NREL

Utility and Grid Operator Resources for Future Power Systems Webinar Series

Weather-Driven Resilience for Distribution Systems

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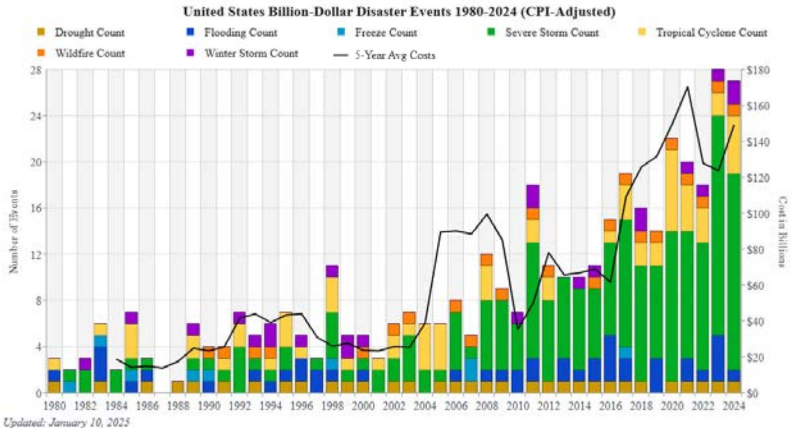
NREL Webinar Series
June 12, 2025

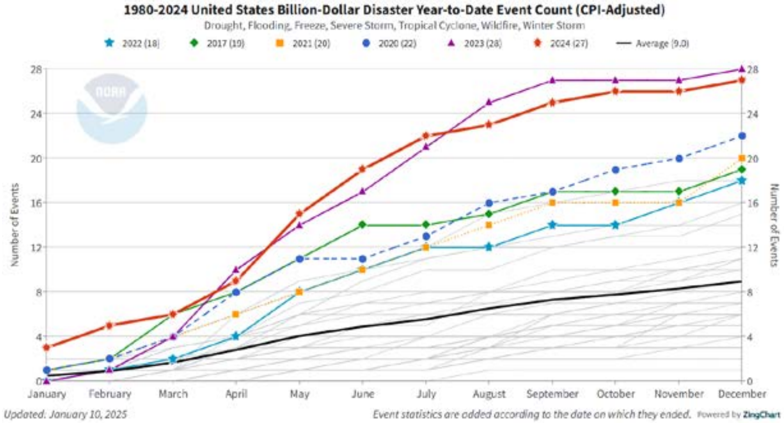
Content credit: Reiko Matsuda-Dunn, Jordan Burns, and Sara Peterson

Outline

Overview and Impact of Natural Hazards on the Grid

Increasing Impact of Natural Hazards in the United States





2014

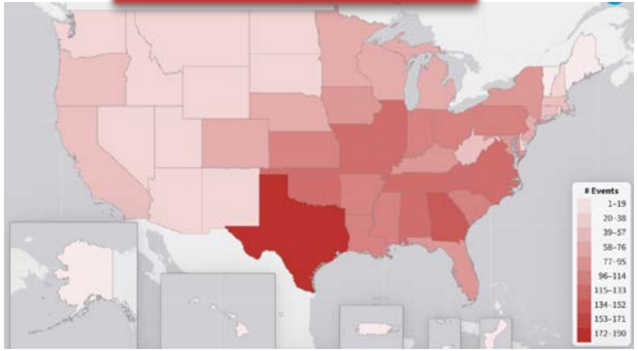
2017

2024

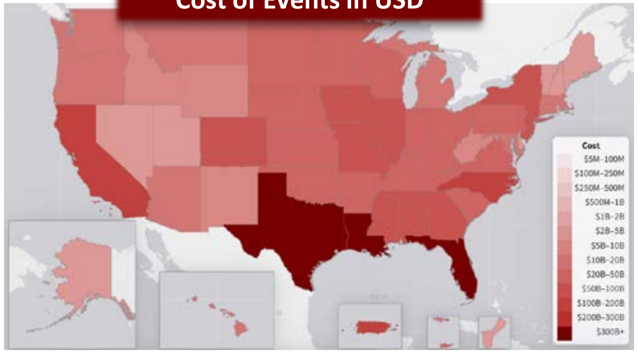
NOAA National Centers for Environmental Information (NCEI). "U.S. Billion-dollar Weather and Climate Disasters, 1980 - present (NCEI Accession 0209268)" URL: https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.nodc:0209268

Natural Hazards in the United States (1980-2024)

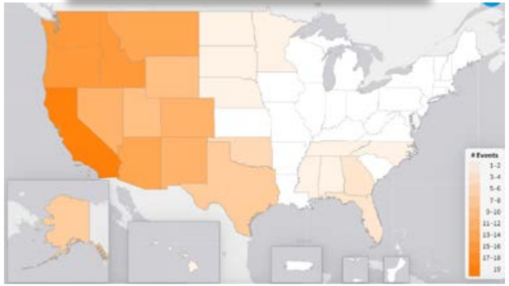
Number of Events



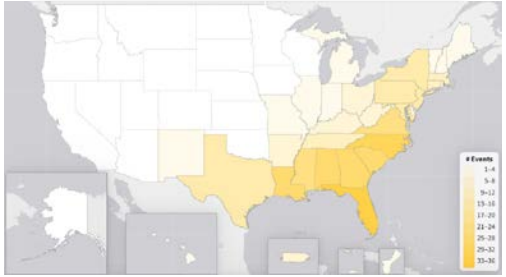
Cost of Events in USD



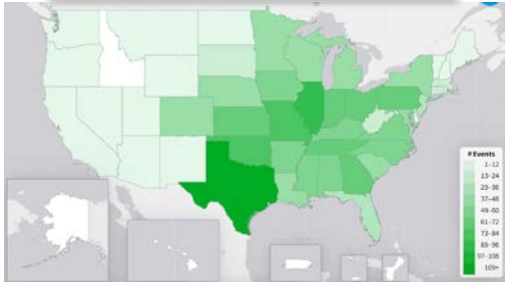
Total Wildfires = 23
Wildfires in California = 19



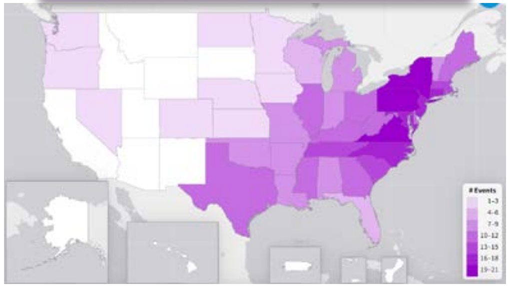
Total Tropical Cyclones = 67
Tropical Cyclones in Florida = 36



Total Severe Storms = 203
Severe Storms in Texas = 126



Total Winter Storms = 24
Winter Storms in New York = 21



** Consumer Price Index (CPI) Adjusted*

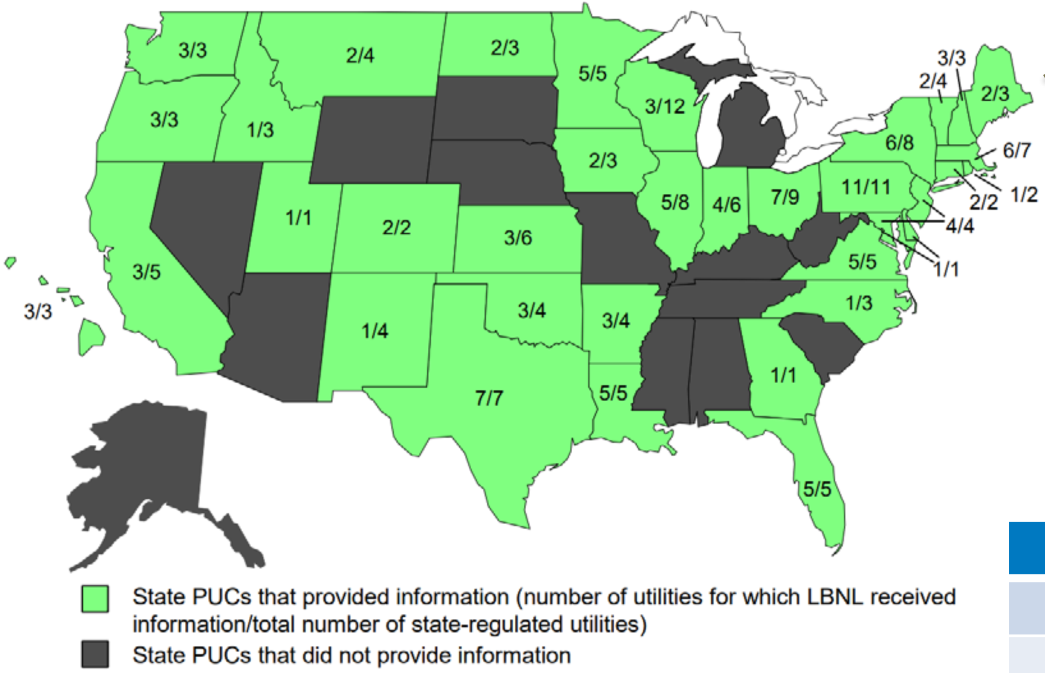
NOAA National Centers for Environmental Information (NCEI). "U.S. Billion-dollar Weather and Climate Disasters, 1980 - present (NCEI Accession 0209268)" URL: https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.nodc:0209268

Power Distribution Reliability Indices

- SAIDI (System Average Interruption Duration Index):
  - Total duration of interruption for an average customer over a predefined period
- SAIFI (System Average Interruption Frequency Index):
  - Number of interruptions for an average customer over a predefined period
- CAIDI (Customer Average Interruption Duration Index):
  - Average time taken to restore service after service interruption
- Major Event Day (MED):
  - An event day in which daily SAIDI exceeds an MED threshold (T_{MED})
- IEEE Standards and Guides
  - IEEE 1366-2022 - IEEE Guide for Electric Power Distribution Reliability Indices
  - IEEE 1782: Guide for Collecting, Categorizing, and Utilizing Information Related to Electric Power Distribution Interruption Events

- IEEE. 2012. *IEEE Guide for Electric Power Distribution Reliability Indices*. New York, NY: IEEE. IEEE Std 1366-2022 (Revision of IEEE Std 1366-2012), 1–44. URL: https://doi.org/10.1109/IEEESTD.2012.6209381.
- IEEE. *IEEE Guide for Collecting, Categorizing, and Utilizing Information Related to Electric Power Distribution Interruption Events – Redline*. New York, NY: IEEE. 12 Sept. 2022. IEEE Std 1782-2022 (Revision of IEEE Std 1782-2014) – Redline, 1–191.

Reliability Reporting Requirements



Eto, Joseph, and Kristina LaCommare. 2008. *Tracking the Reliability of the U.S. Electric Power System: An Assessment of Publicly Available Information Reported to State Public Utility Commissions*. Berkeley, California: Lawrence Berkeley National Laboratory. URL: https://www.osti.gov/servlets/purl/941540.

States with utility-reported reliability information (2008)

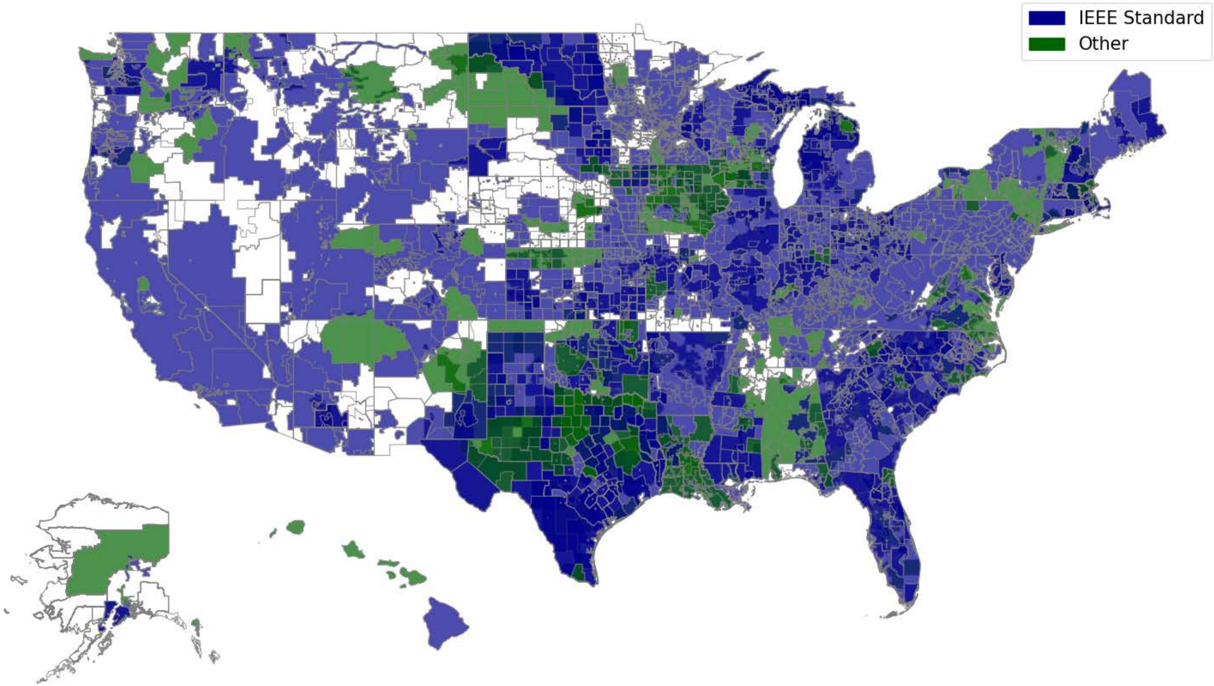
- 35 state public utility commissions (PUCs) require utilities to report reliability events annually
- 21 PUCs have reporting requirements formally defining major events (four follow IEEE 1366-2003 method)
- Definition of major event is inconstant among utilities

American Public Power Association Survey*

	YES	NO
Reliability reporting	95	7
Required by PUC	20	81

A. Hoffman, N. Mitchell, T. Doyle, and J. Y. Lee, "*Distribution System Reliability & Operations Survey Report*", American Public Power Association. Mar. 2022.
URL: https://www.publicpower.org/system/files/documents/Distribution-System-Reliability-Operations-Survey-Report-2020.pdf

EIA Form 861 – Reliability Reporting Utilities: NREL EIA Form 861 Analysis



* Utility territories may overlap in regions where multiple providers serve the same area. Darker colors represent areas of overlap, indicating regions with mixed service standards.

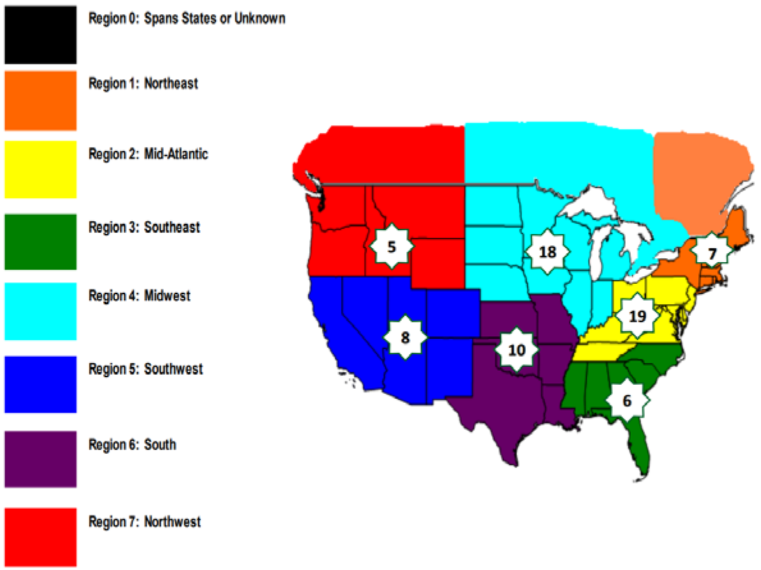
- In addition to PUCs, utilities are also required to report reliability indices to the U.S. Energy Information Authority (EIA) via Form 861:
  - As of 2023, approximately 900 *unique** utilities report their reliability indices to EIA.
  - 80% of utilities follow IEEE 1366-2022 standard whereas 20% of utilities differ in defining major events to compute these metrics

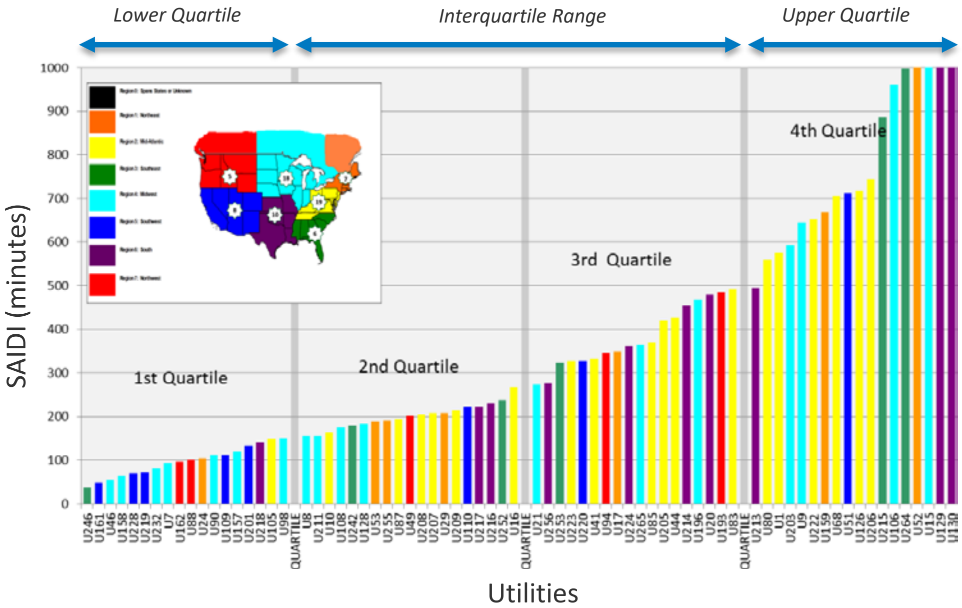
** Utilities may cover more than one state and report separate reliability metrics for each state.*

U.S. Energy Information Administration. 2024. "Annual Electric Power Industry Report, Form EIA-861 detailed data files." URL: https://www.eia.gov/electricity/data/eia861/.

Reliability of U.S. Distribution Grid: IEEE Benchmarks

- Although every region in the U.S. is dealing with some form of natural disaster, regionality alone may not be good predictor of distribution grid reliability.





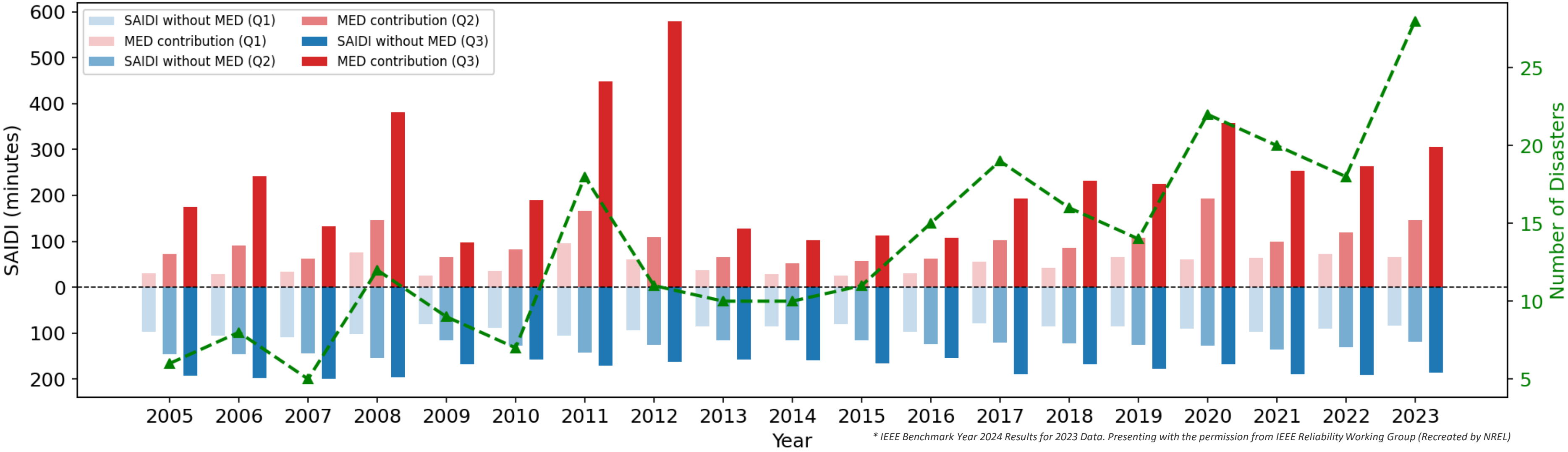
* *IEEE Benchmark Year 2024 Results for 2023 Data. Presenting with the permission from IEEE Reliability Working Group*

IEEE Reliability Working Group. 2024. “IEEE Benchmark Year 2024 Results for 2023 Data.” https://cmte.ieee.org/pes-drwg/wp-content/uploads/sites/61/2024-IEEE-Benchmarking-Survey.pdf.

IEEE Benchmarks: SAIDI

- MED contributions are better indicators of performance comparison between utilities.
- MEDs directly affect the duration of outages and hence increases SAIDI significantly.
- SAIDI with MEDs generally rise in years with more billion-dollar disasters, though some years show higher impact from fewer events.

Q1: Bottom Quartile, Q2: Median, Q3: Top Quartile



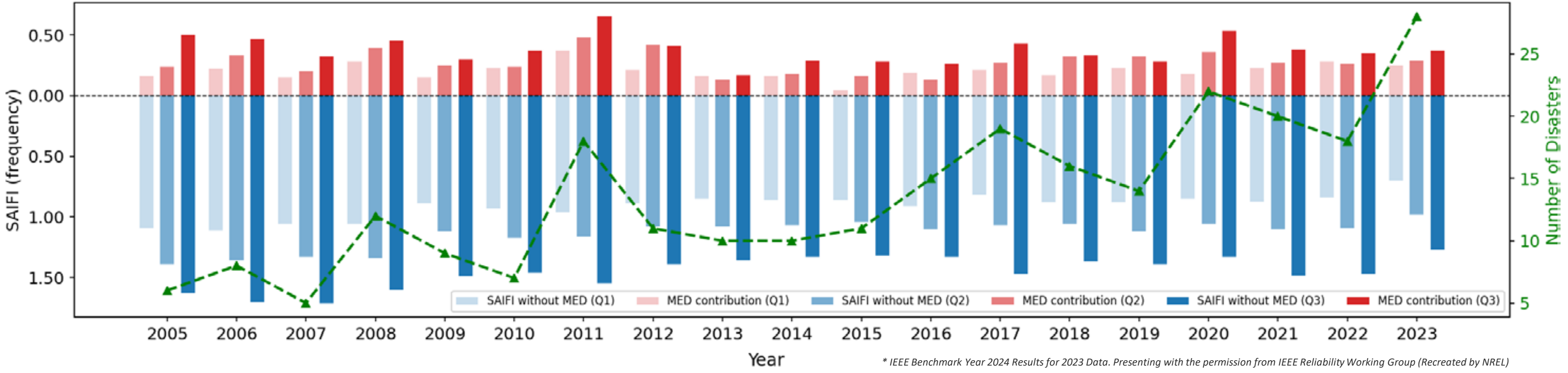
** IEEE Benchmark Year 2024 Results for 2023 Data. Presenting with the permission from IEEE Reliability Working Group (Recreated by NREL)*

- IEEE Reliability Working Group. 2024. "IEEE Benchmark Year 2024 Results for 2023 Data." https://cmte.ieee.org/pes-drwg/wp-content/uploads/sites/61/2024-IEEE-Benchmarking-Survey.pdf
- NOAA National Centers for Environmental Information (NCEI). "U.S. Billion-dollar Weather and Climate Disasters, 1980 - present (NCEI Accession 0209268)" URL: https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.nodc:0209268

IEEE Benchmarks: SAIFI

- SAIFI underrepresents MEDs because it counts each major event as a single occurrence, regardless of its widespread impact.
- Year-to-year stability in SAIFI suggests limited volatility from annual variation in event severity and impact.
- The frequency of MEDs averaged across all utilities is not statistically significant, *though it may be significant at the individual utility level.*

Q1: Bottom Quartile, Q2: Median, Q3: Top Quartile



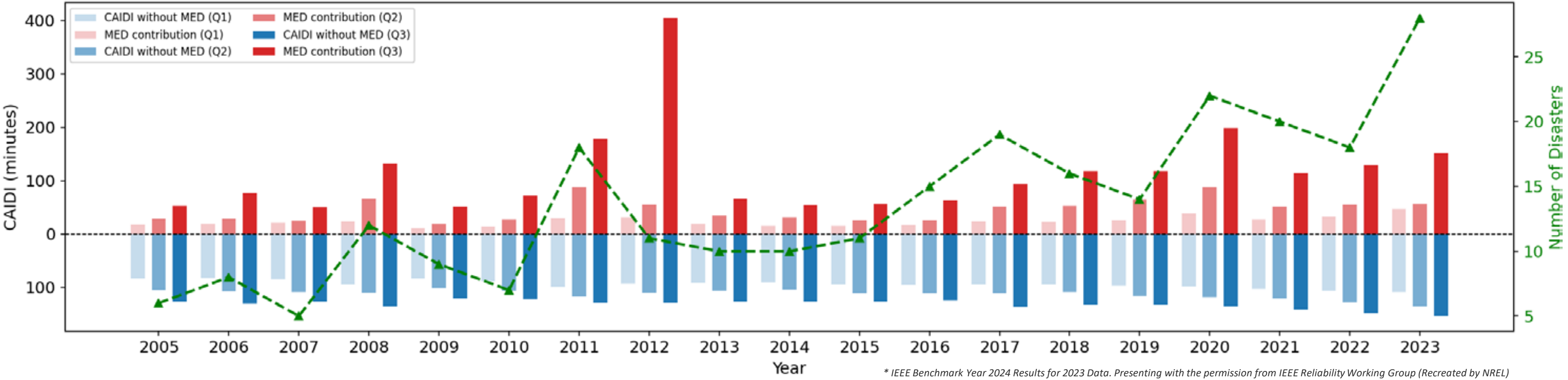
** IEEE Benchmark Year 2024 Results for 2023 Data. Presenting with the permission from IEEE Reliability Working Group (Recreated by NREL)*

- IEEE Reliability Working Group. 2024. “IEEE Benchmark Year 2024 Results for 2023 Data.” https://cmte.ieee.org/pes-drwg/wp-content/uploads/sites/61/2024-IEEE-Benchmarking-Survey.pdf
- NOAA National Centers for Environmental Information (NCEI). "U.S. Billion-dollar Weather and Climate Disasters, 1980 - present (NCEI Accession 0209268)" URL: https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.nodc:0209268

IEEE Benchmarks: CAIDI

- CAIDI is significantly affected by MEDs, reflecting longer average restoration times.
- Extended repair durations stem from infrastructure damage, limited workforce availability, and access challenges during major events

Q1: Bottom Quartile, Q2: Median, Q3: Top Quartile



** IEEE Benchmark Year 2024 Results for 2023 Data. Presenting with the permission from IEEE Reliability Working Group (Recreated by NREL)*

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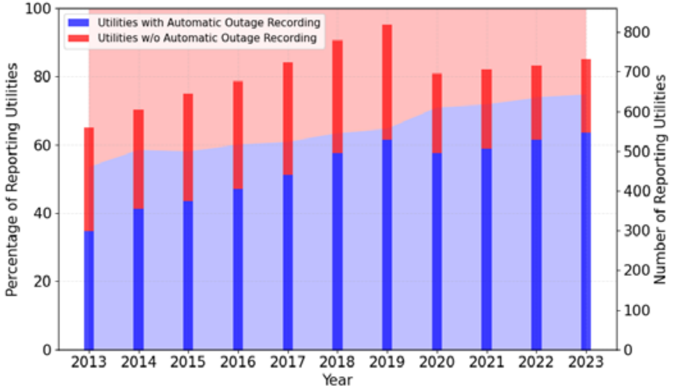
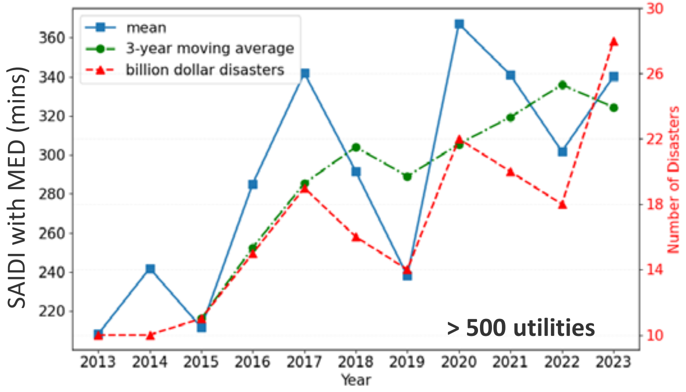
- NOAA National Centers for Environmental Information (NCEI). "U.S. Billion-dollar Weather and Climate Disasters, 1980 - present (NCEI Accession 0209268)" URL: https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.nodc:0209268

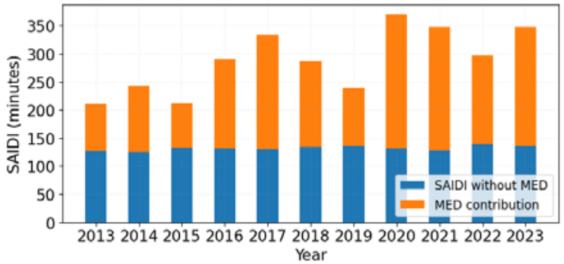
Reliability of U.S. Distribution Grid Over Time: NREL EIA Form 861 Analysis

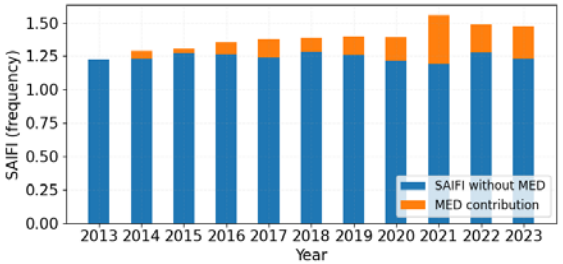
Improved reliability reporting with automated outage recording measures

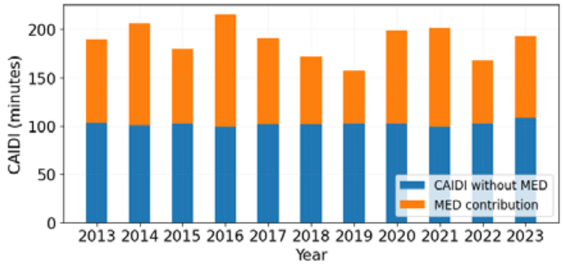


Worsening SAIDI with increasing billion-dollar events







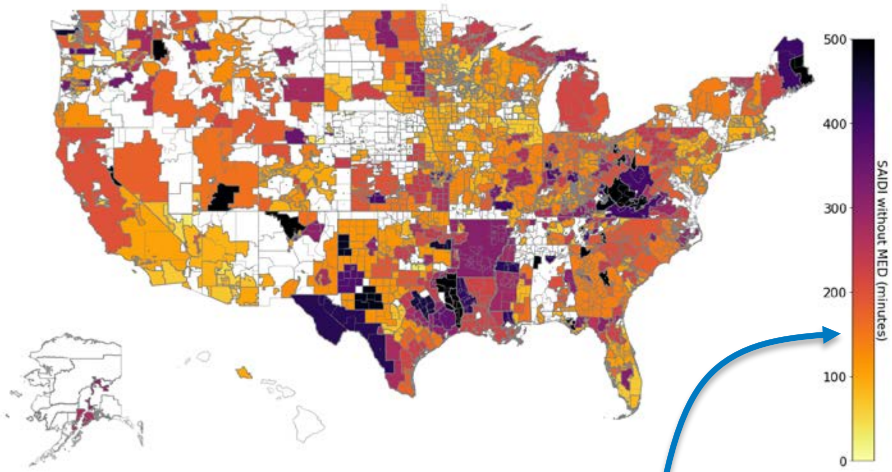


** These plots represent utilities reporting reliability metrics in IEEE Standard*

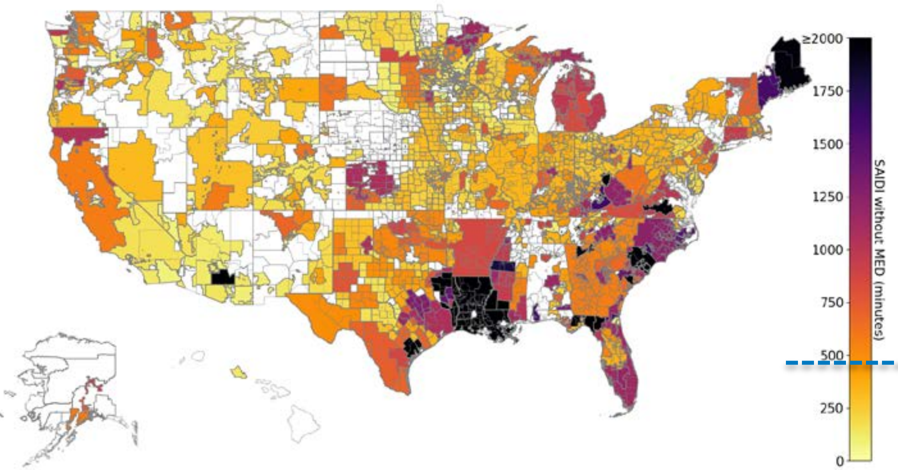
- U.S. Energy Information Administration. "Annual Electric Power Industry Report, Form EIA-861 detailed data files." URL: https://www.eia.gov/electricity/data/eia861/
- NOAA National Centers for Environmental Information (NCEI). "U.S. Billion-Dollar Weather and Climate Disasters." URL: https://www.ncei.noaa.gov/access/billions/

Impact of Major Events on Reliability: NREL EIA Form 861 Analysis

Average of five longest duration SAIDI without MED (minutes)

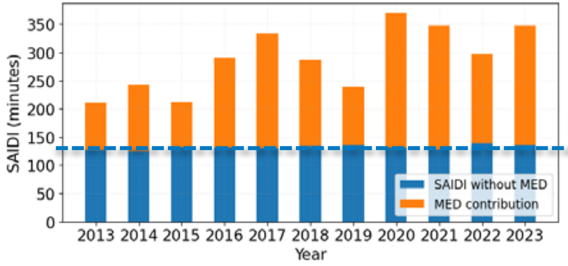


Average of five longest duration SAIDI with MED (minutes)



Major events exacerbate SAIDI

NOTE: The plots with and without MED have different scales.



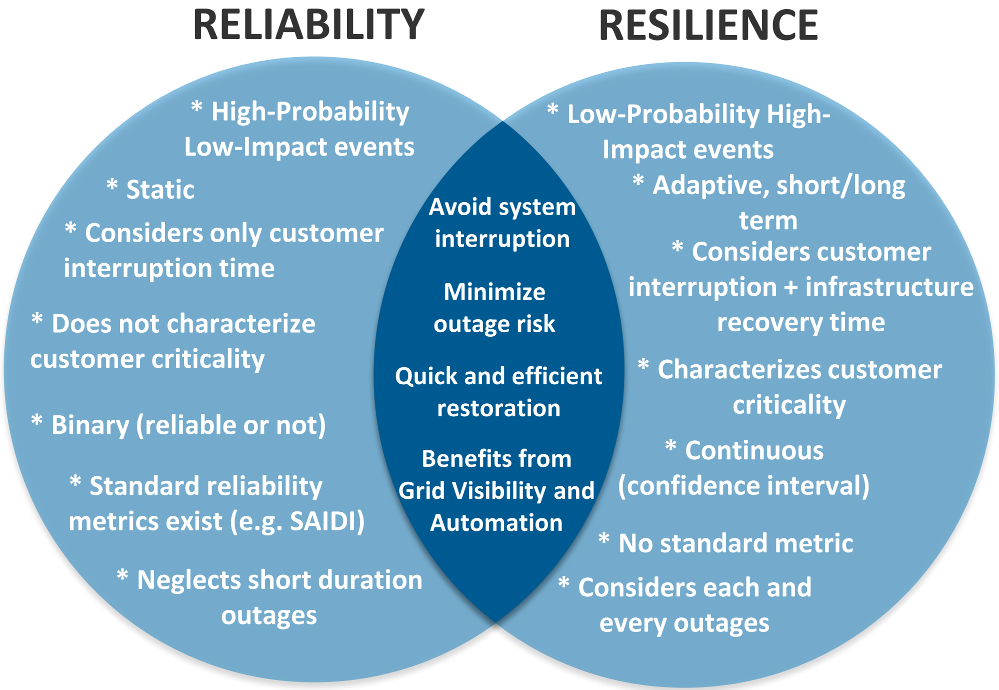
Averaging reliability across the entire United States can be misleading. A more granular analysis—excluding major events—reveals that reliability in many areas is worse than the national average.

Preliminary NREL Analysis. All plots represent utilities reporting reliability metrics in IEEE Standard

- U.S. Energy Information Administration. 2024. "Annual Electric Power Industry Report, Form EIA-861 detailed data files," URL: https://www.eia.gov/electricity/data/eia861/

Power Distribution Systems Resilience

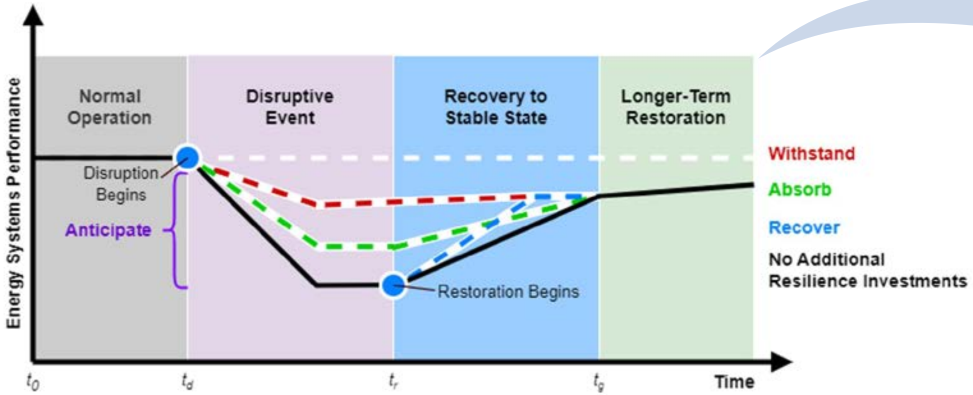
Reliability and Resilience



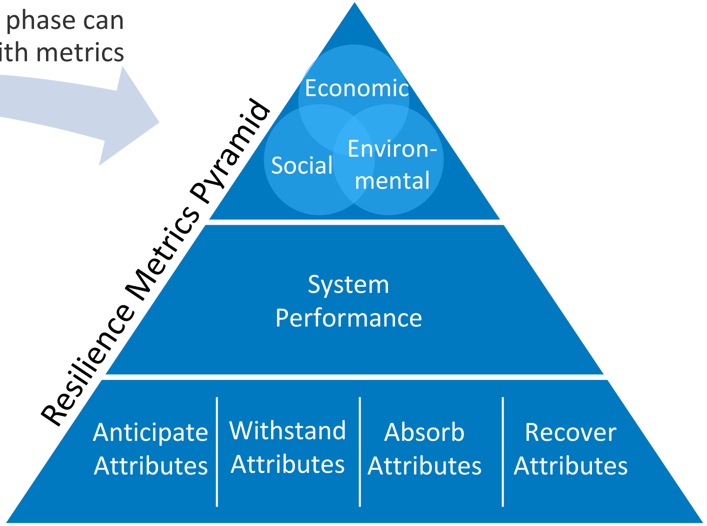
- Reliability metrics **fail to measure**:
  - the *"tail risk"* of extremely long-duration outages that can last days, weeks, or even months.
  - the true extent and intensity of major events.
  - the consequences of outages for customers based on location and density.
- Due to these limitations, reliability metrics, on their own, are not sufficient to guide resilience investment decisions

Characterizing System Resilience

Currently, there is no standardized set of metrics for resilience. Systematic, forward-looking resilience metrics enable comparison between different mitigations and consequences to different sets of customers.



Each resilience phase can be measured with metrics



- Keen, Jeremy, Reiko Matsuda-Dunn, Gayathri Krishnamoorthy, Haley Clapper, Lila Perkins, Laura Leddy, and Nick Grue. 2024. *Current practices in distribution utility resilience planning for wildfires*. Washington, DC: U.S. Department of Energy Grid Deployment Office. URL: https://doi.org/10.2172/2478838.
- Stanković, Aleksandar, Kevin Tomsovic, Fabrizio De Caro, Martin Braun, Joe Chow, and Ninel Čukalevski. "Methods for Analysis and Quantification of Power System Resilience." *IEEE Transactions on Power Systems* 38(5) 4774–4787. https://doi.org/10.1109/TPWRS.2022.3212688.

Attribute-based Resilience Metrics

Attribute metrics define system characteristics that can enhance or degrade system resilience

Metric	Resilience Category
Asset age, location, condition	Anticipate
Asset ignition probability	Anticipate
Tree-related outages (inside/outside right-of-way, storm/non-storm)*	Anticipate
Vegetation density	Anticipate
Recorded wires down per overhead line mile	Anticipate and withstand
Underground to overhead ratio	Withstand
Overhead pole wind stress parameters	Withstand
Fire response time*	Recover
Asset accessibility and terrain	Recover

* Some attribute metrics may also be performance metrics.

- Keen, Jeremy, Reiko Matsuda-Dunn, Gayathri Krishnamoorthy, Haley Clapper, Lila Perkins, Laura Leddy, and Nick Grue. 2024. Current practices in distribution utility resilience planning for wildfires. Washington, DC: U.S. Department of Energy Grid Deployment Office. URL: https://doi.org/10.2172/2478838.

Performance-based Resilience Metrics

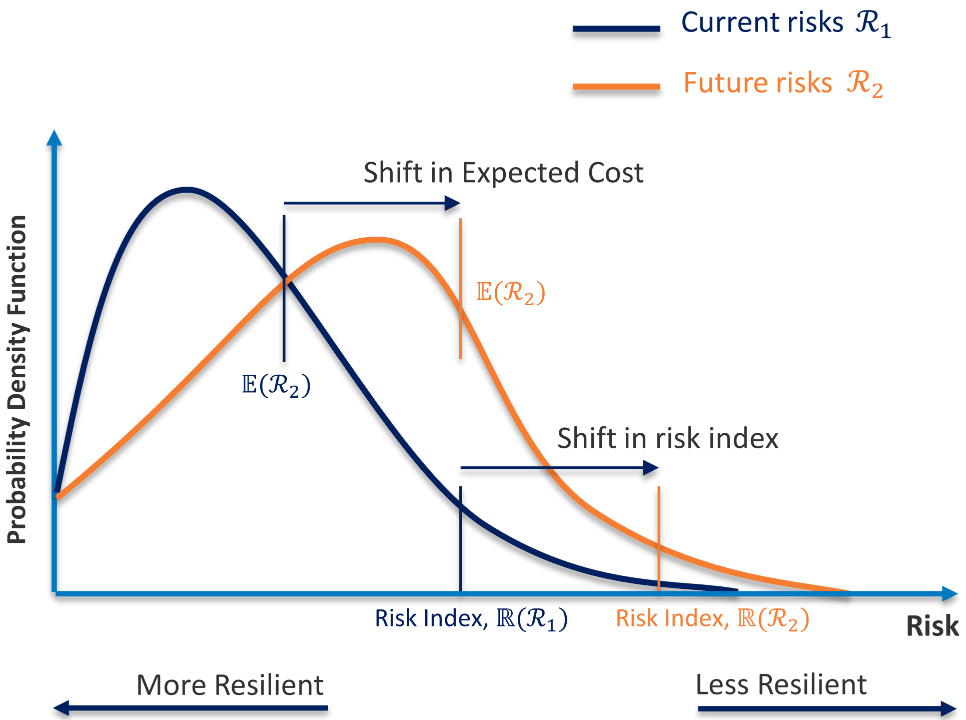
Performance metrics define system's current state to achieve its core objective i.e., evaluate system resilience

Metric
Customer Minutes Interrupted
Restoration cost per event (e.g., major storm)
SAIDI, SAIFI, CAIDI w/wo MED[1]
Faults in High Fire Risk Areas
Number of customers de-energized during public safety power shutoff events
Percentage of customers notified prior to a public safety power shutoff event
Time to restoration for customers experiencing extended outages
Critical services without power for more than N hours

Traditional reliability metrics are not strict indicators of resilience but are standardized, well understood by utilities and regulators, and often appear in utility resilience plans.

- Keen, Jeremy, Reiko Matsuda-Dunn, Gayathri Krishnamoorthy, Haley Clapper, Lila Perkins, Laura Leddy, and Nick Grue. 2024. *Current practices in distribution utility resilience planning for wildfires*. Washington, DC: U.S. Department of Energy Grid Deployment Office. URL: https://doi.org/10.2172/2478838.

Resilience and Risk



- System risks are dynamic and evolves over time.
- A resilient grid reduces both average impacts and extreme tail events.
- Evaluating resilience and risk helps prioritize actions that address both expected and worst-case scenarios.

Resilience Assessment and Planning

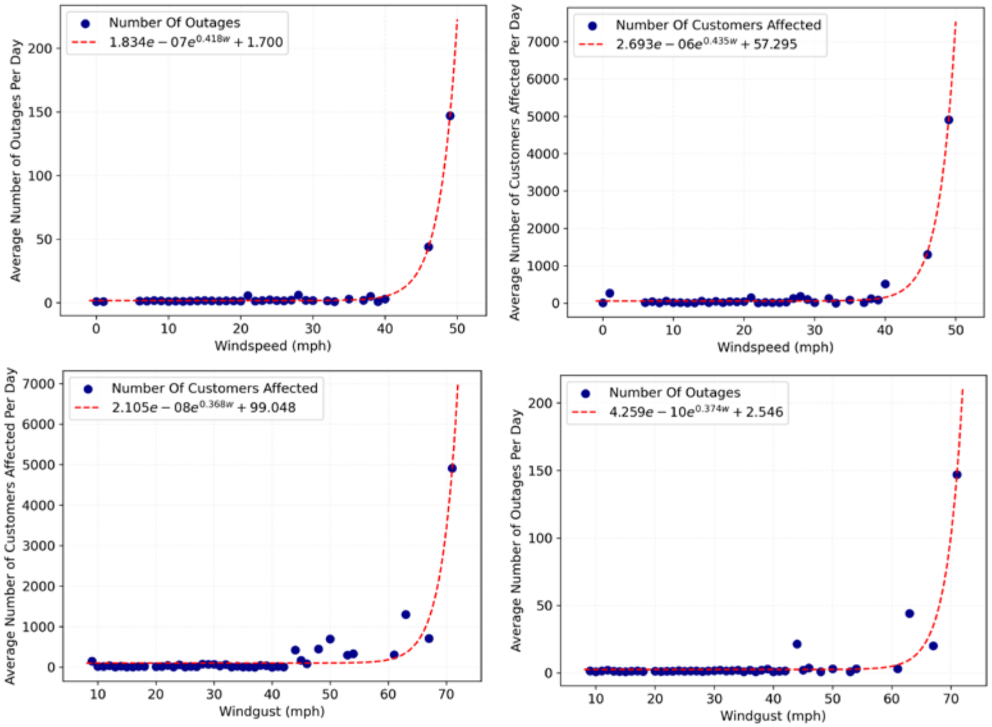
Threat to Consequence Assessment

- Requires quantification of all risk components (probability, vulnerability, and consequence)
- Many utilities have yet to establish quantitative relationships between threats / hazards, vulnerabilities, and consequences.

- **Historical analysis**
  - **Example:** Identification of outage hotspots using a utility's historical outage data

- **Forward-looking analysis**
  - **Example:** Monte Carlo simulations for several flooding scenarios to prioritize investment decisions and flooding risks

Historical Analysis: NREL Case Study to Assess the Impact of Wind-related Power Outages

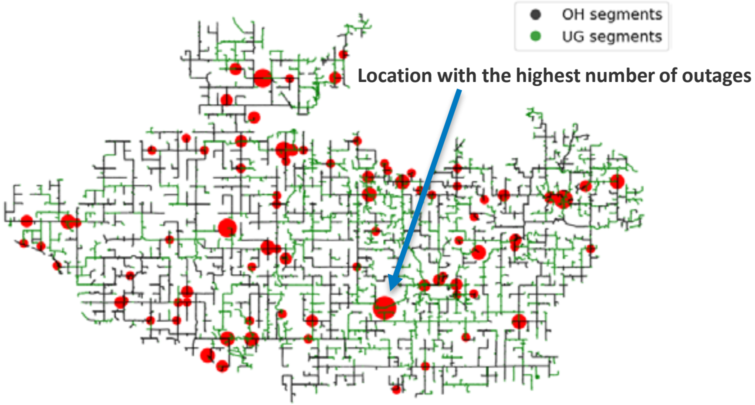


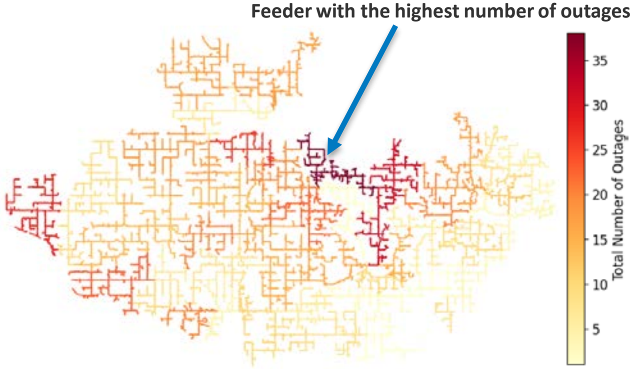
Preliminary NREL Analysis

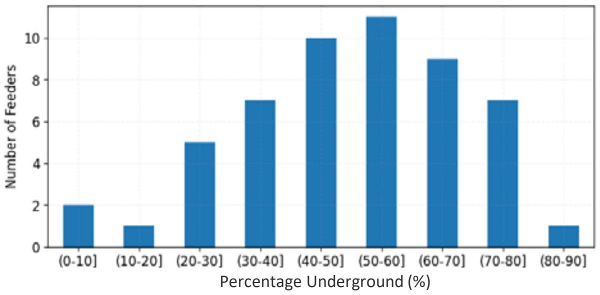
- Wind speed and wind gust corresponds to the maximum value approximated at the isolating device locations.
- Number of outages and number of customers are averaged for each day experiencing a corresponding maximum wind speed or wind gust value
- The relationship is characterized using an exponential model.

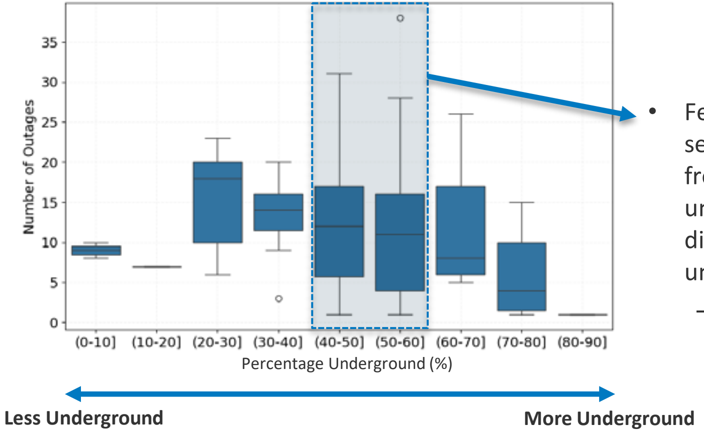
- Ian Dobson. 2023. "Models, Metrics, and Their Formulas for Typical Electric Power System Resilience Events." IEEE Transactions on Power Systems 38(6): 5949–5952. https://doi.org/10.1109/TPWRS.2023.3300125.
- Ahmad, Arslan, and Ian Dobson. 2024. "Towards Using Utility Data to Quantify How Investments Would Have Increased the Wind Resilience of Distribution Systems." IEEE Transactions on Power Systems 39(4) 5956–5968. https://doi.org/10.1109/TPWRS.2023.3342729.
- Visual Crossing Corporation. 2025. "Visual Crossing Weather." URL: https://www.visualcrossing.com/weather-query-builder/.

Historical Analysis: NREL Case Study to Correlate Feeder Attributes with Power Outages







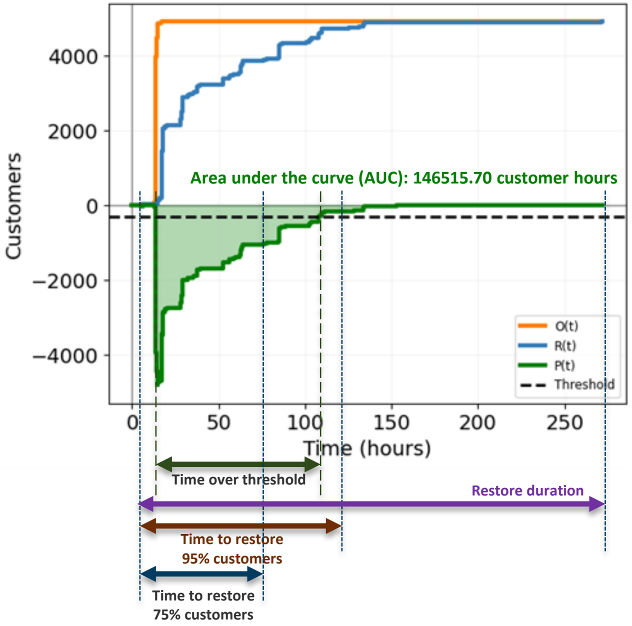


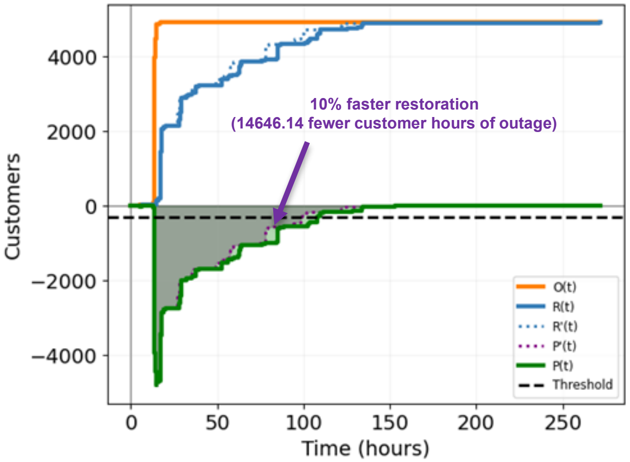
- Over 50 feeders analyzed to evaluate how varying levels of undergrounding affect outage performance
- Feeders with a higher proportion of underground segments generally experienced fewer outages, *though the relationship is not strictly linear.*
  - Likely influenced by other factors such as vegetation or risk exposure
- Feeders with 40%–50% underground segments showed similar outage frequencies to those with 50%–60% underground segments suggesting diminished return to uniform undergrounding.
  - Targeted undergrounding in vulnerable segments may often be a cost-effective way to improve grid resilience

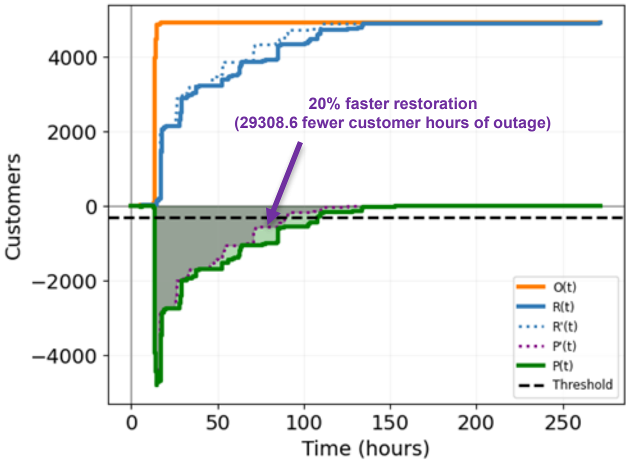
Preliminary NREL Analysis

Historical Analysis: NREL Case Study on Resilience Metrics

Preliminary NREL Analysis







O(t): Outage Process (Number of customers affected over time)

R(t): Restoration Process (Number of customers restored over time)

P(t): Performance Process (Number of non-restored customers over time)

Threshold: 95th percentile of total customers affected over a specified period

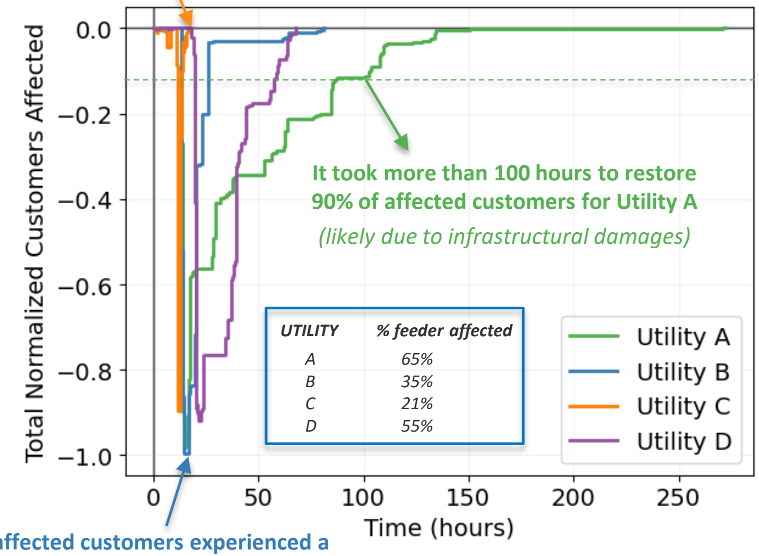
- Ian Dobson. 2023. "Models, Metrics, and Their Formulas for Typical Electric Power System Resilience Events." IEEE Transactions on Power Systems 38(6): 5949–5952. https://doi.org/10.1109/TPWRS.2023.3300125.
- Lee, Sangkeun Matthew, Supriya Chinthavali, Nathan Bhusal, Nils Stenvig, Anika Tabassum and T. Kuruganti. 2024. "Quantifying the Power System Resilience of the US Power Grid Through Weather and Power Outage Data Mapping." IEEE Access 12 5237–5255. https://doi.org/10.1109/ACCESS.2023.3347129.

Historical Analysis: Comparison of Performance Metrics for Utilities Within a Region

- A comparison of resilience metrics for utilities in a region impacted by the same severe weather event can provide additional information on the utility's current state and nature of the hazard.

The service was quickly restored for all customers in Utility C
(momentary outage with no infrastructural damages OR presence of automated grid-edge devices)

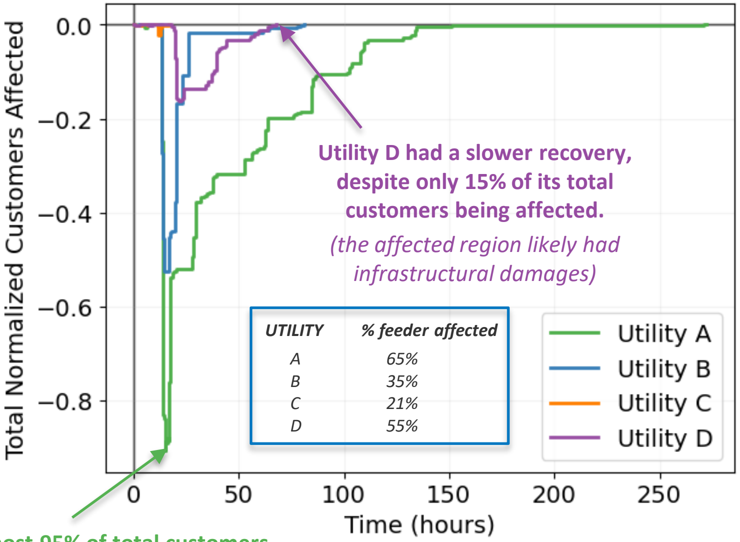
Normalized with respect to number of customers affected



It took more than 100 hours to restore 90% of affected customers for Utility A
(likely due to infrastructural damages)

The affected customers experienced a simultaneous service outage in Utility B.

Normalized with respect to number of customers served

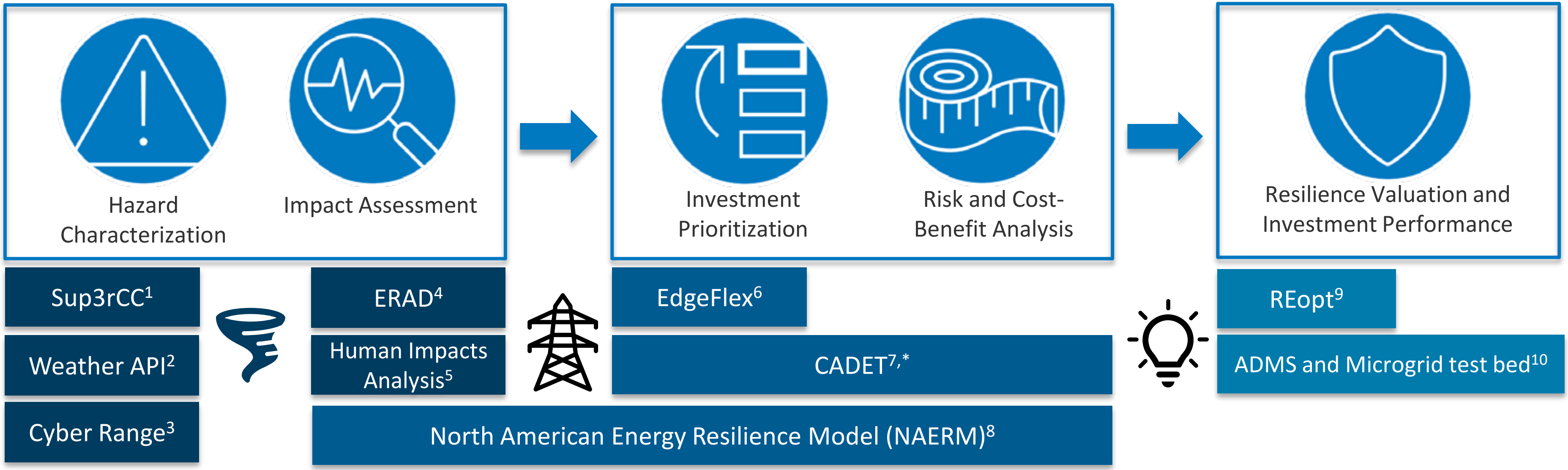


Utility D had a slower recovery, despite only 15% of its total customers being affected.
(the affected region likely had infrastructural damages)

Almost 95% of total customers experienced an outage at peak in Utility A
(likely in direct path of the storm)

Preliminary NREL Analysis

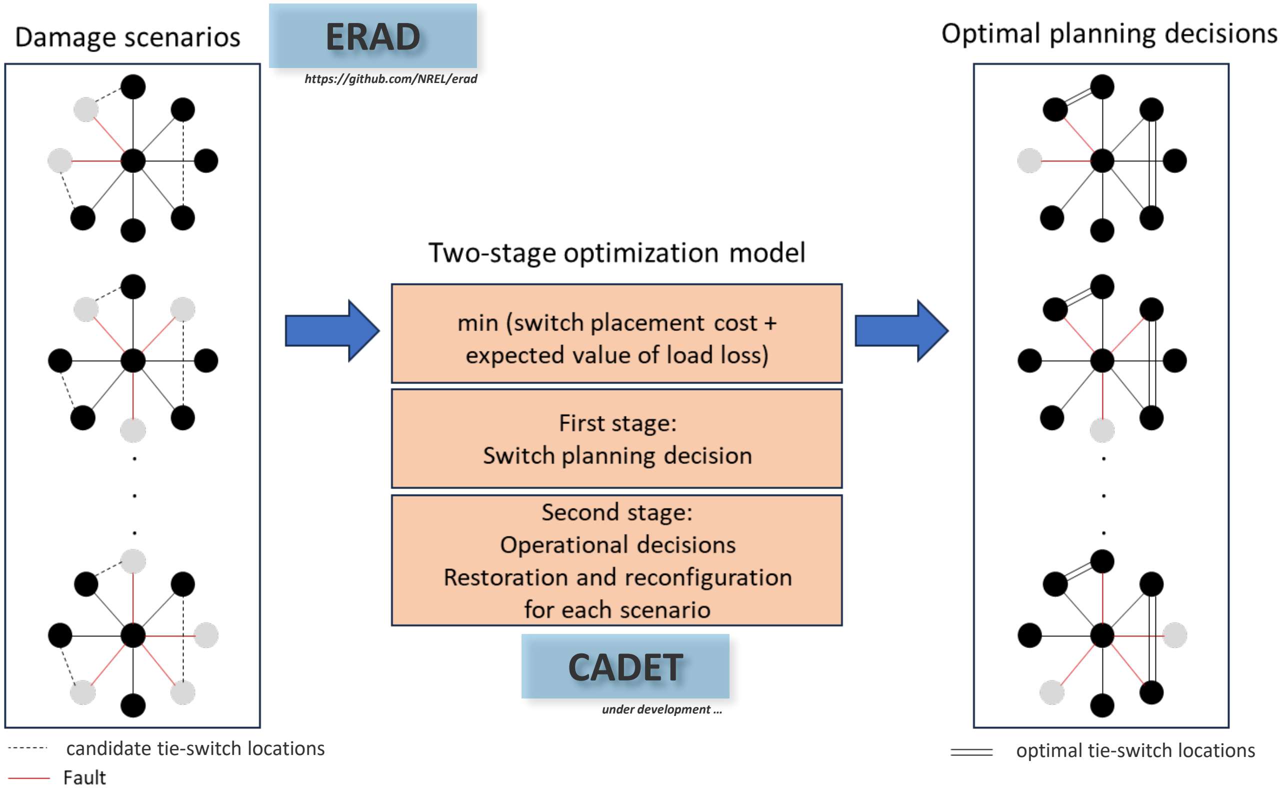
Forward-Looking Resilience Planning Framework



***under development**

1. Buster, Grant, Brandon Benton, Andrew Glaws, and Ryan King. 2024. "High-resolution meteorology with climate change impacts from global climate model data using generative machine learning." *Nature Energy* 9(7): 894–906. https://doi.org/10.1038/s41560-024-01507-9.
2. Visual Crossing Corporation. 2025. "Visual Crossing Weather." URL: https://www.visualcrossing.com/weather-query-builder/.
3. National Renewable Energy Laboratory. "Advanced Research on Integrated Energy Systems Cyber Range." URL: https://www.nrel.gov/security-resilience/cyber-range.
4. GitHub. NREL Distribution Suites. https://github.com/NREL/erad.
5. National Renewable Energy Laboratory. "Energy System Resilience." URL: https://www.nrel.gov/security-resilience/energy-resilience.
6. Ding, Fei, Weijia Lu, Utkarsh Kumar, and Yiyun Yao. 2022. "Unleash Values From Grid-Edge Flexibility: An overview, experience, and vision for leveraging grid-edge distributed energy resources to improve grid operations." *IEEE Electrification Magazine* 10(4): 29–37. https://doi.org/10.1109/MELE.2022.3211017.
7. National Renewable Energy Laboratory. "CADET: Capacity Expansion Decision Support for Distribution Networks." URL: https://www.nrel.gov/grid/cadet.
8. U.S. Department of Energy. "North American Energy Resilience Model to Strengthen Power System Planning" URL: https://www.energy.gov/oe/north-american-energy-resilience-model-strengthen-power-system-planning.
9. National Renewable Energy Laboratory. "REopt: Renewable Energy Integration & Optimization." URL: https://www.nrel.gov/reopt/.
10. National Renewable Energy Laboratory. "Advanced Distribution Management System Test Bed." URL: https://www.nrel.gov/grid/adms-test-bed.

Forward-looking Analysis: Tie switch placement NREL-led capability for NAERM*



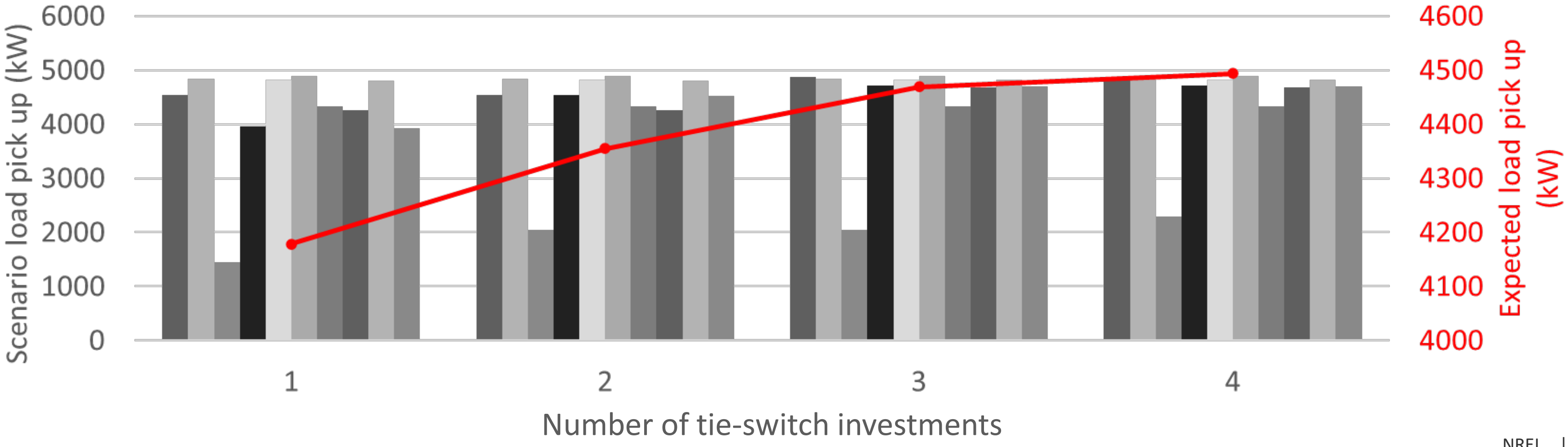
- Legacy planning targets individual threat scenarios, often missing broader system vulnerabilities, and extreme tail risks.
- Scenario-driven optimization supports multiple objectives, including cost-efficiency and resilience to both expected and extreme tail events.
- Tools like ERAD and CADET enable investment prioritizations and optimal decision-making.

Preliminary NREL Analysis: North American Energy Resilience Model

Forward-Looking Analysis: Tie switch placement

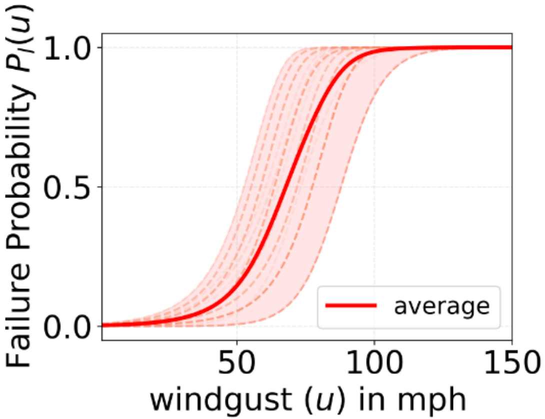
- Increasing investment in tie-switches minimizes the expected load loss over the range of damage scenarios
  - Each bar shows load loss for an individual scenario. The red line indicates the expected load loss across all 10 scenarios

- While fault locations within a given scenario determine how effectively tie switches will perform, investments must be deployed without foresight to increase restoration performance across scenarios

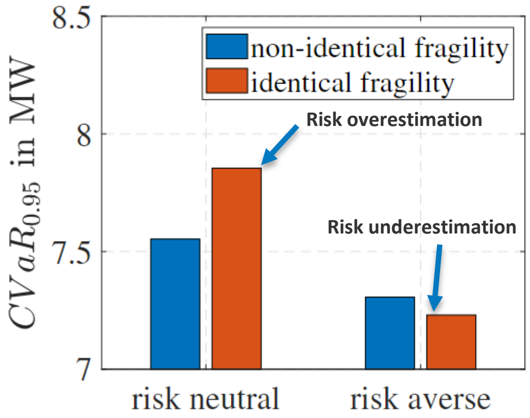


Preliminary NREL Analysis: North American Energy Resilience Model

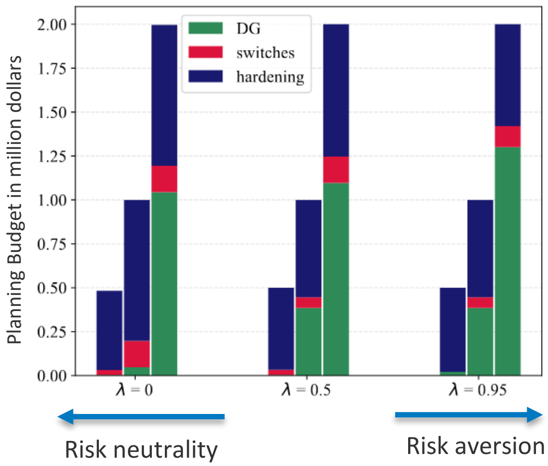
Scenario-Driven Cost, Benefit, and Risk Analysis



Average curve used as an identical fragility curve for all line segments



CVaR: Conditional Value-at-Risk



Component-level fragility models are essential for accurate modeling of the impact of severe weather events

Inaccurate representation of fragility models can result in improper risk analysis and risk estimation

Cost-benefit analysis and investment prioritizations are key to meaningful resilience investments

- Poudyal, Abodh, Shiva Poudel, and Anamika Dubey. 2023. "Risk-Based Active Distribution System Planning for Resilience Against Extreme Weather Events." *IEEE Transactions on Sustainable Energy* 14(2) 1178–1192. https://doi.org/10.1109/TSTE.2022.3220561.
- Poudyal, Abodh, and Anamika Dubey. 2024. "Multi-Resource Trade-Offs in Resilience Planning Decisions for Power Distribution Systems." IEEE Transactions on Industry Applications 60(6): 8031–8043. https://doi.org/10.1109/TIA.2024.3454205.

Resilience Investment Decisions

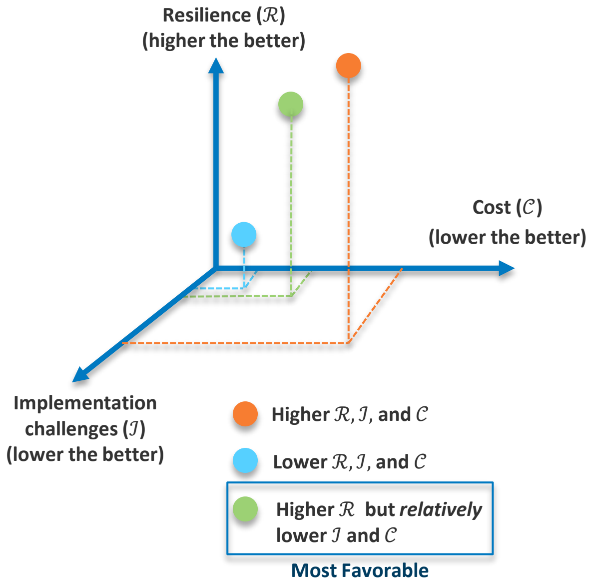
Category	Examples
Vegetation	Targeted vegetation management Widening right-of-way for lines
Overhead Hardening	Pole materials (e.g., steel poles) Fire wrapping poles
Undergrounding	Targeted undergrounding
Network Redundancy	Split network Adding primary feeder loops within and between networks Ties between exposed substations and/or distribution networks Additional distribution substations
Nonelectric Grid Physical Infrastructure	Floodwalls at substations Debris booms near fire-damaged area More frequent equipment maintenance to mitigate increased equipment wear
Grid Modernization	Distributed energy resources (DER) and Non-Wires Alternatives (NWA) Advanced Metering Infrastructure (AMI) for targeted load shedding Microgrid formation Automated switching operations Energy storage, on-site generation Resilience hubs
Advanced Resource Planning	Mutual assistance programs Resilient supply chains Allowing crews to take the repair trucks home
Operations	Training and threat response Emergency drills

Cost-effective

Addresses multiple hazards

Benefits from coordination with other municipal agencies

Supports additional objective



Aspects of Human Impacts in Distribution Resilience

Customer-driven Resilience: Human Impacts

Human Impact is the concept that people must spend resources fulfilling their needs. The amount spent varies according to the **availability of infrastructure** and the **level of need.**

Service accessibility measures the relative availability of critical services across a neighborhood at any point in time.

Service score captures the value of service locations within and across categories.
Shelters will have a relatively lower service score across many categories and Hospitals will have relatively higher service score on categories related to health categories

$$\left(\frac{\text{Service Score of Location}}{\text{Travel Time to Household A}}\right) + \left(\frac{\text{Service Score of Location}}{\text{Travel Time to Household B}}\right) \cdots \text{Etc.}$$

Customer-driven Resilience: Human Impacts

Human Impacts Analysis provides **performance-based evaluation** of resilient energy solutions.

What do people lose when they lose power?

→ **Where should we site investments to minimize those losses?**

→ **How do we "optimize" energy resilience for well-being?**

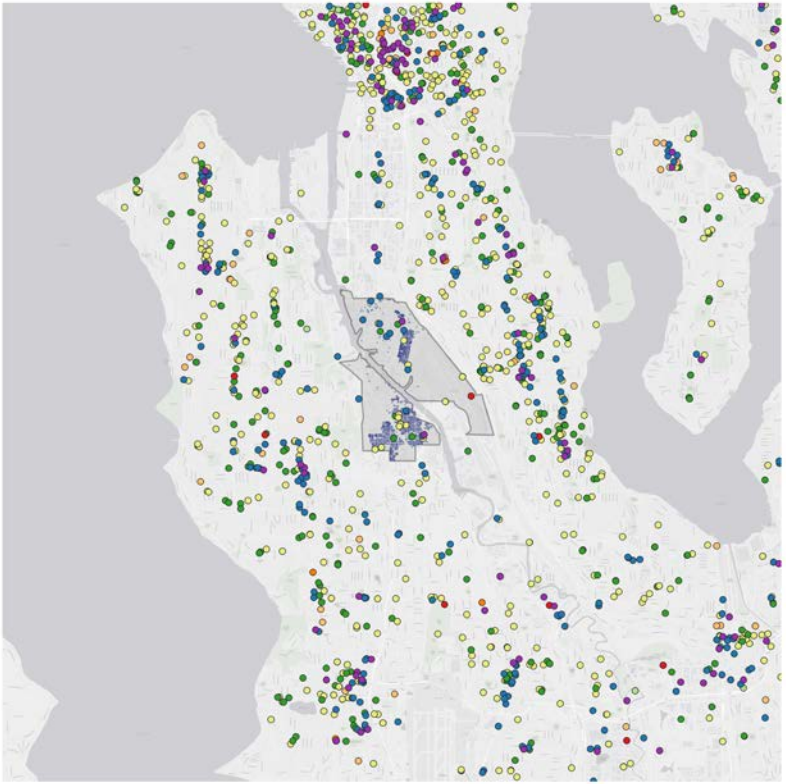
Human Impacts Analysis: Service Impacts

- Service Impact Metrics

How much does service access decrease for households during power outages?

1. What kinds of services do households need?
2. Where do households access those services?
3. How much service access does each feeder provide?
4. Which households lose the most service access during outages?
5. Which investments protect the most access for the most households?

Human Impacts Analysis: Seattle



Where do households access services in the Duwamish Valley?

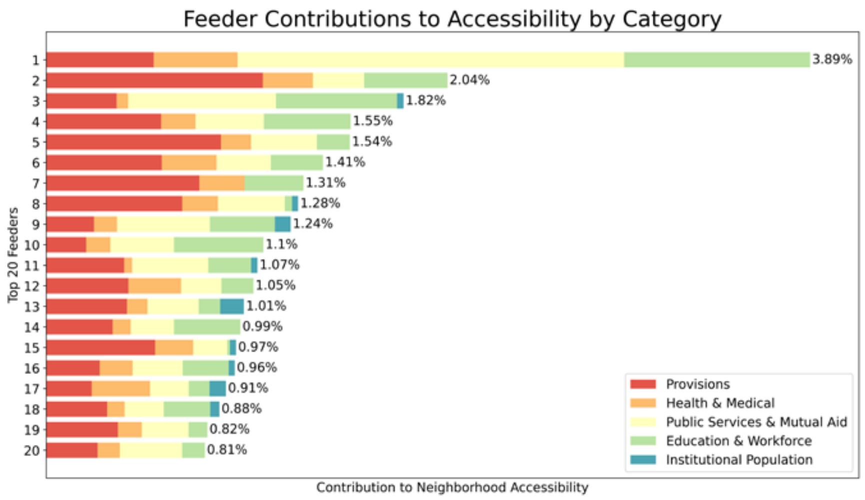
Service Categories

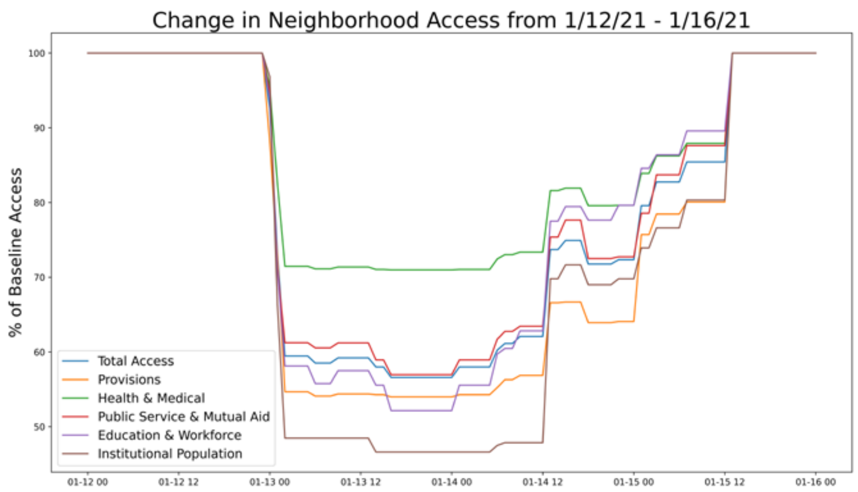
- **Provisions**
- **Health & Medical**
- **Public Services & Emergency Aid**
- **Education & Workforce**
- **Institutional Population**

- Provisions, Health & Medical
- Health & Medical, Public Services & Emergency Aid
- Education & Workforce, Institutional Population

Preliminary NREL Analysis

Human Impacts Analysis: Seattle

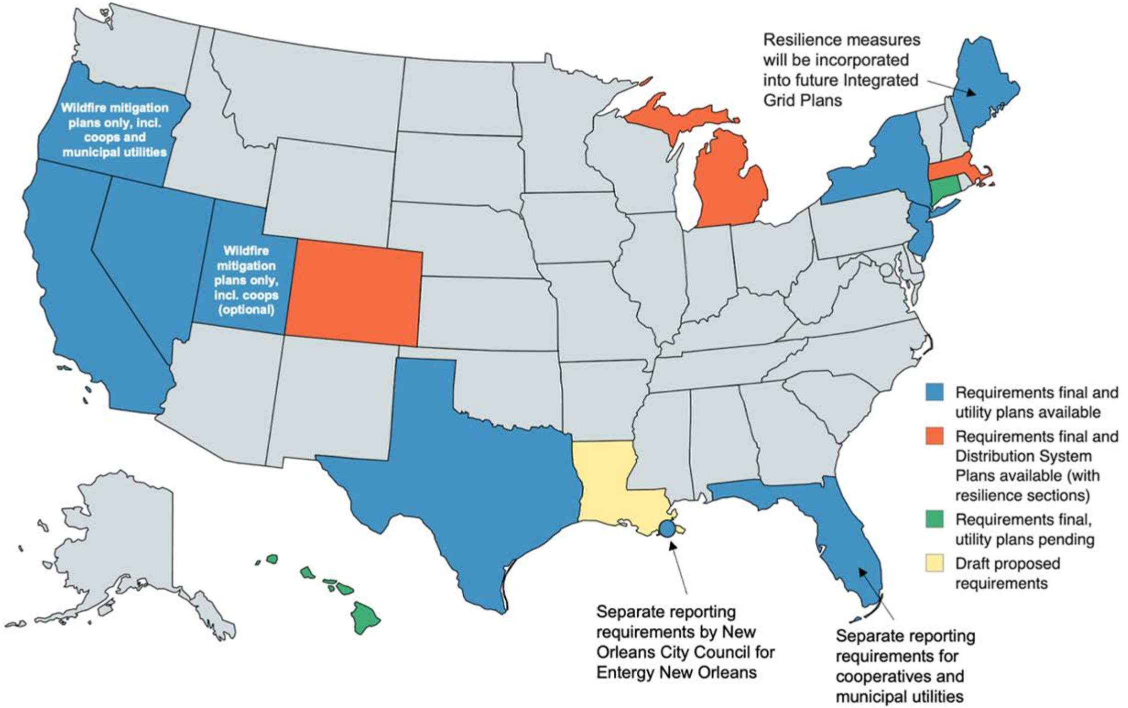




Preliminary NREL Analysis

Current State of the Industry on Distribution Resilience

Resilience Plan Requirements



- Over 30 utilities were required to file one or more resilience plans with regulatory commissions.
  - Applicable to over 47 million customers
- The scope of "resilience plan" is local to utilities or jurisdiction based on hazard in scope.
- Cooperatives and municipal utilities have optional requirements and are less stringent compared to Investor-owned utilities.

- Schellenberg, Josh, and Lisa Schwartz. 2024. "Grid Resilience Plans: State Requirements, Utility Practices, and Utility Plan Template." Energy Markets and Policy, Lawrence Berkeley National Laboratory. URL: https://eta-publications.lbl.gov/sites/default/files/grid_resilience_plans_template_report_20240723.pdf.

Proactive Planning at ConEdison

- Has invested >$1 billion in infrastructure hardening since superstorm Sandy
  - Switchgears on elevated platforms at substations
  - Undergrounding overhead poles and use stronger poles
  - Deployment of smart switches for quick reconfigurations
  - Fly mutual aid workers to use on-site repair trucks
  - Avoided nearly 1.2 million customer interruptions as of Dec 2023

- Incorporate future weather projections into planning practices to prioritize investments.
  - Facilities that can withstand 100-year storm and additional 3 inches of sea level rise

- Anticipate spending more than $5.6 billion in the coming 20 years

- New York State Climate Impacts Assessment. "Con Edison's Resilience Journey: Adaptation Planning for a Changing Climate." URL: https://nysclimateimpacts.org/explore-the-assessment/case-studies/con-edison-resilience-planning/.
- New York State Climate Impacts Assessment. 2022. "Con Edison's Investments and Climate Research Prevent Outages, Protect Customers: 10-Year Sandy Anniversary Update." URL: https://www.coned.com/en/about-us/media-center/news/2022/10-14/con-edisons-investments-and-climate-research-prevent-outages-protect-customers.

Center Point Energy Resilience Plan

- 2026–2028 Resilience plan – larger resilience investments compared to prior plans

- Additional initiative on Greater Houston Resilience Initiative*
  - Distribution poles installation + replacements
  - Installation of grid automated devices
  - Vegetation management with tree trimming
  - Undergrounding
  - Installation of weather monitoring stations

- CenterPoint Energy. 2024. "CenterPoint Energy Systemwide Resiliency Plan." URL: https://www.centerpointenergy.com/en-us/corporate/about-us/system-wide-resiliency-plan.
- CenterPoint Energy. 2024. "Greater Houston Resiliency Initiative Phase One." URL: https://www.centerpointenergy.com/en-us/Corp/Pages/GHRI-Progress-Update.aspx?sa=ho&au=res.

ComEd Risk Adaptation Plans and Resilience Studies

- Risk analysis within ComEd’s service territory in partnership with Argonne National Laboratory
- Research-based studies to explore the viability of energy storage for planning and metric-driven microgrid planning
- Bronzeville Community Microgrid (pilot)
  - Serves about 1000 customers with 7MW of aggregated load
  - Includes DER technologies such as solar PV and energy storage
- The regulatory order requires ComEd to quantify the benefits of the microgrid deployment.

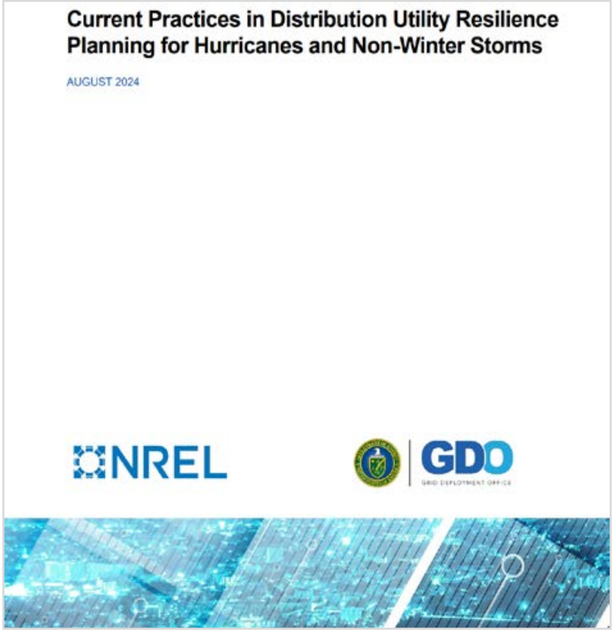
- Aleksi Paaso, “ComEd’s Advanced Distribution System Planning,” Commonwealth Edison. Feb. 2020. [Online] Available at: https://tinyurl.com/58a78fkf.
- R. Burg, R. Kartheiser, et al. 2022. “ComEd Climate Risk and Adaptation Outlook, Phase 1: Temperature, Heat Index, and Average Wind.” Commonwealth Edison and Argonne National Laboratory. URL https://publications.anl.gov/anlpubs/2022/12/180058.pdf.

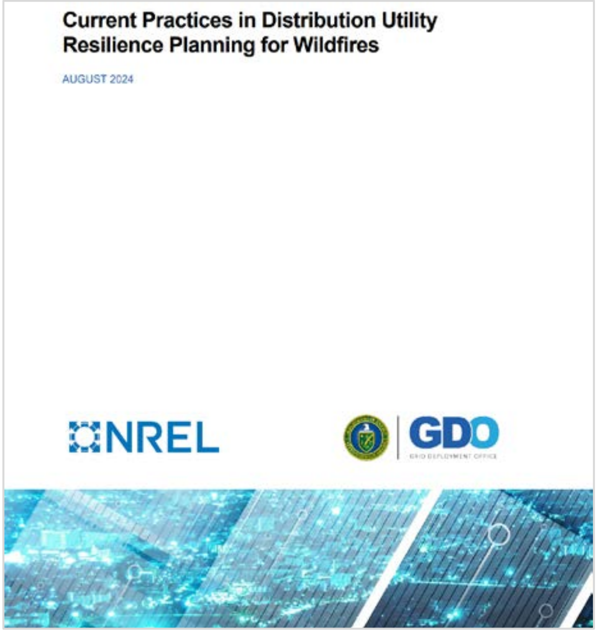
Wildfire Mitigation Plans

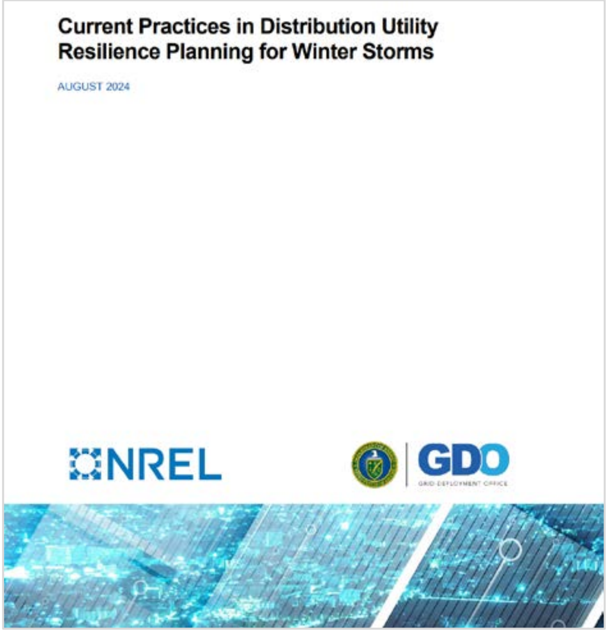
- Xcel Energy, Colorado
  - Forward looking analysis through wildfire risk spread modeling software
  - Has installed 28 Wildfire detection cameras with artificial intelligence technology as of July 2024
  - Use of high-resolution satellite imagery to enhance vegetation management
- Pacific Gas and Electric, California
  - Wildfire cameras and asset inspections through wildfire distribution risk modeling and use of machine learning methods
  - Enhanced Powerline Safety Settings and Downed Conductor Detection
  - 10,000-mile distribution undergrounding program

- "Xcel Energy's AI-powered cameras aid in Bear Creek Fire containment," Xcel Energy. Jul. 2024. [Online]. Available at: https://stories.xcelenergy.com/stories/Xcel-Energy-s-AI-powered-cameras-aid-in-Bear-Creek-Fire-containment
- "Wildfire Mitigation Plan 2023 Annual Report," Xcel Energy (Public Service Company of Colorado). May 2024. [Online]. Available at: https://www.xcelenergy.com/staticfiles/xe-responsive/Company/Rates%20&%20Regulations/2023-Wildfire-Mitigation-Plan-Annual-Report.pdf
- "2023 – 2025 Wildfire Mitigation Plan R 5," Pacific Gas & Electric. Apr. 2024. [Online]. Available at: https://www.pge.com/assets/pge/docs/outages-and-safety/outage-preparedness-and-support/pge-wmp-r5-040224.pdf

Current Utility Practices for Natural Hazard Management







- Keen, Jeremy, Reiko Matsuda-Dunn, Gayathri Krishnamoorthy, Haley Clapper, Lila Perkins, Laura Leddy, and Nick Grue. Current Practices in Distribution Utility Resilience Planning for Hurricanes and Non-Winter Storms. No. NREL/TP-6A40-88591. National Renewable Energy Laboratory (NREL), Golden, CO (United States), 2024.
- Keen, Jeremy, Reiko Matsuda-Dunn, Gayathri Krishnamoorthy, Haley Clapper, Lila Perkins, Laura Leddy, and Nick Grue. Current Practices in Distribution Utility Resilience Planning for Wildfires. No. NREL/TP-6A40-88589. National Renewable Energy Laboratory (NREL), Golden, CO (United States), 2024.
- Keen, Jeremy, Reiko Matsuda-Dunn, Gayathri Krishnamoorthy, Haley Clapper, Lila Perkins, Laura Leddy, and Nick Grue. Current Practices in Distribution Utility Resilience Planning for Winter Storms. No. NREL/TP-6A40-88974. National Renewable Energy Laboratory (NREL), Golden, CO (United States), 2024.

Q&A + Discussion

Thank You

www.nrel.gov

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