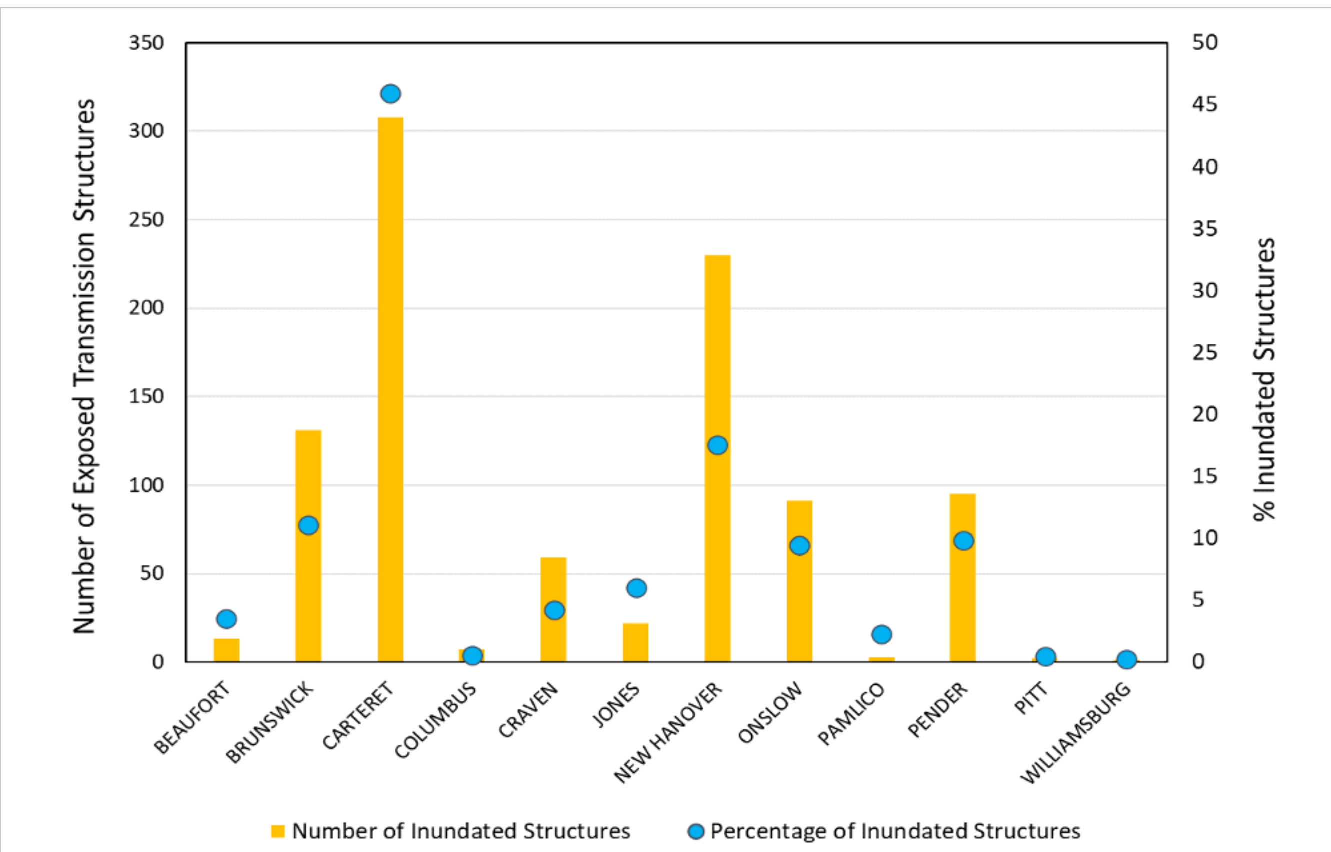


Figure 18: Count and percentages of inundated transmission structures by county due to sea level rise in a 100-year storm in 2050 under an intermediate-high sea level rise scenario.

Even with sea level rise and increased exposure, storm surge alone is unlikely to compromise concrete/steel structures, and Duke Energy's current 100-year storm exposures are greater than the projected sea level rise change under high-end climate change. Still, flood events may delay restoration activities for transmission infrastructure damaged during hurricanes, and heavy storm surge (including floating debris) may also increase the cumulative horizontal stresses on transmission towers during high-wind events, meaning that the high-consequence event of tower failure should not be considered impossible.

Overall, structures exposed to the greatest frequency of inundation are most at risk. On a chronic level, higher water exposures may result in floodwaters or saline spray overtopping concrete tower foundations and subjecting steel lattice to corrosion. Inundated ground may also reduce the stability of towers not previously exposed to such conditions, either through softening of the ground or through scouring around the bases of structures. Given the high criticality of transmission equipment, Duke Energy should prioritize ensuring the resilience of potentially affected structures.

Substations

The overall vulnerability priority of Duke Energy substations to climate-driven changes in coastal flooding across both the 2050 RCP 4.5 50th percentile scenario and RCP 8.5 90th percentile scenario is **medium**. Since increasing intensity of hurricanes is a major driver of the coastal flooding vulnerability scores, the ratings remain the same under both future scenarios.

If flooding of a substation does occur, it is likely to require forced outage of the station during the flood event, and potentially for an extended period following. In particular, substation transformers and regulators, protection and control devices, circuit breakers, and instrument transformers are unable to tolerate inundation without significant disruption or failure. Notably, none of the substations highlighted as exposed to sea level rise experienced historical flood-related outages in past major North Carolina

Flooding Adaptation Strategies: Substations

A growing number of Duke Energy's existing substations are protected by a combination of permanent flood walls and temporary modular flood walls that can be deployed prior to an adverse weather event. Permanent flood walls have been built at locations that experienced past flooding while temporary flood walls (e.g., "Tiger Dams") can be deployed at facilities that are in flood zones, but which have not experienced past flooding. Duke Energy personnel monitor weather forecasts and river tide gages to monitor flooding conditions and identify where temporary flood protections may be needed.

New substations are currently designed to a Design Flood Elevation (DFE) standard that requires equipment elevations at or above the 100-year storm level plus 2 feet, the 500-year flood level plus 1 foot, or local ordinances, whichever is higher. However, not all existing substations are built to Duke Energy's current flood resilience standard since some were constructed before the standard was put in place and not all have yet been retrofitted.

Figure 19. Permanent flood barriers at Duke Energy's Nichols 115-KV substation.

hurricanes and tropical storms (Dorian, Michael, Florence, or Zeta) – highlighting that precipitation-driven flooding has historically been more of a risk for Duke Energy than coastal flooding.

Sea level rise alone presents minor incremental risks to substations, even considering the highest historical water levels, given that only a small number of substations are in locations that face increased flooding, and only under the intermediate-high sea level rise scenario.

Substations face very low risks from blue-sky sea level rise (i.e., without a storm); even under the RCP 8.5 90th percentile climate change scenario, only one substation faces potential blue-sky inundation, and not until 2080. However, under a high climate change scenario and 100-year storm conditions, three substations (0.1% of Duke Energy's total substations) are projected to experience coastal flooding by 2030. Notably, all three of these substations are already within the FEMA 100-year flood plain and two out of three have undergone recent storm hardening protections. By 2050 under the intermediate-high climate change scenario, two additional substations (five total) are projected to experience flooding under projected sea level rise plus historical 100-year storm levels.

This study also used modeling to project potential impacts of the most extreme versions of major hurricane events – a low-probability stress-test case. NOAA SLOSH model[25] projections indicate that up to 16 substations could face potential storm surge flooding during a worst-case Category 3 storm event at their individual locations, with this number rising to 24 substations under a Category 4 and 36 substations under a Category 5. Figure 20 provides more detail and projected maximum flood depths at each of these substations. These scenarios

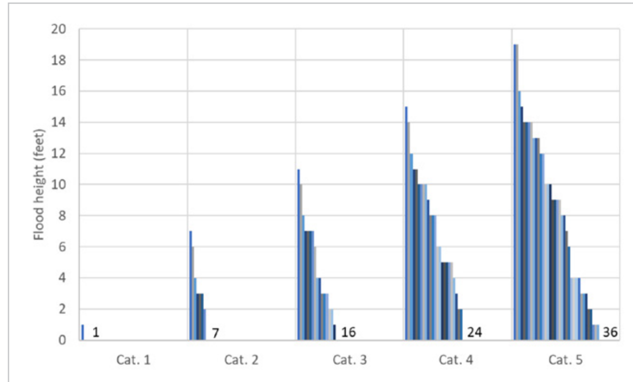


Figure 20: Number (x axis) and max flood height (y axis) of substations potentially exposed to storm surge under a composite maximum storm scenario, assuming present-day sea levels (NOAA SLOSH model).

reflect extreme worst-case maximum values at any given location (i.e., a direct hit at high tide); under any individual storm track, only a subset of this composite number of substations could be expected to flood.

Since critical substation assets are unable to tolerate significant flooding, inundation is a high-consequence event. Substation inundation typically requires de-energizing the substation in order to reduce risk of equipment damage and ensure the safety of restoration crews. Offline substations can result in outages affecting thousands of customers, and repair times for flood-damaged substations could range from days to weeks.

Duke Energy should monitor the progression of sea level rise and consider whether rates of sea level rise require additional protective measures (e.g., flood barriers) at substations projected to be exposed. Duke Energy may also consider confirming the presence of appropriate flood-protection and response/restoration plans at substations facing storm surge risk, given the potential for increasing storm intensity. Finally, Duke Energy may also consider monitoring changes in groundwater levels and soil salinity for at-risk coastal substations, in order to monitor risks to grounding grids and other buried/below-grade equipment, which may materialize earlier than surface inundation.

[25] Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model is a computerized numerical model developed by the National Weather Service (NWS) to estimate storm surge heights resulting from historical, hypothetical, or predicted hurricanes by taking into account the atmospheric pressure, size, forward speed, and track data. These parameters are used to create a model of the wind field, which drives the storm surge.

Distribution

The overall vulnerability priority of Duke Energy distribution equipment to climate-driven changes in coastal flooding across both the 2050 RCP 4.5 50th percentile scenario and RCP 8.5 90th percentile scenario is **low**. Since increasing intensity of hurricanes is a major driver of the coastal flooding vulnerability scores, the ratings remain the same under both future scenarios.

Pad-mounted transformers and cabinets and (to a lesser degree) poles and the overhead structures they support are the most sensitive distribution assets to flooding. While some areas of concern exist, the overall proportion of assets exposed is low, and consequence at individual distribution assets is constrained compared to substations and transmission assets.

Sea level rise is projected to result in limited increases in exposure of these assets, especially relative to assets that would already be affected by a 100-year flood. At assets with present-day flood exposure, flood depth may increase by up to 1 foot by 2030 and up to 2 feet by 2050. Blue-sky flooding is the most severe exposure condition for assets, but the number of exposed assets (primarily poles) only becomes significant by 2050 under severe climate change, or 2080 under the lower-end scenario. Under blue-sky conditions, by 2050 Duke Energy may see an additional 16 cabinets, padmounts (i.e., transformers), and vaults inundated (combined, less than 1% increases for each asset) and up to 1,203 additional poles (0.1% of total poles) inundated, depending on the climate scenario. Over the long term, exposed poles may require relocation. During the 100-year storm scenario, impeded outage restoration and emergency response is likely Duke Energy's most significant concern, given the number of potentially flooded poles and coastal areas with underground conduit. As seen in Figure 21, flood exposure is primarily concentrated in New Hanover and Carteret counties. The average exposed padmount in these counties (see figure) may face 1-1.5 feet of flooding under 100-year water levels, assuming a high climate change scenario.

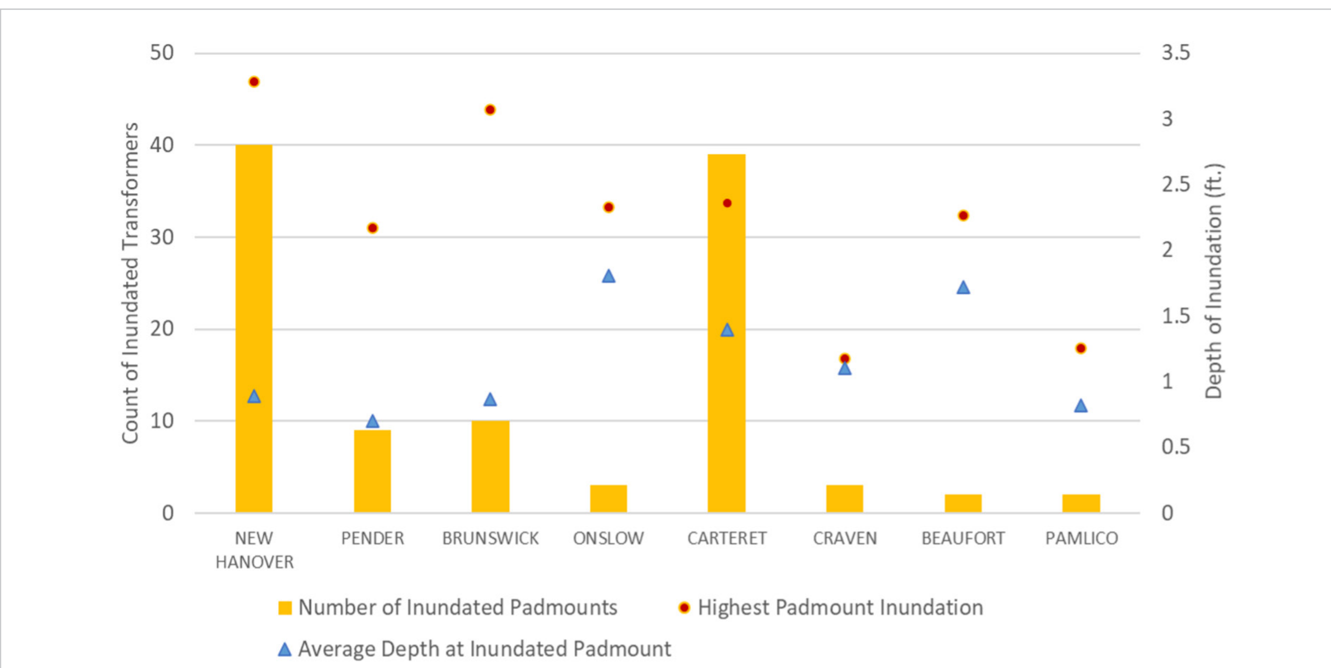


Figure 21: Counts (yellow bars, left axis) and avg/max flood depths (points, right axis) of inundated padmount transformers under a 100-year storm by 2050 under an intermediate-high scenario.

Exposures of padmounts and cabinets to flooding will require adaptation, given that these are ground-level assets containing sensitive electrical equipment – but the number of exposed assets is very small relative to Duke Energy's overall asset base, and consequences at the distribution level of impacts to any individual asset are relatively constrained. Vaults and underground conduits are generally waterproofed, but may be subject to marginal increased vulnerabilities where existing defects are present. While severe storm surge can contribute to pole failure, poles can generally withstand temporary surface flooding, though as noted above it can impede restoration. Rising coastal groundwater tables may also present increased exposures to underground equipment, even outside of flood conditions. Overall, increased potential frequency and depth of flooding, including during hurricanes, may warrant waterproofing/hardening of select poles and padmounts.

Precipitation and Inland Flooding

Heavy precipitation has affected Duke Energy assets in the past, and changes in precipitation intensity result in heightened vulnerability. Higher atmospheric moisture content and other factors may increase the amount of rainfall during heavy downpours, increasing the potential for fluvial (riverine) and pluvial (rainfall driven) flooding, as well as landslides and debris flows. This study assesses potential for fluvial flooding on a site-specific basis based on available flood plain data; ground-level pluvial flooding is more difficult to model, but directional change in risk can be assessed based on precipitation projections.[26] Figure 22 provides overall vulnerability ratings for transmission, substation, and distribution asset groups for inland flooding. Vulnerability priority is summarized on a low, medium, high scale, which indicates the relative level of overall potential impact and exposure of assets, with emphasis on the 2050 upper bound climate change scenario.

Transmission

Duke Energy transmission infrastructure faces a **medium** priority vulnerability to changes in precipitation and inland flooding under the 2050 RCP 8.5 90th percentile scenario. Under the RCP 4.5 50th percentile scenario transmission infrastructure faces a **low** priority vulnerability. Transmission poles and towers that are located within present-day landslide risk areas, such as in the western and mountainous areas of the state, are likely to experience the highest vulnerability to precipitation and inland flooding impacts. Precipitation levels consistent with a high climate change scenario could increase transmission asset exposure to landslide activity.

Duke Energy's transmission assets are projected to see an increase in frequency and intensity of inland flooding, as precipitation increases, with approximately 12,787 transmission structures (6%) located in the present-day FEMA 100 year flood plain and 14,571 (8%) are located in the 500-year flood plain (inclusive of the FEMA 100). Approximately 43,752 transmission structures (21%) are located in areas of high landslide incidence or susceptibility, and may be subject to increased potential for damage from precipitation driven landslides or debris flows. Landslide risks are most prevalent in the mountains region of the territory, as seen in Figure 23. Notably, landslide regions as defined by the U.S. Geological Survey data avialable for this study are relatively coarse, and further site-level analysis is likely required to narrow down the equipment at highest landslide risk within this conservative area.

Riverine flooding can also result in transmission asset damage. Riverine flooding occurs when streams and rivers exceed the capacity of their natural or constructed channels to accommodate

[26] FEMA flood maps represent the best available public domain flood risk information and are generally considered an industry standard, though this study also acknowledges that these maps have known limitations in some areas and supplemental local knowledge of flood risk can provide an important complement.

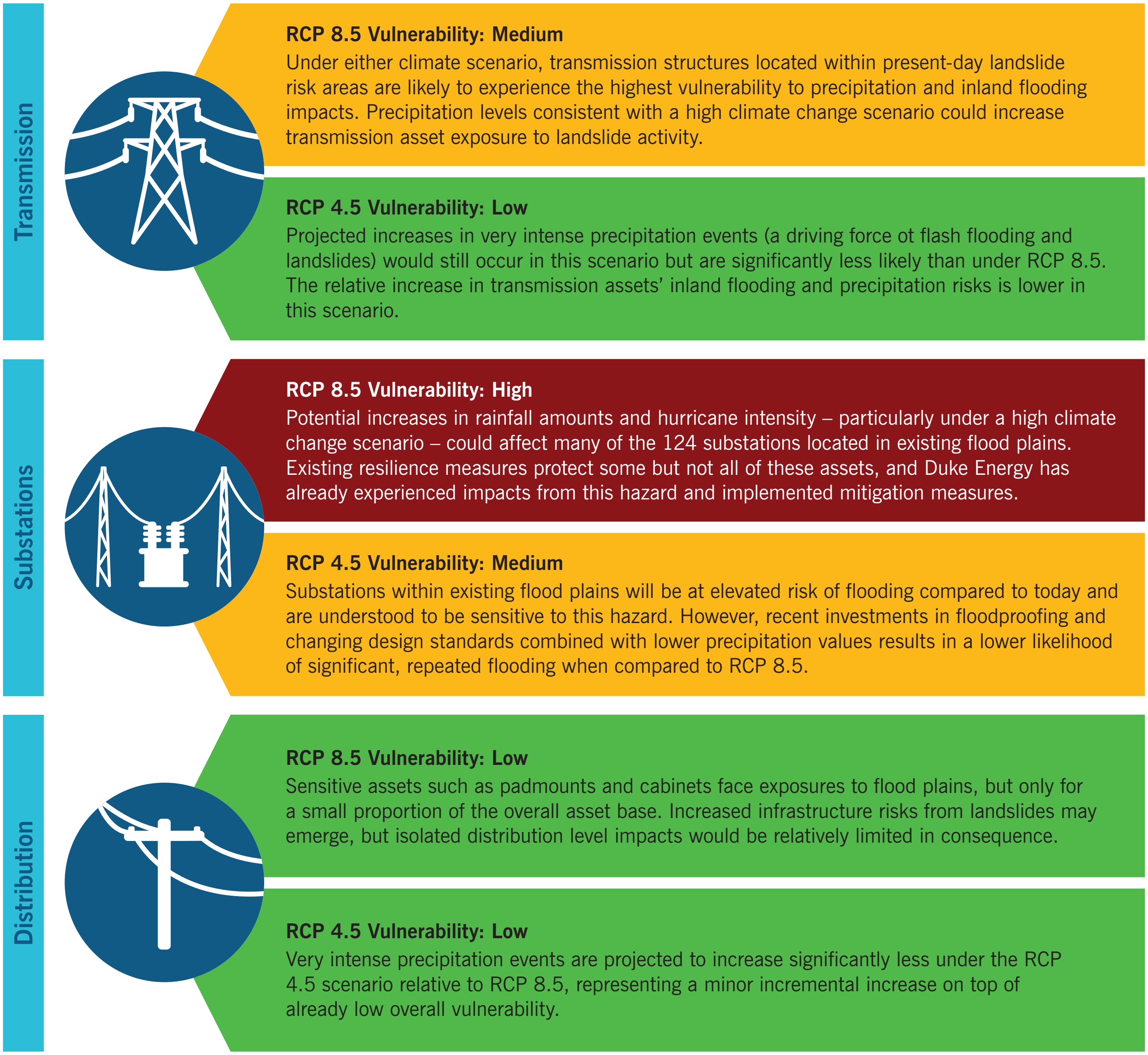


Figure 22. Inland flooding and precipitation asset group vulnerability ratings and explanations.

water flow and, as a result, water overflows the banks, spilling out into adjacent low-lying, dry land. Other utilities have seen flood-damaged transmission structures as a result of recent severe riverine flooding, including an example in Nebraska in which the course of a river was permanently altered.[27] Heavy flooding events like these may also increase the stress on transmission towers during high-wind events, especially if towers experience impact from floating debris. Tower failure during such an event would be low probability but high impact.

While chronic corrosive/scouring due to repeated surface flooding is an important consideration, transmission structures are robust in construction and are likely to sustain only minimal damage from acute flood events. Underground and ground-level equipment is generally protected, but in some cases may experience corrosion and water intrusion due

[27] Associated Press, "OPPD Repairs 3 Flood-Damaged Transmission Line Towers," *Associated Press*, March 2020, https://journalstar.com/news/state-and-regional/nebraska/oppd-repairs-flood-damaged-transmission-line-towers/article–91dec378-4a10-537b-866a-95342ecd44e4.html?mode=nowapp.

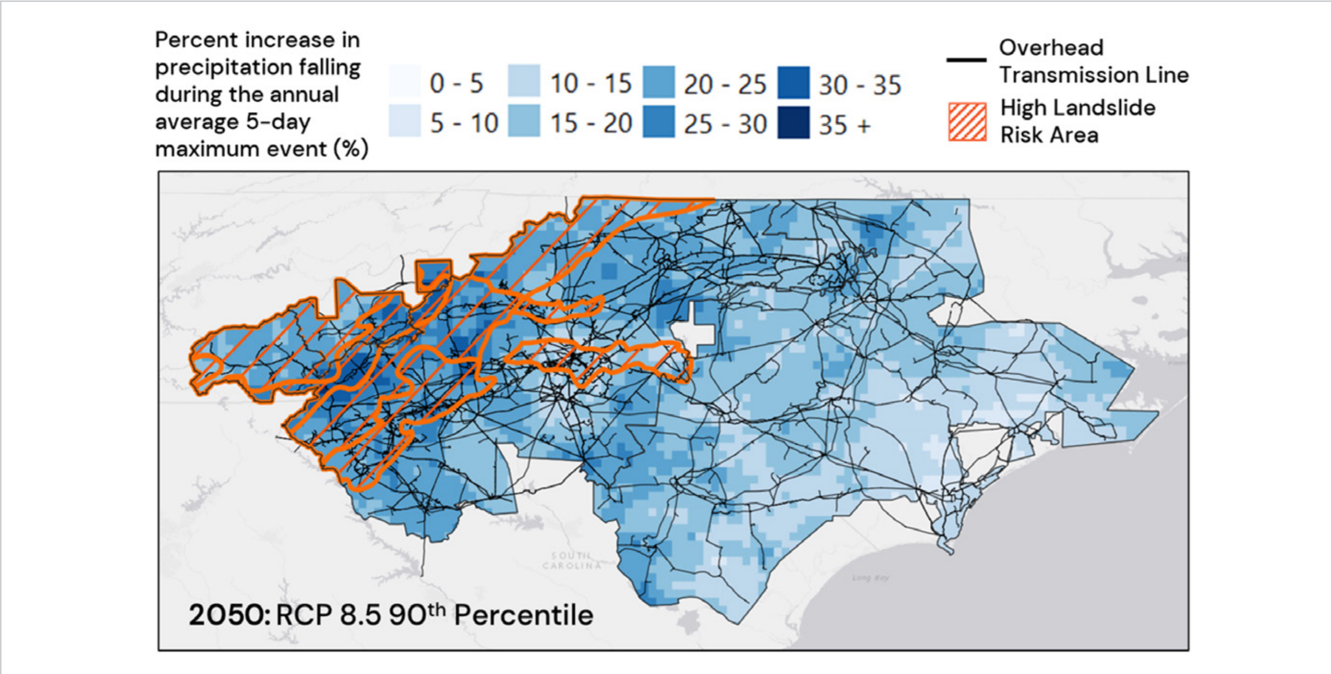


Figure 23. Overhead transmission lines relative to percent increase in precipitation falling during the annual average five-day maximum event (RCP 8.5 90th percentile), and high landslide risk area.

to floodwater exposure, especially for assets with failing waterproofing. Widespread flooding could also impede restoration activities for transmission infrastructure damaged during floods.

Substations

The overall vulnerability priority of Duke Energy substations to climate-driven changes in precipitation and inland flooding is **high** under the 2050 RCP 8.5 90th percentile scenario. Under the 2050 RCP 4.5 50th percentile scenario transmission infrastructure faces a **medium** priority vulnerability. If significant flooding of a substation does occur, it is a high-sensitivity, high-consequence event, and Duke Energy has been subject to long-duration substation outages in recent years due to heavy rainfall. In particular, substation transformers and regulators, protection and control devices, circuit breakers, and instrument transformers are unable to tolerate inundation without risk of significant disruption or failure.

Substations located in flood plains and surrounding areas could be at elevated risk of exposure to inland flooding under heavier future precipitation. However, due to complexities in modeling how changes in precipitation will impact local flood depths, it is not currently possible to determine the depth, and hence the significance, of flooding at specific substations – meaning that these counts should be considered somewhat conservative and site-specific evaluation of at-risk sites is recommended. Overall, 86 substations (4%) across 45 counties lie in present-day 100-year FEMA flood plains while 38 additional substations fall within the present-day 500-year FEMA flood plains, which can be considered a proxy for the future flooding areas of higher frequency. Figure 24 illustrates where these substations are located across the service territory.[28] Projections suggest that precipitation intensity increases of more than 35% (annual average five-day maximum) in some areas are possible in 2050 under a high climate change scenario.

[28] Substation flooding and landslide analyses include existing substations and proposed substations across the Duke Energy service area.

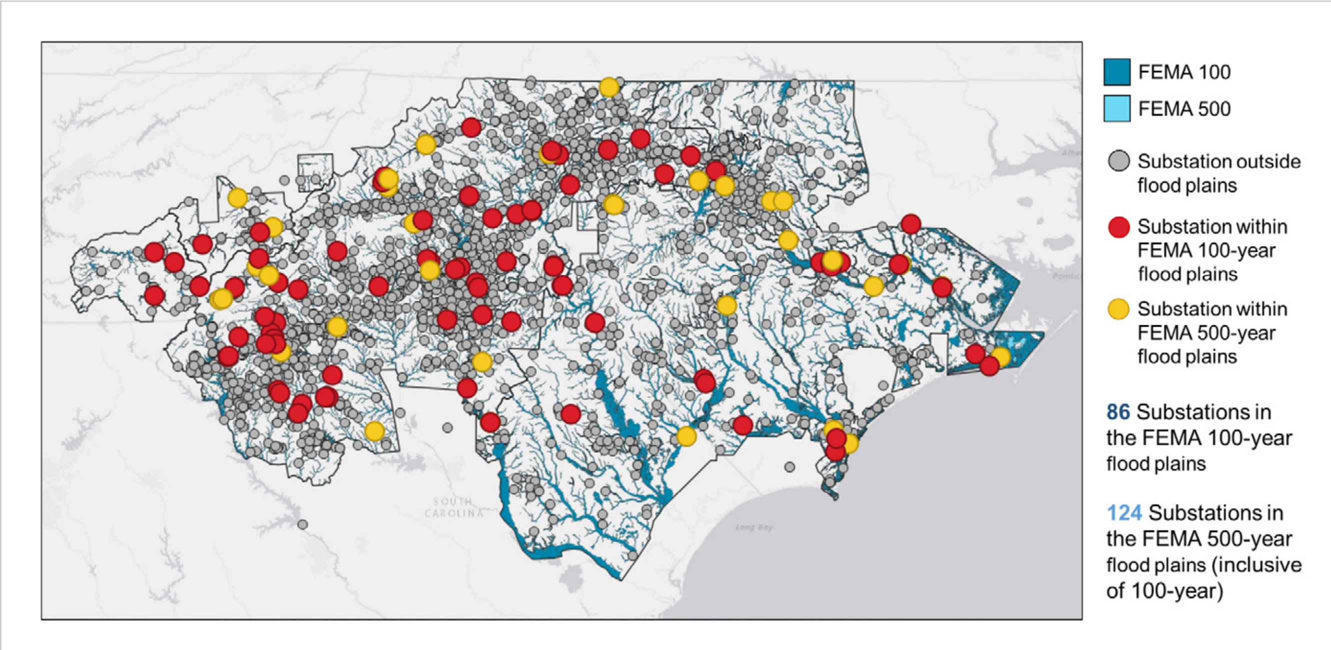


Figure 24: Location of substations within the 100- and 500-year FEMA flood plains. Note: These numbers also include a small number of substations within coastal flood plains, which are also discussed in the prior section.

These potential increases in rainfall amounts and potential increases in hurricane intensity within the region could affect many of the substations located in existing flood plains. Existing resilience measures protect some, but not all, of these assets, and Duke Energy has already experienced impacts from this hazard. For example, during Hurricane Florence in 2018, at least 10 substations required de-energization due to flooding or flood risk where heavy rainfall and resulting inland flooding, rather than coastal flooding, was the driver of impacts at these stations. Heavy inland rainfall also increases the risk of landslides and debris flows, which could damage substations at select locations (though substations are generally easier to safely site and protect as compared to more distributed assets such as poles and towers).

While heavier future rainfall events could increase the number of substations at potential risk of flooding, projections under lower-end climate scenarios may be within Duke Energy's existing design tolerances by 2050. As noted above, Duke Energy has implemented permanent flood protection measures at new substations located in flood plains and substations with a prior history of flooding. Standards for these substations indicate design elevations should be at least at the FEMA 100-year base flood elevation plus 2 feet, the 500-year elevation plus 1 foot, or as required by local ordinance (if higher). However, these standards are being adopted over time at identified at-risk substations and have not yet been universally implemented at all existing substations in the flood plain.

To enhance protection at these and other substations, Duke Energy has the capability to deploy temporary flood protections, as needed, at substations. This is a time-consuming adaptation and, in very severe events temporary barriers may become insufficient to mitigate heightened flood risk (e.g., some flooding may still occur, although overall damage would be less severe than with no flood barriers). Finally, substations existing outside of flood plains are not necessarily free of risk from heavier precipitation, as heavy rainstorms could overwhelm drainage and/or spill containment countermeasures, which are typically required to consider the historical 25-year storm.[29]

Distribution

The overall vulnerability priority of the Duke Energy distribution system to climate-driven changes in precipitation and inland flooding under both the 2050 RCP 8.5 90th percentile scenario and the RCP 4.5 50th percentile scenario is **low**. Sensitive assets such as padmounts and cabinets face exposures to flood plains, but only for a small proportion of the overall asset base. Increased infrastructure risks from landslides may emerge, but isolated distribution-level impacts would be relatively limited in consequence.

Duke Energy's distribution equipment faces relatively limited exposure to additional inland flooding and precipitation, as a proportion of the total system. 1,066 miles (2%) of distribution conductor, 75,979 distribution poles (3%), 417 cabinets (2%) and 421 padmount transformers (1%) lie in present-day 100-year FEMA flood plains, while 1,396 miles (3%) of conductor, 85,956 distribution poles (4%), 538 cabinets (3%), and 562 padmount transformers (2%) lie in the 500-year FEMA flood plains (inclusive of 100-year). Figure 25 shows pad-mounted distribution transformer exposures within the FEMA 100- and 500-year flood plains. Distribution assets in FEMA flood plains could be at elevated risk of exposure to inland flooding including distribution assets in river flood plains where the upstream watershed is subject to higher precipitation. Ground-level distribution assets outside the riverine or coastal floodplain could also face potential heightened risks from rain-driven flooding overwhelming drainage systems.

Flooding of padmount transformers and distribution cabinets could result in equipment damage and/or distribution-level outages if floodwaters are high enough to intrude into equipment. Prolonged surface flooding also could impede distribution-level restoration efforts, including vegetation-related damages to overhead equipment that may occur during heavy storms. Underground distribution equipment is typically designed to be submersible, although prolonged flood conditions may result in increased vulnerability where equipment defects are already present for both underground and grade-level equipment.

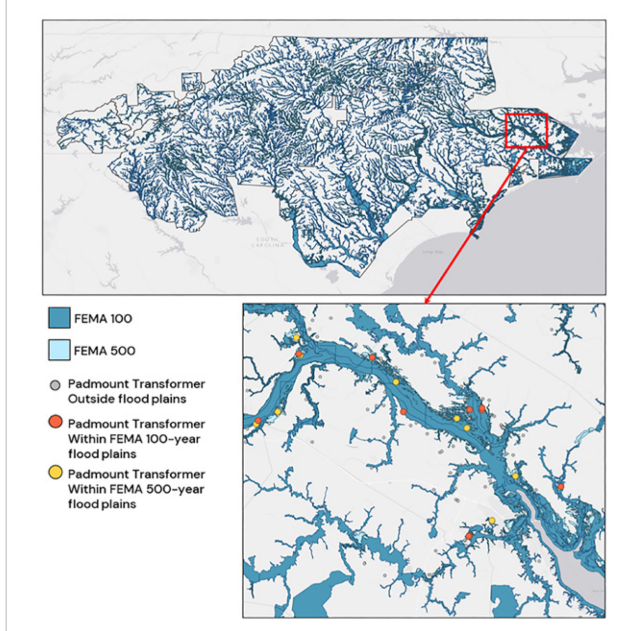


Figure 25: Pad-mounted distribution transformer exposures relative to FEMA 100- and 500-year flood plains

A relatively large proportion of Duke Energy's distribution system, particularly in the mountain region may be at risk of landslides. At present-day 25,514 overhead distribution conductor miles (25% of the entire Duke Energy system), 623,110 distribution poles (27%), 10,921 distribution cabinets (57%) and 9,897 padmount transformers (31%) lie in high landslide risk areas. Landslide risk areas in Duke Energy territory correspond relatively closely with areas of the highest projected precipitation increases. Further site-based assessment is likely needed to assess specific asset risk to landslides within these broad regions.

[29] "IEEE Guide for Containment and Control of Oil Spills in Substations," in *IEEE Std 980-2013 (Revision of IEEE Std 980-1994)*, vol., No., pp.1-55, 19 Dec. 2013, doi: 10.1109/IEEESTD.2013.6687196.

Landslides could become a higher risk for a relatively large proportion of Duke Energy's distribution system, particularly in the mountain region. However, impacts from any individual distribution-level incident are likely to be localized and individual impacts at the distribution level are generally lower in the scale of cost and customer consequence than transmission or substation impacts. In 2018, for example, mudslides in Polk County resulted in outages for several hundred Duke Energy customers, most of which were restored within 48 hours.[30]

Wind

Analysis of wind projections and potential impacts to assets suggests that potential future wind presents a low-to-medium vulnerability for Duke Energy assets, especially under a high climate change scenario. Figure 27 shows overall vulnerability ratings and summaries for transmission, substation, and distribution asset groups. Vulnerability priority is summarized on a low, medium, high scale, which indicates the relative level of overall potential impact and exposure of assets, with emphasis on 2050. In general, Duke Energy's assets are built to industry standards that are resilient to high wind conditions, and projections do not suggest significant changes to wind conditions under most storms. However, given heightened future potential for rare and extreme coastal storm events, this analysis considers the high potential consequences of these climate hazards on overhead transmission and distribution assets.

Transmission

The overall 2050 vulnerability of Duke Energy's transmission assets to wind under both scenarios is **medium**. The overhead and above-ground characteristics of transmission assets increase their overall exposure to wind relative to other assets. Figure 26 shows that only small changes are projected in 98th percentile wind speeds from 2030 to 2080, under an RCP 8.5 90th percentile climate scenario.

Vulnerability of the transmission system is somewhat mitigated by Duke Energy's adherence to National Electrical Safety Code (NESC) design standards, which provide for an overall high level of resilience of transmission assets against winds. However, research has highlighted the possibility of structural fatigue and subsequent failure of steel due to wind loading.[31] Additionally, older and legacy equipment may require special attention and may be more vulnerable to high wind speeds, given that some of this equipment may not be built to current NESC standards.

Duke Energy designs overhead transmission equipment to NESC standard 250C, which requires transmission towers to be resilient to at least 90 mile per hour wind speeds. Transmission assets located along the coastline require additional resilience design measures. For example, Reliability Class 1 lines nearest to the coast must be built to withstand 150 mile per hour winds and Reliability Class 6 lines situated 150 or more miles from the coast must be built to withstand 100 mile per hour winds. Overhead and above-ground assets, such as poles, towers, and overhead conductors exhibit the highest vulnerability compared to other transmission components. In rare situations, extreme winds may cause transmission tower and low

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[30] Associated Press, "No Officials Assess Damage from Fatal Mudslides," *Washington-Salem Journal*, May 2018, https://journalnow.com/nc-officials-assess-damage-from-fatal-mudslides/article_5d22e346-aff4-5604-8ce6-74d41cba5b8d.html.

[31] Hamdulay, H., Molly Matthew, and Swapnil Wani, "Study of Fatigue and Life Assessment of Steel Structures: IS 800:2007 Provision," *International Journal of Scientific & Engineering Research* 5, No. 12 (2014): 17-21, https://www.ijser.org/researchpaper/Study-of-Fatigue-and-Life-Assessment-of-Steel-Structures-IS-800-2007-Provision.pdf.

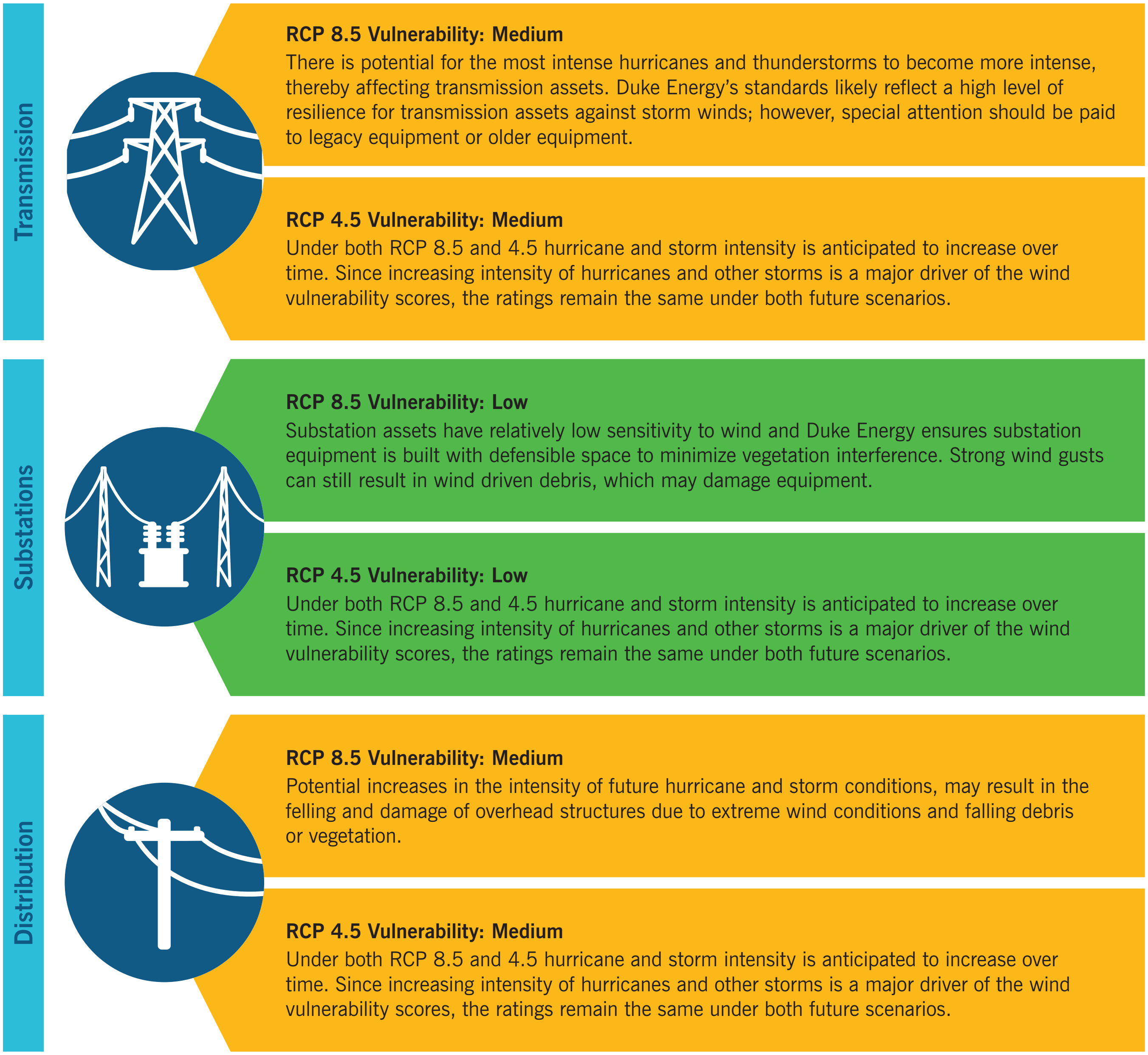

Figure 26. Wind asset group vulnerability ratings and explanations.

voltage transmission line failure when occurring in combination with falling debris or ice.

Wind gusts alone rarely cause transmission tower failure, however, wind speeds from tornados and Category 3+ hurricanes have the potential to exceed transmission wind resilience requirements, potentially resulting in tower failure. As storms become more intense, due to rising atmospheric and oceanic temperatures, wind speeds commonly associated with categorical hurricanes may increase (although they will remain rare), and therefore create higher vulnerability for transmission assets.

Substations

The overall 2050 vulnerability of Duke Energy substation assets to wind under both scenarios is **low.** Substation assets have relatively low sensitivity to wind in part due to the assets' relatively small size and ground-level siting. In addition, Duke Energy ensures substation equipment is built with defensible space to minimize vegetation interference.

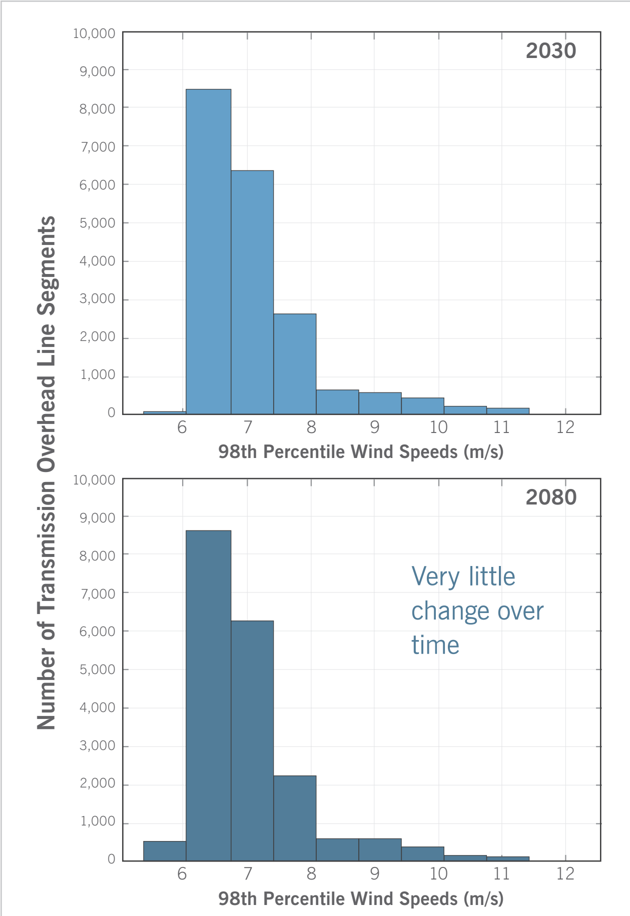

Figure 27. Number of overhead transmission line segments at each average daily wind speed under RCP 8.5 90th percentile.

However, strong wind gusts can result in wind driven debris, which may damage equipment, especially during exceptionally intense storm system, such as hurricanes.

Duke Energy's ongoing work and obligations to NESC design standards ensure adequate wind loading is embedded in systemwide designs.

Distribution

The overall 2050 vulnerability priority of Duke Energy distribution assets to wind under both scenarios is **medium.** Overhead structures, including poles and conductors, can generally withstand elevated wind speeds but have the potential to be felled by extreme wind events or damaged under less extreme wind events that result in vegetation and wind-driven debris impacts. There are millions of distribution poles within Duke Energy's territory. Although vegetation can be problematic in high wind situations, it can also help shield Duke Energy assets. Notably, vegetation cover can reduce wind speeds, and a majority of Duke Energy's distribution poles are located within vegetated areas – meaning that incidence of full-force wind on poles in many areas is significantly limited by windbreak conditions.

Duke Energy's adherence to overhead distribution design standards under NESC, standard 250B, increases the overall resilience of the system to withstand wind conditions. Specifically, NESC design standards specify that overhead distribution assets should be designed to withstand 40 mile per hour 3-second wind gusts, even with ¼ inch of ice covering overhead distribution lines. Various studies have explored the vulnerability of wood pole-based distribution systems to extreme storms. For example, a study by Darestani and Shafieezadeh (2019) developed wood pole fragility curves that indicate that wood pole distribution systems are vulnerable to failure at wind speeds greater than about 75-100 mph with failure probabilities for medium-sized poles, reaching 20% at 125 miles per hour.[32] Based on these wind speeds and failure probabilities, pole failure due to wind gusts alone, without vegetation involvement or ice, will continue to be rare and unlikely, except during intense wind events spurred by tornados and the strongest winds in Category 3+ hurricanes. Overall, the probability of pole failure at wind speeds above 75 miles per hour is a function of pole diameter size, with larger pole diameters able to withstand faster wind speeds than less wide poles. Notably, wind speeds above 25 miles per hour can result in vegetation-driven impacts to distribution assets, even if assets themselves are resilient to wind.

[32] Darestani, Yousef Mohammadi and Abdollah Shafieezadeh. "Multidimensional Wind Fragility Functions for Wood Utility Poles," *Engineering Structure* 183, No. 15 (2019): 937-948, https://doi.org/10.1016/j.engstruct.2019.01.048.

Some of the distribution poles within Duke Energy's distribution system are owned by companies other than Duke Energy (e.g., telecommunications companies), referred to as foreign-owned poles. Duke Energy's Joint Use program identified connection of distribution assets to nearly 150,000 foreign-owned poles (7% of all distribution poles) in DEC and nearly 64,000 (4%) foreign-owned poles in DEP. Foreign-owned poles may not be of equivalent condition or build to NESC design standards, which may increase the overall vulnerability of the system to wind. Additionally, older infrastructure, if constructed under an older design standard or by an operator later acquired by Duke Energy may be more vulnerable if not built or maintained to updated design standards.

Wildfire

Analysis of 2050 wildfire projections and potential impacts to assets suggest that potential climate-driven changes in wildfire conditions under both scenarios present a medium-priority vulnerability to Duke Energy assets. Wildfire risk to T&D utilities includes both the potential for wildfire to damage assets and the potential for T&D assets to cause ignitions. Notably, wildfire projections are characterized by high uncertainty, especially regarding the efficacy of societal wildfire mitigation, and err on the side of conservatism given this uncertainty. For a nuanced understanding of these projections and their implications, please refer to the wildfire discussion in Section III above. While atmospheric wildfire risk conditions may be increasing, several key factors point away from a trend toward the recent megafires seen in the western United States. Figure 28 shows overall vulnerability ratings and summaries for transmission, substation, and distribution asset groups. Vulnerability priority is summarized on a low, medium, high scale, which indicates the relative level of overall potential impact and exposure of assets, with emphasis on 2050.

Transmission

The overall 2050 vulnerability priority of Duke Energy transmission assets to wildfires under the RCP 8.5 90th percentile scenario is **medium**, while the 2050 vulnerability priority under the RCP 4.5 50th percentile scenario is **low.** Exposure to wildfire-prone conditions may increase to a greater or lesser degree relative to present day, particularly under an RCP 8.5 90th percentile climate change scenario. Overhead electric transmission equipment is subject to damage from wildfire, especially if severe fire threatens the structural integrity of towers. Transmission lines are likely to be less sensitivity to wildfire exposure than distribution lines because it is easier to maintain a defensible area away from wildfire susceptible vegetation, given lower overall lengths of transmission line, systemwide. Additionally, transmission assets are characterized by more steel than wood materials, leading to generally lower flammability, relative to distribution assets. However, transmission systems do that cross expansive, continuous stretches of wooded area, which could have the potential to face exposure to larger fires, relative to the more development-adjacent distribution system.

Transmission electrical equipment also has potential to cause ignitions in wildfire-prone areas, in the event of contact with vegetation or flashover. To minimize the risk of vegetation contact, Duke Energy uses a condition-based trimming model to inform vegetation management along transmission systems; this has the ancillary benefit of reducing potential for ignition or contact with burning vegetation

Substations

The overall 2050 vulnerability priority of Duke Energy substation assets to climate-driven changes in wildfires is **medium** due to the active practice of maintaining defensible space around assets and substation's relatively low risk of causing ignition or facing contact with burning vegetation. 2050 vulnerability under the RCP 4.5 50th

Transmission

RCP 8.5 Vulnerability: Medium
Transmission assets may experience increased exposure due to worsening wildfire conditions, and have the potential to ignite wildfires, especially if conductors come into contact with vegetation.

RCP 4.5 Vulnerability: Low
Projections under RCP 4.5 demonstrate a more moderate increase in wildfire risk than under RCP 8.5, resulting in a lower rating for transmission assets. Additionally, some evidence suggests mitigating development trends and improved wildfire control measures may reduce the degree to which climate change increases this risk.

Substations

RCP 8.5 Vulnerability: Medium
Substation vulnerability is moderated by the active practice of maintaining defensible space around assets and substation’s relatively low risk of causing ignition, although substations can still be subject to site damage and wildfire ignition from transformer fires or equipment contacting flammable material.

RCP 4.5 Vulnerability: Low
Projections under RCP 4.5 demonstrate a more moderate increase in wildfire risk than under RCP 8.5, resulting in a lower rating for substations. Additionally, some evidence suggests mitigating development trends and improved wildfire control measures may reduce the degree to which climate change increases this risk.

Distribution

RCP 8.5 Vulnerability: Medium
While historic instances of wildfire causing disruption to Duke Energy distribution systems has been rare and consequences to distribution assets is generally constrained in scale, distribution assets may experience increased exposure due to worsening wildfire conditions and growing land area within the Wildland Urban Interface.

RCP 4.5 Vulnerability: Low
Projections under RCP 4.5 demonstrate a more moderate increase in wildfire risk than under RCP 8.5, resulting in a lower rating for distribution assets. Additionally, some evidence suggests mitigating development trends and improved wildfire control measures may reduce the degree to which climate change increases this risk.

Figure 28. Wildfire asset group vulnerability ratings and explanations.

percentile scenario is rated as **low.** Vulnerability could increase from current levels in the coming decades under a high climate change scenario, due to increasing exposure risk. However, upkeep mitigation tactics such as clearing of nearby grass, weeds, brush, and trees and gravel covering will continue to limit the substation sensitivity in the coming decades. Duke Energy already maintains defensible space from flammable vegetation around substations, thereby lessening exposure.

Substations with limited defensible space in areas with increasing wildfire exposure, such as the coastal plain and western mountains, could face increased wildfire vulnerability into the future due to hotter and drier conditions and changing landscape susceptibility, and equipment is sensitive in the event of exposure to fire.

Distribution

The overall 2050 vulnerability priority of Duke Energy distribution assets to wildfires under

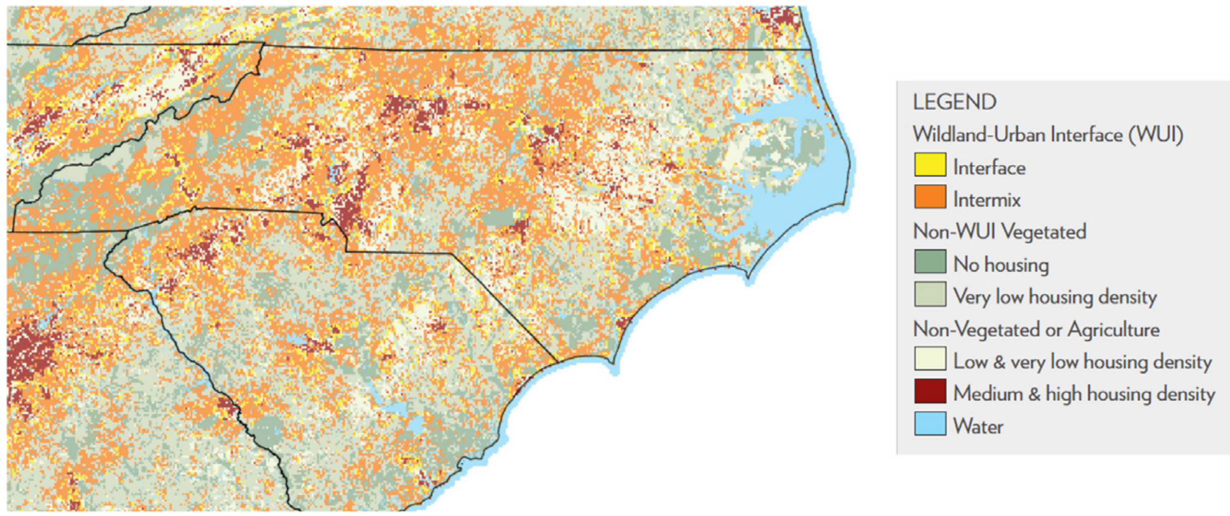

Figure 29: 2010 Wildland-Urban Interface (WUI) map. (Source: University of Wisconsin, Silvis Lab).

the RCP 8.5 90th percentile scenario is **medium**, while the 2050 vulnerability priority under the RCP 4.5 50th percentile scenario is **low.** Exposure of distribution assets to wildfire can result in equipment damage or failure that can lead to customer outages and increased costs. In general, wooden distribution poles are the most susceptible assets to ground-level wildfire damage, given that many other distribution components are typically located overhead. Additionally, distribution conductors that come in contact with vegetation or flashover (an electric discharge across an insulator) have the potential to ignite and cause fire.

Potential for asset exposure will be greatest where development encroaches into wooded landscapes, as shown in the Wildland-Urban Interface (WUI) map in Figure 29. Historically, major wildfires in proximity to Duke Energy assets have been rare. However, the Party Rock fire, which occurred during the fall of 2016 caused Duke Energy to proactively shut down distribution lines in the western portion of the state as wildfires threatened areas near Chimney Rock. Worsening wildfire conditions and growing WUI land area could increase exposure and vulnerability in the coming decades, although wildfire projections are accompanied by significant uncertainty and moderating influence, as described above. Duke Energy uses a region-specific time-based trimming model to manage vegetation along distribution lines to maintain reliable electric service, and an ancillary benefit of this is minimized ignition risk from vegetation and fuel loading.

Workshop Discussion Summary – Sequential Events

A growing body of research shows that climate change will likely increase the frequency and intensity the most extreme weather events, including those that directly impact the Duke Energy service area. Such events include major coastal storms, heat waves, and ice storms. While science suggests that these events may become more frequent and severe, global climate models are less able to resolve specific probabilities and intensities of these "tail risk" events. However infrequent, these extreme weather events also present outsized risks to utility infrastructure, operation, and customers.

Extreme Event Descriptions

SCENARIO 1:
Category 5 Hurricane Followed by an Extreme Heat Wave

This scenario includes a catastrophic hurricane and heat wave occurring sequentially. A Category 5 hurricane makes landfall near the North Carolina and South Carolina border. This storm would cause major issues including strong winds, extreme storm surge, large amounts of precipitation leading to riverine flooding, and more. After the storm a persistent high-pressure system causes an extensive heat wave with record-breaking temperatures across the Carolinas. For a single day, temperatures would exceed 115°F in Charlotte, Fayetteville and Greensboro N.C. High relative humidity would also lead to extreme heat indexes throughout the Carolinas, exceeding 130°F in the hottest parts of the service territory.

SCENARIO 2:
Ice Storm Followed by Extreme Cold

This scenario includes a strong winter storm that would bring a mix of snow, freezing rain, ice, and rain to the entire service territory. Snow accumulations in the highest elevations would reach over 3 feet and freezing rain would cause significant issues along the coastal plain and Piedmont. Sustained winds up to 50 mph would occur across the Carolinas. Afterward, a polar vortex event descends southward across the Carolinas bringing frigid temperatures to the entire service area. Overnight lows would plummet to near 0°F across the Piedmont, and -8°F near Asheville, N.C. The coldest temperatures would last approximately one to two days with significantly below average temperatures lasting approximately four to six days.

To address these high-impact, low-frequency events, ICF developed two plausible event scenarios: (1) a major hurricane making landfall in the service area followed by an intense heat wave, and (2) an intense winter storm followed by a severe cold snap (see box to left for more detail on these event scenarios). Notably, these hypothetical scenarios intentionally consider events that approach the boundaries of plausible severity – meaning that they will remain possible but highly unlikely. These events also exceed the standards to which the electric utility industry designs, and aim to examine Duke Energy's ability to respond to and mitigate to events likely to result in equipment failure. In these scenarios emergency response considerations and the identification of areas where preparedness could be increased are critical to mitigate the worst impacts of future climate change-driven extreme events.

To explore what these events and their aftermath may look like, ICF and the Duke Energy Climate Change Risk and Resilience Study team conducted a workshop on Feb. 4, 2022. Findings discussed were drawn from the **responses of workshop participants**, which represented subject matter experts from across Duke Energy's focus areas (e.g., transmission, customer delivery, system operations, community relations, and more).

Overall, workshop participants validated the notion that some high-impact, low likelihood weather events exceed electric utilities' capacity to reasonably harden all system elements against, and consequently that event preparedness and response activities are particularly important in such scenarios. Participants indicated that both scenarios lead to infrastructure damage across asset types. Customers could experience impacts including widespread and extended outages, which could lead to public safety risks, especially for low-income, elderly, and customers with a disability, and customers that reside in homes with limited insulation. Discussion of these scenario events included consideration of Duke Energy's robust existing emergency communication protocols, storm preparation procedures, and restoration priority procedures, in addition to potential additional hardening and planning measures that could be beneficial in planning for future extreme events. Considerations identified in this discussion will further inform Duke Energy's ongoing climate change adaptation planning.

Planning and Operations Vulnerabilities

In addition to assessing the climate change vulnerabilities of Duke Energy's infrastructure, the study team also reviewed potential risks to Duke Energy's planning processes and operations. The ratings provided below reflect the potential number of changes that may need to occur within Duke Energy's planning and operation processes to address climate change. These ratings are climate scenario agnostic.

Asset Management: High

Asset management processes are in place across Duke Energy to monitor, repair, replace, and augment equipment and systems as needed. This includes setting engineering and design standards, which specify technical requirements for equipment and facilities. Among other objectives (e.g., safety, affordability), asset management processes are meant to keep the T&D system operating reliably through all weather conditions, including heat waves and storms, by maintaining the health of the system.

The study team identified several risks to Duke Energy's asset management process:

- Climate change is projected to increase average summer temperatures as well as the frequency and intensity of heat waves, which may increase equipment aging and replacement rates.
- Precipitation and flooding patterns are changing, and existing design practices may be insufficient in some cases.
- Duke Energy's T&D assets reside not only on Duke Energy-owned poles, but also on poles owned by other parties (e.g., telecommunication companies) and those poles are not covered by Duke Energy's inspection program. Those poles may be less prepared for increasing frequency and intensity of extreme weather events.
- Duke Energy has limited insight into failure data and the impact of climate on failure rates.

Without adaptation, climate change impacts on asset aging and replacement rates may result in higher capital costs, which would require financing and would be reflected in customer bills. Faster aging and the consequential increase in failure rates may also impact service reliability, particularly if asset failures occur during high load periods.

Load Forecasting: Medium

The load forecasting team is responsible for developing customer load forecasts in the DEC and DEP service territories to help Duke Energy understand how changes in land use (e.g., expanded urbanization, new job centers, or decreased popularity of certain regions) and other factors (e.g., growth of the electric vehicle market) may increase or decrease future electric demand. The load forecasting process is a foundational input to Duke Energy's planning activities for its T&D systems.

Duke Energy's load forecasting planning has recently begun to incorporate the temperature impacts of the RCP scenarios as an alternative to its longer term jurisdictional baseline planning process. The 10-year granular forecasting process known as Morecast, which is now used for distribution planning purposes, does attempt to address the impact on load due to higher temperatures by publishing circuit level forecasts that use an extreme (95th percentile) historical weather scenario.

Not incorporating future changes in climate in its long-term baseline planning runs could result in Duke Energy consistently under forecasting its long-term load projections. While annual forecast updates will catch gradual trends, even the historical 30-year period used by Duke Energy does not always capture past extremes. If this resulted in under investment in the system, it could be difficult and costly to reactively increase capacity as compared to gradually increasing it over time using more accurate forecasts.

Absent adaptation, the projected future increase in temperature extremes could result in increased load and ultimately in equipment overloads during summer periods. Potential consequences of these overloads range from a reduction in the life span of equipment to Duke Energy needing to implement load shedding. Load shedding has the potential for major impacts on communities, including public safety implications, and may also have financial implications for Duke Energy.

Capacity Planning: Medium

Capacity planning identifies portions of the grid where load growth could exceed existing capacity and identifies and executes the necessary investments to align system capacity with expected customer demand.

Although Duke Energy's transmission capacity planning incorporates regional variation in ambient temperatures, it does not account for local "hot spots" in ambient temperature that may exist across the service territory and will likely be exacerbated by climate change. On the distribution side, DEC has incomplete visibility into hot spots since it only has real-time equipment temperatures for approximately 50% of distribution substation transformers, which are critical elements of the power system. DEP does have real-time monitoring of various substation transformer temperatures and has distribution supervisory control and data acquisition alarms and alerts associated with those temperatures. Neither DEC nor DEP are incorporating forward-looking temperature projections into transmission or distribution asset ratings, which would help anticipate system needs over the coming years. This is meaningful since Duke Energy subject matter experts indicated that line capacity decreases by approximately 0.48% per degree F between 95°F to 105°F.

Absent adaptation to incorporate projected increases in ambient temperature and localized variation in temperatures there is risk of a mismatch between planned and actual energy delivery capacity of Duke Energy's system. This mismatch could result in accelerated equipment aging along with a marginally higher risk of equipment failure. For example, incomplete visibility into real-time equipment temperatures for substation transformers presents the risk that a localized summer hot spot, coupled with peak loads, could result in distribution transformer temperatures operating above design ratings, leading to accelerated loss of life and a marginally higher risk of transformer failure over time and in extreme cases, load shedding, as occurred on the Avista system during the summer of 2021.

Reliability Planning: Medium

Reliability planning identifies investments and actions to achieve target reliability performance of Duke Energy's systems. The process includes setting reliability performance targets, understanding the influence of external factors such as temperature, wind, extreme events and component failure rates on reliability performance, and finally identifying investments and operating process improvements to achieve target reliability.

Duke Energy's transmission reliability planning criteria complies with North American Electric Reliability Corporation (NERC) requirements;

however, NERC has not updated their requirements to reflect the potential risks posed by climate change. It may be prudent for Duke Energy to consider more conservative transmission planning criteria than the NERC TPL-001 assumptions due to projected increases in extreme weather events. Absent modification, planning to the current reliability requirements may result in reduced performance of Duke Energy's transmission system during future extreme events that are projected to be more frequent and intense.

For the distribution system, Duke Energy's reliability analysis is performed via an in-house, data-driven tool that considers historical reliability performance, historical reliability program spending, and predicts the potential impact of future investments on end customer reliability. This reliability analysis tool does not currently have the capability to incorporate the impact of climate change on reliability. One inherent challenge with incorporating upper bound climate change scenarios into reliability planning is that it is difficult to predict the reliability effects from more extreme weather conditions since there is very little operating experience within these conditions. This can make it more challenging to earn support from customers and regulators for more extensive adaptation investments. Absent modifications to incorporate climate change into reliability planning, there may be an unanticipated decrease in the reliability of Duke Energy's distribution system to extreme events.

Emergency Response: Low

Duke Energy's emergency response activities help the company prepare and respond to extreme weather events, including storms and other emergencies in the service area. Duke Energy coordinates emergency response activities using an Incident Command System (ICS), which represents a proven and industry-standard approach and allows Duke Energy to effectively scale response efforts across functional areas including command, operations, logistics and planning. Duke Energy also coordinates with municipalities and provides timely and accurate information to its customers during extreme events and their aftermath.

Climate change will likely increase the frequency and intensity of many extreme weather events, including those that directly impact the Duke Energy service area. This could result in Duke Energy's emergency response activities facing increasing challenges. However, Duke Energy's current emergency response activities are structured so that they are able to incorporate new learnings, enhancing their flexibility and scalability for a range of potential extreme events, including those potentially exacerbated by climate change. For example, Duke Energy maintains a diversified inventory of emergency response resources drawing on resources from regional partners and mutual assistance agreements as needed.

Workforce Safety: Low

Duke Energy is committed to workforce safety and maintains a range of company policies, specifications, and procedures on worker safety, environment and health. These range from protocols for avoiding worker heat stress, to requirements for employees to wear fire-retardant clothing, to a host of other safe work practices.

Climate hazards such as extreme heat, high winds, flooding, and wildfire can pose risks to workforce safety. While Duke Energy may be required to stop or modify work plans more often, especially because of increasing temperatures, the company's existing practices to proactively monitor and react to climate hazards can mitigate worker risks. Overall, Duke Energy's current workforce safety practices are robust and should be appropriate for most projected changes in climate. However, Duke Energy should consider incorporating humidity (via "real feel" type of temperatures) into workforce safety protocols to better represent the risk of combined heat and humidity to workers.

Vegetation Management: Low

Vegetation contact with T&D lines is one of the leading causes of outages. Duke Energy invests significantly in reactive pruning, planned maintenance, mowing, felling trees, aerial trimming, and herbicide applications to manage vegetation growth along distribution circuits and transmission lines.

Increasing temperatures, greater atmospheric CO_2, and longer growing seasons could affect annual vegetative growth, altered geographic distribution of tree species, increased prevalence of pest and disease, and reduced wood density. Duke Energy's existing vegetation management systems are likely sufficiently robust to address these changes as they occur, although the cost of vegetation management could increase due to enhanced tree growth and other potential complications.

V. Insights on Potential Community Vulnerability

Communities with socioeconomic or physical disadvantage (hereby referred to as "vulnerable communities") may be disproportionately affected by climate change-driven natural hazard events due to higher levels of exposure and lower capacity to adapt.[33] Power system malfunctions can worsen the impacts of climate hazards to vulnerable communities. For example, during particularly prolonged periods of high heat, loss of power may pose serious health hazards to affected communities. Research has found that in more than 70% of counties across the Unites States, vulnerable communities experience significantly hotter temperatures than surrounding communities,[34] and these communities often have fewer options to cope with this heat in the case of a power outage due to limited resources, mobility, communication ability, or access. As such, the maintenance of functioning power systems and the identification of resilience solutions in and around socially vulnerable communities, especially during climate hazard events, are important and should be given special attention by the serving utility company.

To understand the locations and social vulnerability levels of these communities, the study relies on the Centers for Disease Control and Prevention's Social Vulnerability Index (SVI), a widely adopted metric of social vulnerability.[35] For the purpose of this analysis, *high* and *extremely high* SVI tracts were defined as the following:

- Highly socially vulnerable census tracts are tracts receiving a national SVI score in the 75th to 90th percentile nationwide. (482 in Duke Energy service territory, or 18% of tracts in the service area)
- Extremely vulnerable census tracts are tracts receiving a national SVI score above the 90th percentile nationwide. (312 in Duke Energy service territory, or 12% of tracts in the service area)

Based on the county-level SVI information presented in this study,[36] high and extremely high socially vulnerable populations are prevalent across the Duke Energy service area, with somewhat fewer extremely vulnerable populations along the coast. Slightly higher concentrations of vulnerable populations occur around Charlotte, Fayetteville and Greensboro.

Overall, the social vulnerability findings are intended to be preliminary and illustrative: identifying further areas for community-level study as part of the adaptation planning process and piloting data-driven methods for characterizing differential social vulnerability. The data generated by this study provides Duke Energy with the tools to overlay and further analyze asset vulnerability and social vulnerability in a way that can inform subsequent adaptation planning and community partnership.

[33] Cutter, S.L., B. Boruff, and W. Shirley, "Social Vulnerability to Environmental Hazards," *Social Science Quarterly* 84 (2003): 242-261, https://doi.org/10.1111/1540-6237.8402002.

[34] Benz, S. and J. Burney, "Widespread Race and Class Disparities in Surface Urban Heat Extremes across the United States," *Earth's Future* 9 (2021): e2021EF002016, https://doi.org/10.1029/2021EF002016.

[35] SVI ranks U.S. tracts on 15 social factors, including minority status, income, level of education, and many others. The full methodology can be found here.

[36] The SVI data presented in this study helps identify counties with higher proportions of vulnerable populations. The counties are comprised of census tracts that have higher or lower proportions of vulnerable populations as compared to their countywide averages.

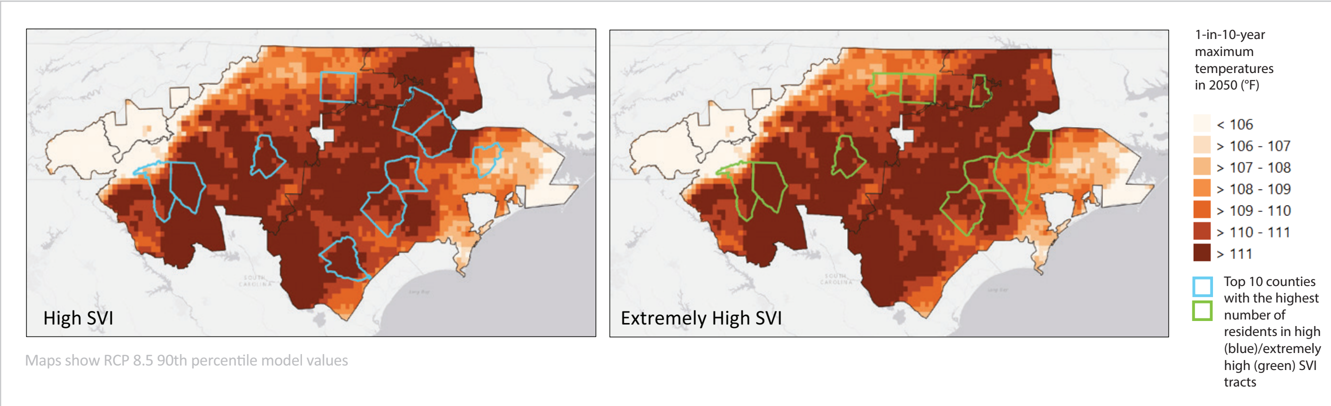

Figure 30: Communities with 10 highest numbers of people in high and extremely high SVI tracts, overlaid on a map of 1-in-10-year maximum temperatures in 2050.

Extreme Heat

The Piedmont is projected to see the most intense extreme temperatures in the Duke Energy service area; the majority of counties with the highest number of people living in high or extremely high SVI tracts fall within this zone of high heat. Figure 30 shows top 10 counties with the highest numbers of residents in high and extremely high SVI tracts. A high number of Duke Energy assets serve these communities; their reliability is and will continue to be important during periods of high heat. The reduced capacity of vulnerable populations to adapt to rising average and extreme temperatures emphasizes the need for access to air conditioning and other utility-related services.

Flooding

Substation flooding has been identified as a high priority climate change vulnerability for Duke Energy. Absent any adaptation action, flood impacts at substations could result in potentially long-duration outages in nearby communities. Socially vulnerable communities may have less capacity to adapt to these outages, due to lack of backup power sources and limited mobility. Some members of these communities, for example elderly individuals, may also rely more heavily on access to functioning power sources to carry out their everyday lives.

Figure 31 below, shows the locations and number of substations falling within FEMA flood plains and high or extremely high SVI counties across the Duke Energy service area.

Climate change is also projected to increase Atlantic hurricane rainfall and intensity; these changes, coupled with sea level rise, will drive deeper and

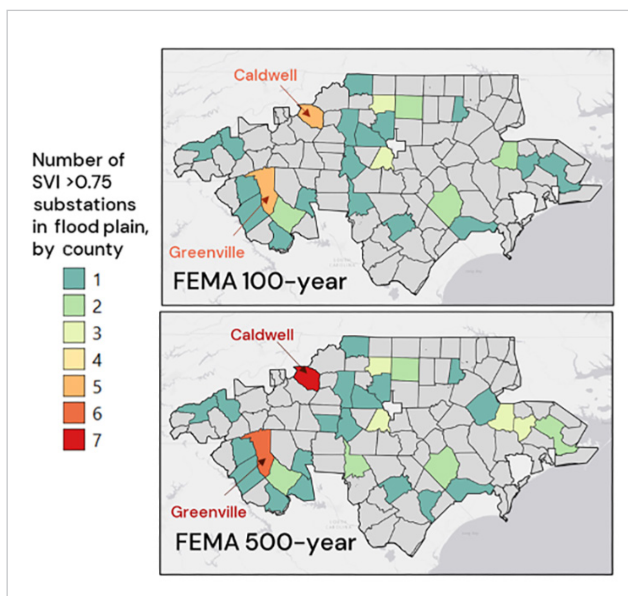

Figure 31: Location and number of substations falling within FEMA flood plains and high or extremely high SVI counties.

more extensive coastal flooding in the future. Coastal regions of Duke Energy's service territory are home to relatively fewer high and extremely high SVI populations compared to inland areas, though several high SVI census tracts are present in coastal areas. Figure 32, shows overlap between high and extremely high SVI tracts and the 2050 SLR + 100-year storm flood plain.

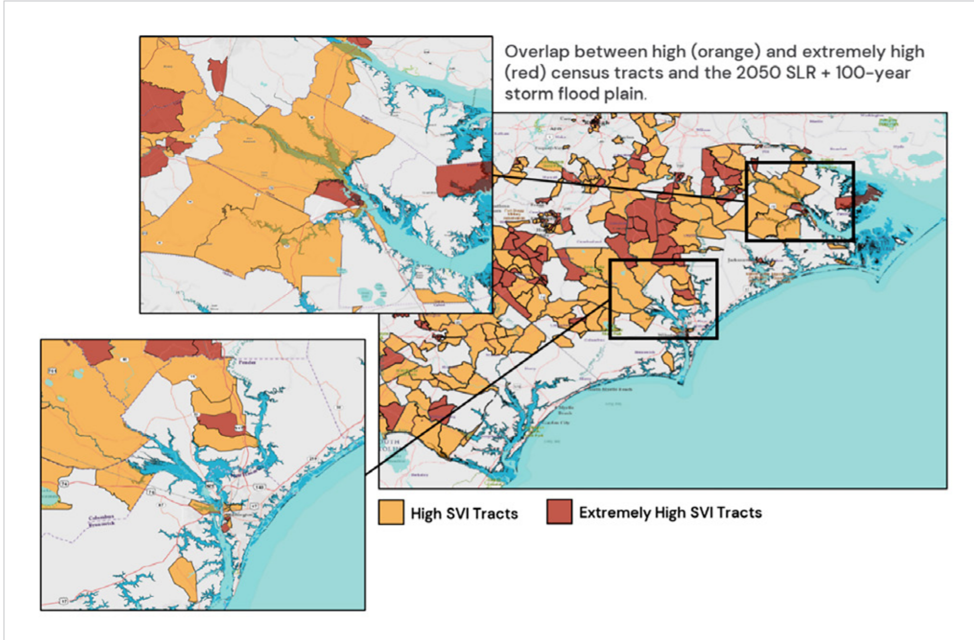

Figure 32: Overlap between high and extremely high SVI tracts and the 2050 sea level rise and 100-year storm flood plain.

Landslides

Landslide events may threaten the structural integrity of Duke Energy's assets or the land and transportation routes surrounding Duke Energy's assets. The northwestern portion of the Duke Energy service area falls within high landslide risk areas. Notably, this region is also projected to see some of the largest increases in high precipitation events, potentially exacerbating landslide risk. Anderson, Greenville, Spartanburg, and Mecklenburg counties (circled in Figure 33, below) have a high number of people living in high and extremely high SVI-rated census tracts, and large portions of these counties fall within high landslide risk areas.

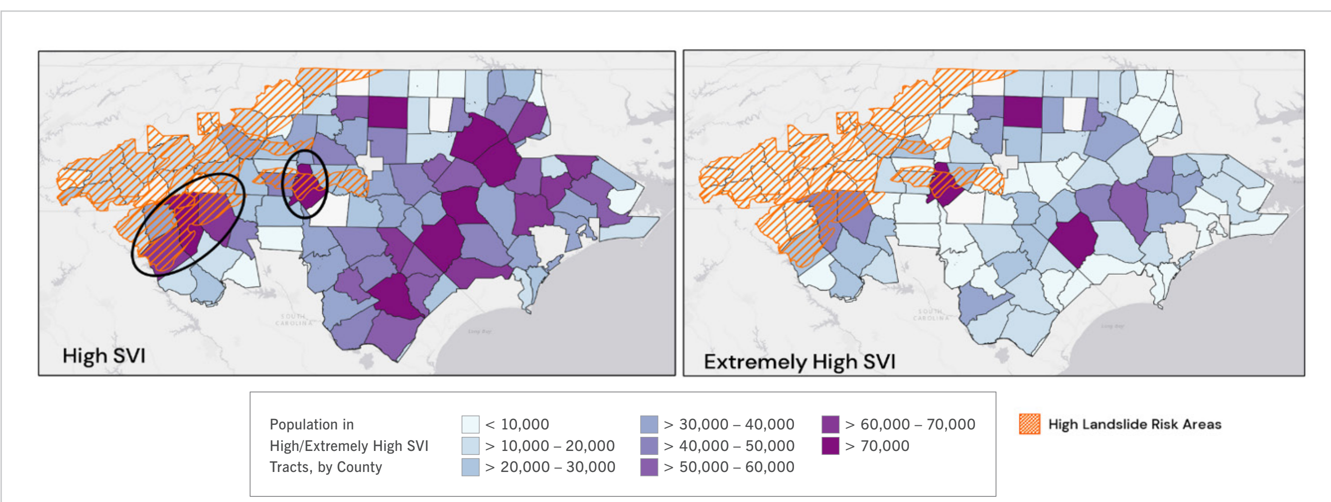

Figure 33. High landslide risk areas (orange cross-hatched), overlaid on county-level maps showing population in high/extremely high SVI tracts.

VI. Next Steps: Adaptation Framework Development

This report provides information on the potential for climate change to create vulnerabilities in Duke Energy's T&D systems in the Carolinas, and it points to planning and operational process that may, as a result, require updating in the future. In the next phase of this project on flexible adaptation planning, ICF will collaborate with Duke Energy and the TWG to discuss possible approaches to increase its preparedness for climate change. The preliminary objective for the adaptation planning phase of the project is to identify opportunities to improve Duke Energy's ability to meet or exceed expectations for performance with future investments and existing systems over their useful life despite changes in climate. This will be accomplished by:

- Selecting a climate change scenario for use in Duke Energy planning and design.
- Identifying existing Duke Energy guidance documents that should incorporate climate projections.
- Identifying adaptation strategies and events that would prompt their implementation, particularly for assets ranked highly vulnerable.
- Identifying potential adaptation strategies for extreme events, including options for partnership with local communities.
- Establishing key considerations for implementation of strategies such as community resilience.

One of the first tasks will be to select the climate change scenarios that Duke Energy could plan for moving forward. While this vulnerability assessment analyzed the "worst-case" risk (RCP 8.5 90th percentile) and a much more moderate climate change scenario (RCP 4.5 50th percentile), ultimately Duke Energy may select to plan and design for something in the middle. Climate change projections provide a range of plausible climate futures, reflecting uncertainty in future greenhouse gas concentrations, climate sensitivity to greenhouse gas increases, natural climate variability, and other factors. Climate change planning and design scenarios narrow this range and provide standardized climate change projections to guide Duke Energy's adaptation efforts.

In parallel, the study team will identify internal documents that could require updating to incorporate information on climate change and Duke Energy's potential selection of a planning and design scenario. Example documents may include design manuals, engineering standards, procedures, and other technical documentation. This work will illuminate the scope and scale of future efforts to imbue Duke Energy's internal documentation and practices with a selected climate change planning and design pathways.

The TWG has already provided constructive input on the range and types of strategies that they would like to see reflected in these frameworks. For example, some of the strategies that Duke Energy could consider implementing include:

- Working with equipment manufacturers and other utilities to increase industry standards to reflect climate change.
- Instituting end-of-life replacement programs that incorporate advanced conductors/high temperature equipment.
- Updating new construction standards, particularly feeder exits, to consider underground or Grade B overhead construction.
- Continuing to implement the Flooded Substations Initiative.

Examples of strategies from TWG members that highlight the potential for Duke Energy to continue working with stakeholders on adaptation include:

- Supporting and encouraging local power options that would ensure access to air conditioning (e.g., microgrids, rooftop solar, community solar).
- Partnering with local government to deploy more sensors to measure and track local flood impacts and enhance timely alerts for people, property and infrastructure.

ICF will integrate the feedback received to date into our adaptation framework thinking and will solicit additional feedback from the TWG over the coming months via email and an additional meeting to discuss the early draft frameworks.

In any event, adaptation planning in any organization is a long-term undertaking. Internal preparations and additional investments may be undertaken over years and even decades and would need to be considered in an organization's strategy and aligned with its other priorities and plans. This project will conclude with an initial step in this long-term process: the study team will develop conceptual frameworks for addressing climate change risks to T&D assets and for managing future extreme events. These frameworks could be used to help inform Duke Energy's long-term plans for its T&D systems in the Carolinas.