Integrating Resilience Planning with Distribution System Planning

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National Association of State Utility Consumer Advocates Webinar

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Today's webinar

- We'll discuss preliminary findings of an upcoming Berkeley Lab report.
  - Objectives, scope, and background
  - Typology and framework
  - Utility practices
  - Pole hardening and microgrid case studies
  - Review of emerging practices

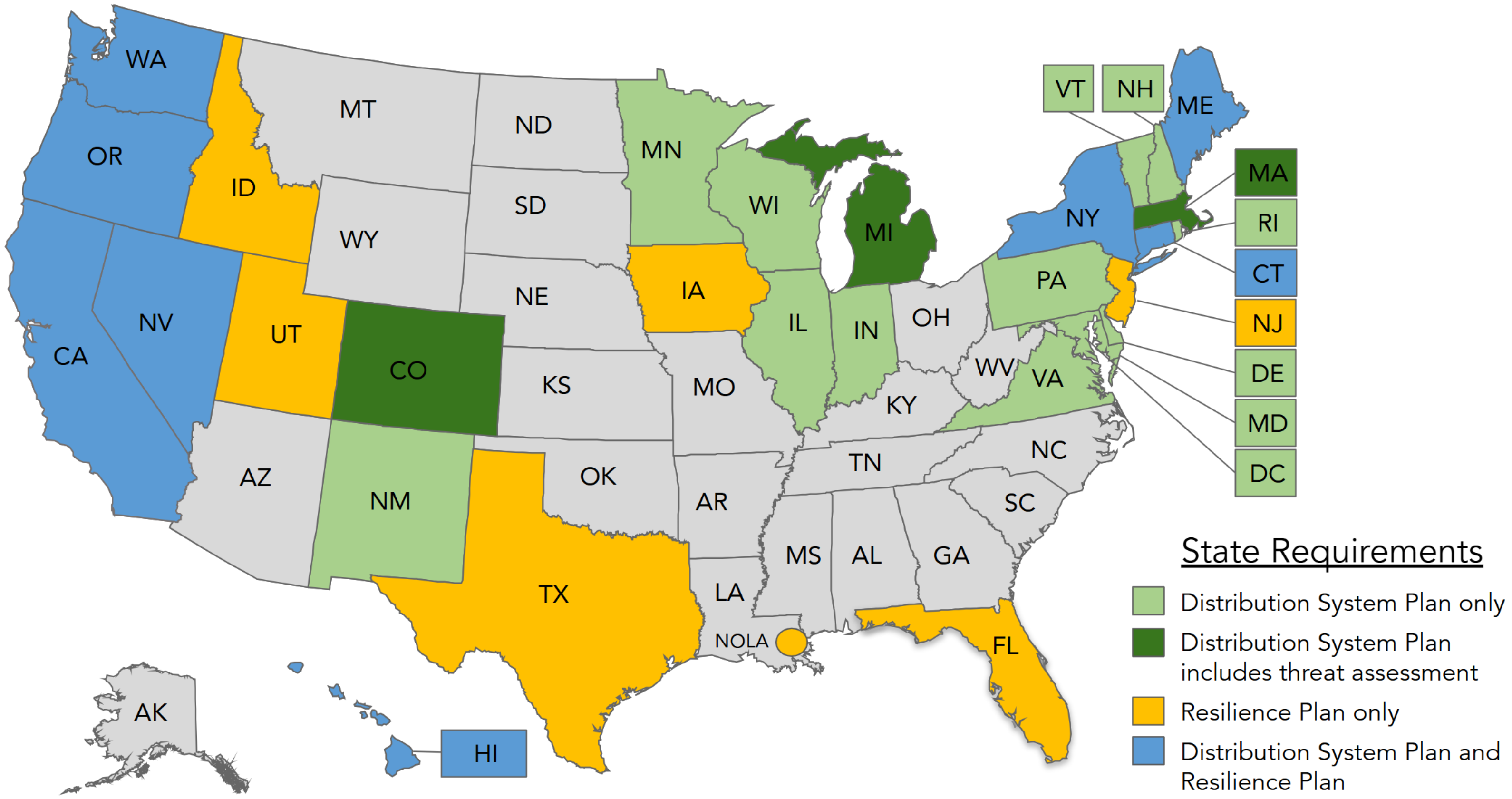
Objectives and Scope

- States and utilities are aiming to improve resilience to threats posed to electricity grids — including distribution systems — from severe weather, earthquakes, and physical threats.
- Resilience and distribution system planning are largely siloed, and methodologies for these planning processes may not align.
- Utilities are exploring different methods for identifying, prioritizing, and optimizing resilience investments with other investments that achieve other objectives.

- Objective: This study assesses current state and utility practices, identifies leading practices, and provides considerations for integrating resilience planning into distribution system planning (DSP).

State Requirements for Distribution System and Resilience Planning

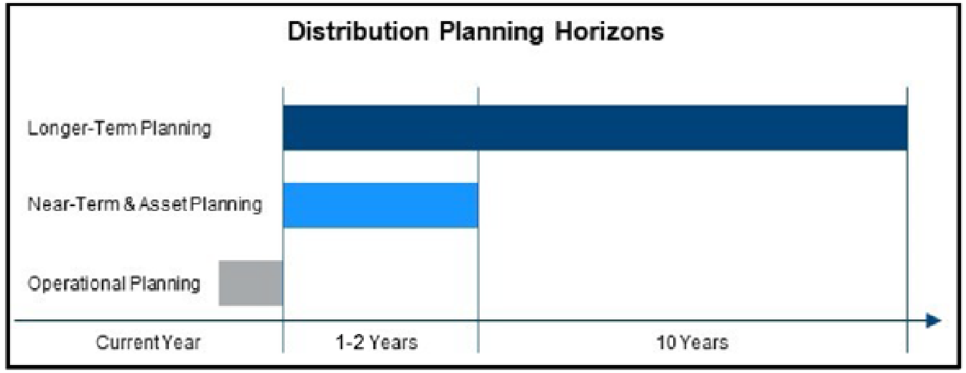
- A growing number of states are establishing requirements for electric utilities to file distribution system plans and grid resilience plans.
- Types of distribution system plans
  - Distribution improvement plans, grid modernization plans, grid edge resource (GER) plans, and integrated distribution plans
- Types of resilience plans
  - Vulnerability assessments (multiple hazards), resilience plans, wildfire mitigation plans, and storm prevention plans



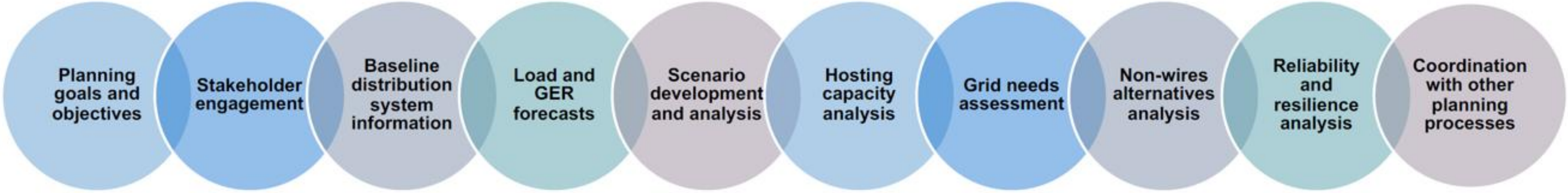
Distribution System Planning Overview

DSP "focuses on designing, managing, and maintaining lower-voltage networks that connect end users to the larger power system" (ESIG, 2025)

- DSP assesses any physical and operational changes needed to maintain safe and reliable service on the local grid
- Annual DSP covers a 1- or 2-year planning horizon
  - Identifies and defines distribution system needs
  - Identifies and assesses possible solutions
  - Selects projects to meet system needs
- DSP includes a long-term utility capital plan
- Includes solutions and cost estimates, typically over a 5- to 10-year horizon

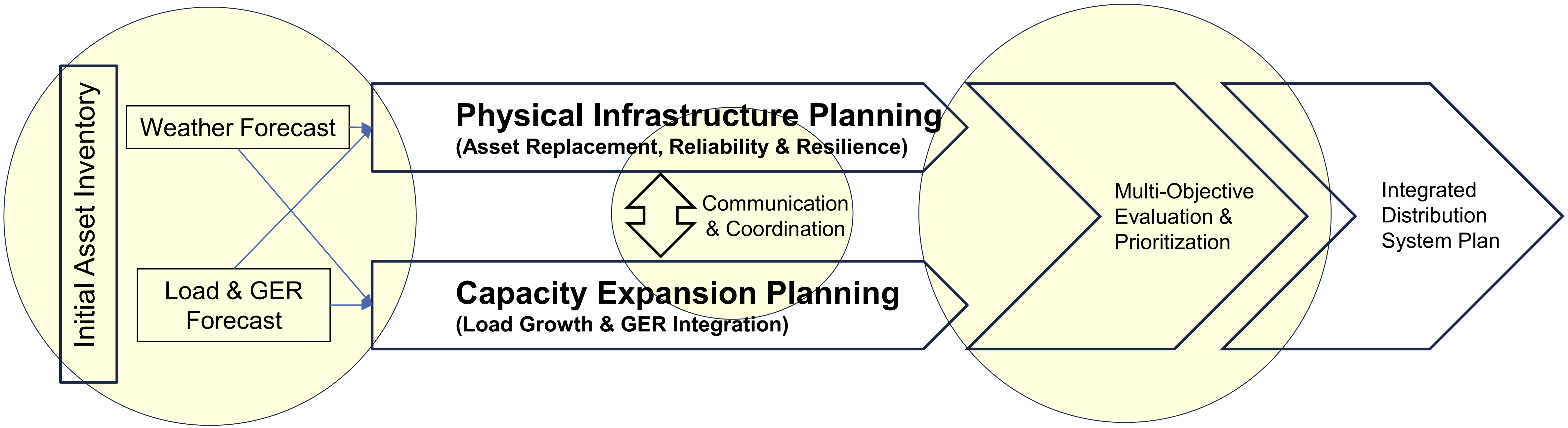


DSP components



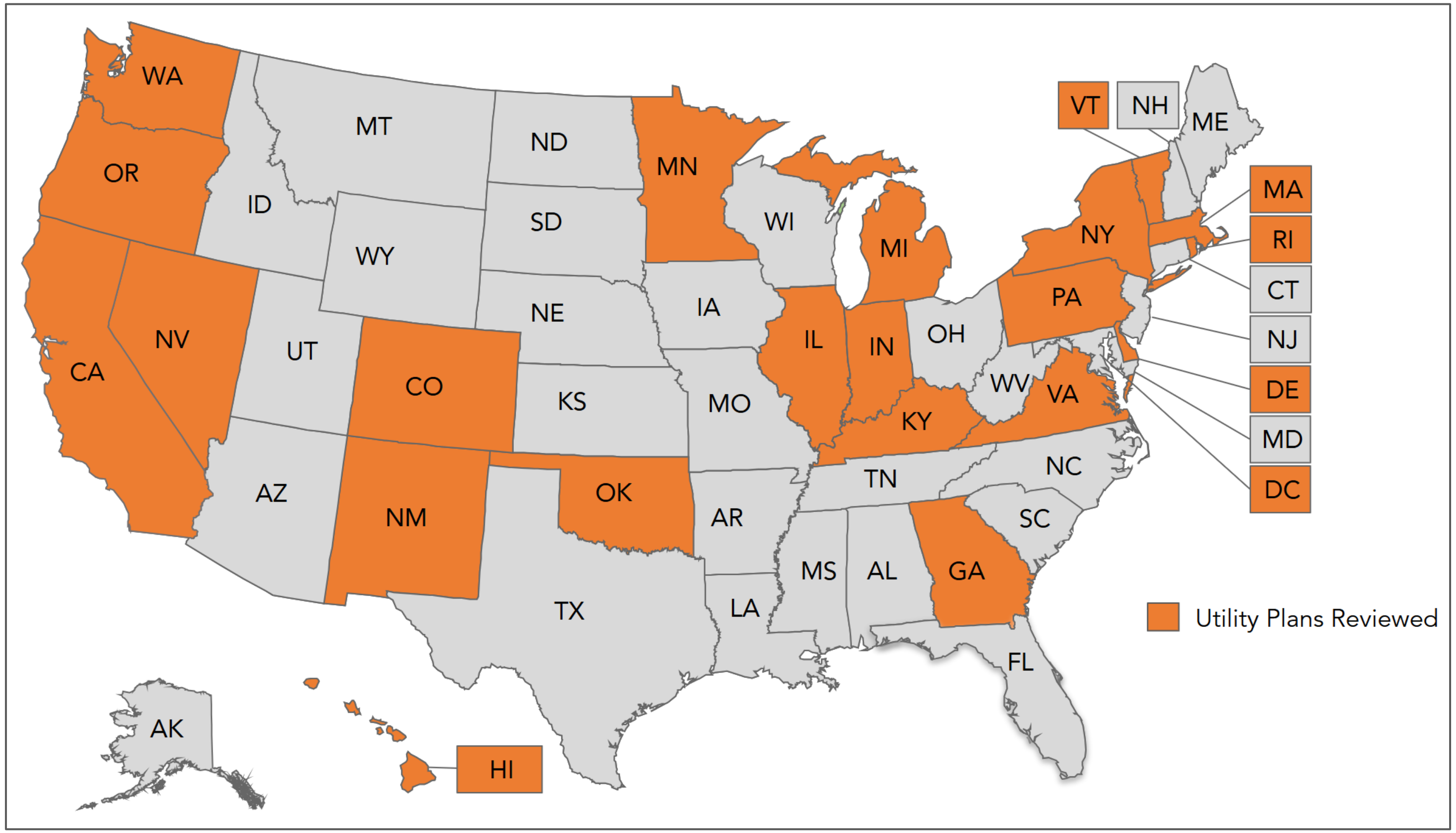
Source: DOE (2020), LBNL (2025)

High-Level Resilient Integrated DSP Process



Distribution System Plans Reviewed

- Initial review covered distribution system plans by 50 utilities (see map)
- Deep-dive review focused on 21 plans in 16 jurisdictions (CA, CO, DC, GA, HI, IL, IN, KY, MA, MI, MN, NY, OK, OR, PA, VA) to hone typology and draw examples of utility practices



Distribution System Plans – Deep-Dive Review

State	Plan Name	Utility Plans Reviewed
California	Grid Needs Assessment, Distribution Deferral Opportunity Report	Southern California Edison (SCE) (2024)
		Pacific Gas & Electric (PG&E) (2024)
Colorado	Distribution System Plan	Xcel Energy CO (2024)
Georgia	Rate case filing	Georgia Power (2022)
Hawaii	Integrated Grid Plan	Hawaiian Electric Company (HECO) (2023)
Illinois	Multi-Year Integrated Grid Plan	Ameren (2024)
		Commonwealth Edison (ComEd) (2024)
Indiana	6-Year Electric Plan	Duke Energy (2024)
Kentucky	Rate case filing	Louisville Gas & Electric and Kentucky Utilities Company (LG&E and KU) (2025)
Massachusetts	Electric Sector Modernization Plan	Eversource (2024)
Michigan	Distribution Grid Plan	DTE Electric (2023)
	Electric Distribution Infrastructure Investment Plan ("EDIIP")	Consumers Energy (2023)
Minnesota	Integrated Distribution Plan	Xcel Energy MN (2023)
New York	Distributed System Implementation Plan	Consolidated Edison (ConEd) (2023)
Oklahoma	Rate case filing	Oklahoma Gas & Electric (OG&E) (2021)
Oregon	Distribution System Plan	Portland General Electric (PGE) (2024)
Pennsylvania	Distribution System Plan	UGI Utilities (UGI) (2024)
	Long-Term Infrastructure Improvement Plan	PECO Energy Company (PECO) (2024)
Virginia	Integrated Resource Plan	Dominion (2024) - Part 1/2 and Part 2/2
		Appalachian (2022) - Part 1/3, Part 2/3, and Part 3/3
Washington, DC	Annual Consolidated Report	Pepco (2025)

State Regulatory Settings

- Technical documents providing rationale for grid resilience expenditures are filed in planning proceedings (DSP or resilience related) and/or submitted in rate case testimony.

	Rate Case	Planning Proceeding
Primary focus	Financial, focused on determining utility's revenue requirement and setting retail rates	Strategic and technical, focused on utility plans to build and how it plans to operate the grid
Time horizon	Near-term – spending over the next 3 to 4 years to recover capital investments already completed or planned	Also includes long-term plan – details of infrastructure needs over next 5 to 10+ years
Metric of success	Determination that costs were prudently incurred	Ability of plan to achieve utility and state objectives
Outcome	Order setting authorized revenue requirement and tariffs	Accepted or approved strategy document that guides future investment decisions; supports revenue requested in subsequent rate case(s) for related projects

Typology and Framework

Framework for Integrating Distribution and Resilience Planning

Typology Component	Description
Strategy Process	Explain how resilience fits into utility strategic planning process.
Data	Ensure consistency between data for resilience planning and other DSP analyses.
Threat Assessments	Conduct vulnerability or risk assessment of distribution system assets, operations, and processes.
Solution Identification and Prioritization	Identify and prioritize potential solutions to mitigate threat risk.
Consideration of Other Grid Needs	Determine investment plan and implementation process to efficiently address multiple grid needs.
Metrics	Measure performance of investments to improve resilience.

Levels of Integration – Distribution and Resilience Plans*

Stated Plans for Future Integration	Enhanced Reliability Analysis	Resilience Integration in Distribution System Plans
• Distribution system plans mention or discuss utility efforts to integrate resilience planning in the future	• Distribution system plans address major event days (MEDs) by leveraging methods for resilience threat analysis • Utility uses worst performing circuits and root cause analyses for assessing circuits, but also incorporates data from extreme events	• Distribution system plans incorporate long-term resilience planning components

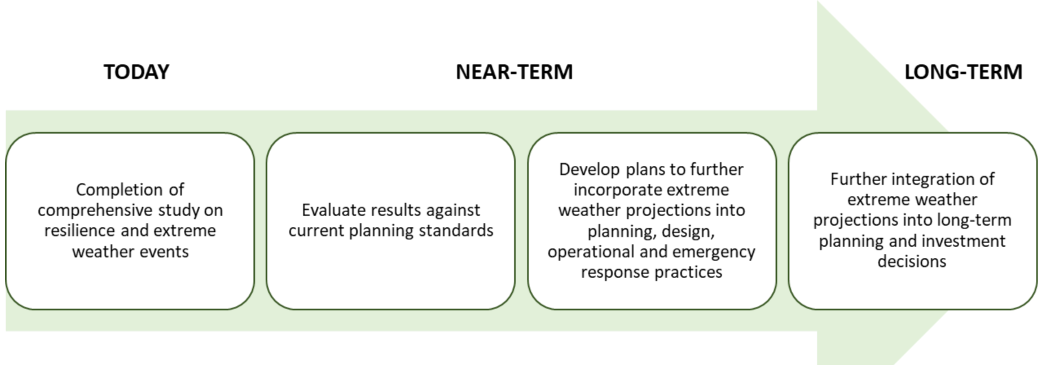
*Applies to Threat Assessments, Solution Identification and Prioritization, Consideration of Other Grid Needs, and Metrics (not all levels are relevant to all of these categories)

Utility Practices

Strategy Process

Explain how resilience fits into utility strategic planning process.

- Virtually all of the 50 DSPs we reviewed mentioned resilience as an objective.
  - Including resilience to wildfire, extreme weather, earthquakes, and physical and cyber[1] threats
- Some plans mention integration of resilience into existing DSP processes as an objective.



Adapted from Xcel Energy CO (2024)

"Fundamentally, this Plan is based on the understanding that the elements of distribution planning are related to the core objectives of meeting customer needs through a safer, more reliable, and resilient energy grid." (Indiana & Michigan Power, 2024)

"Our investments in our distribution system are focused on … preparing for new and increased loads [and] maintaining and enhancing reliability and resilience…." (Northern States Power Co., 2024)

"Integrated planning across the electric and gas networks and the T&D systems will be critical to effective and accurate business planning that ensures reliability, resiliency, and affordability during this transformation." (Niagara Mohawk, 2023)

[1] Cybersecurity is not included in DSPs given the sensitivity of the data and is not in scope for this study.

Data

Ensure consistency between data for resilience planning and other DSP analyses.

- Data for projections
  - Downscaled climate projections
  - Scenarios
  - Hazard data
- Data collection for situational awareness
  - Measure and monitor
    - Detection / weather
    - Light Detection and Ranging (LiDAR) for vegetation management
    - Drone tech in conjunction with sensing capabilities
  - Restoration effectiveness

Data for Projections

- Downscaled climate projections and scenarios inform threat assessments and can feed into other aspects of DSP, such as load forecasting.
  - Downscaled climate projections are translated from the coarse resolution of global climate models to a finer, more regional or local scale.
  - A scenario is a self-consistent description of a potential future state used to assess investment decisions against a range of possible future conditions and uncertainties.

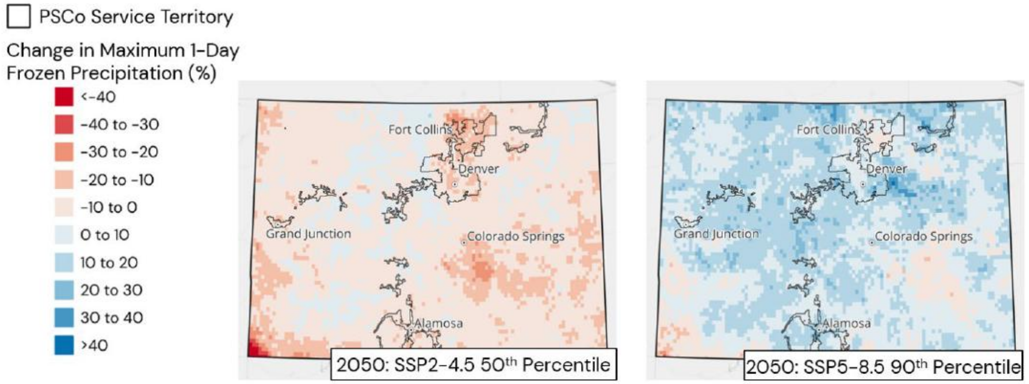
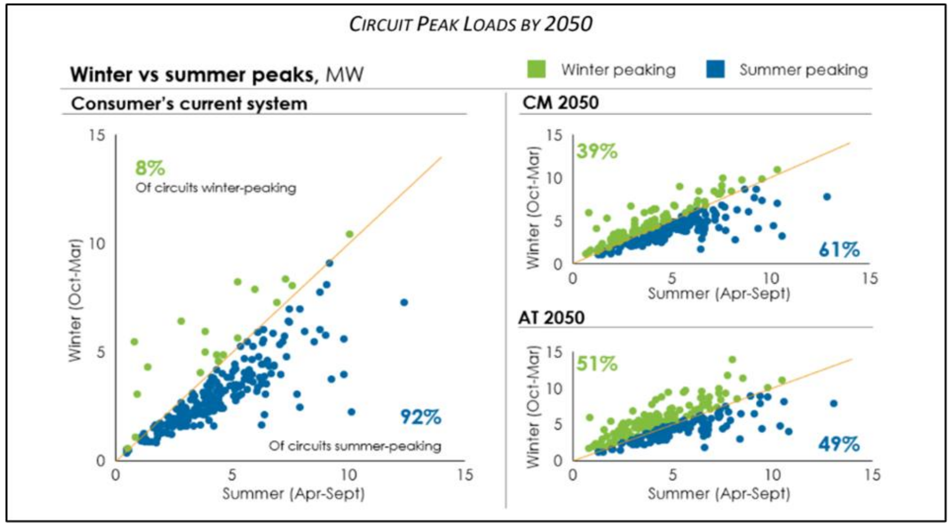


Figure 17. Projected percent change in the maximum 1-day frozen precipitation amounts by 2050 across the PSCo service territory.

Source: Xcel Energy CO (2024)



Source: Consumers Energy (2023)

Data Collection for Situational Awareness

- Measure and monitor
  - LiDAR for vegetation management and wildfire mitigation (ComEd, DTE, Rhode Island Energy, PGE)
  - Drones in conjunction with sensing technology for inspection and data collection related to asset management, maintenance, and system assessment (Consumers Energy, Xcel Energy MN, ComEd, Ameren, Indiana & Michigan Power)
- Restoration effectiveness
  - Advanced Metering Infrastructure to remotely ping meters during major outage events to verify whether customers have regained power, eliminating the need for manual verification through customer calls or truck dispatches

IMAGERY FROM DRONE INSPECTION COMPARED TO VISUAL GROUND INSPECTION

Source: Consumers Energy (2023)

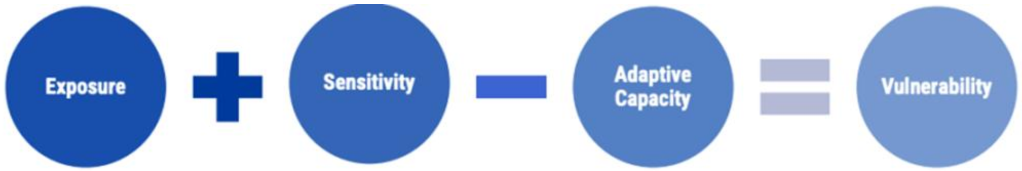
Drone Image from Aerial Inspection

Source: Xcel Energy MN (2024)

Threat Assessments

Conduct vulnerability or risk assessment of distribution system assets, operations, and processes.

- Vulnerability assessments are evaluations of the susceptibility of systems, communities, assets, and processes to potential harm from identified hazards.
- Risk assessments use vulnerability as an input and incorporate the potential consequences of a hazard event.
- Vulnerability and risk assessments may include the following elements:
  - *Hazard characterization* – Hazard analysis relative to infrastructure and process areas
  - *Exposure* – Degree to which utility assets could face a given hazard, based on asset location and climate information (historical, projected)
  - *Sensitivity* – Degree to which availability or performance of an asset could be affected by exposure to climate hazards
  - *Consequence* – Estimated magnitude of negative outcomes if an asset faces negative impacts to availability or performance
- Vulnerability assessments also may take into account community sensitivity and adaptive capacity.



Source: City of Seattle (2023)

RG&E and NYSEG Vulnerability Rating Rubric

Consequence \ Sensitivity	(Low)	(Medium)	(High)	(N/A)
(Low)	Low	Low	Medium	N/A
(Medium)	Low	Medium	High	N/A
(High)	Medium	High	High	N/A

RG&E and NYSEG Transmission Asset Vulnerability Ratings

Asset \ Hazard	Temperature	Precipitation	Flooding	Wind	Wind & Ice
Line Structures (Poles/towers)	N/A	N/A	High*	High	High
Conductors (Overhead)	Medium	Low	N/A	Medium	High
Conductors (Underground)	Medium	N/A	Medium	N/A	N/A
Open-Air Current-Carrying components	Medium	Low	N/A	Low	Medium
Priority Vulnerability	No	No	No	Yes	Yes

Source: Avangrid (NYSEG & RG&E) (2023)

Threat Assessments

Stated Plans for Future Integration | Enhanced Reliability Analysis | Resilience Integration in Distribution System Plans

- Utilities can indicate plans to conduct threat assessments and integrate them into future planning processes.
- Example: Ameren's Multi-Year Integrated Grid Plan
  - Using a third-party industry expert to analyze impacts of natural hazards, such as wildfire, flooding, and ice storms
  - Will incorporate threat assessment results into project selection and prioritization

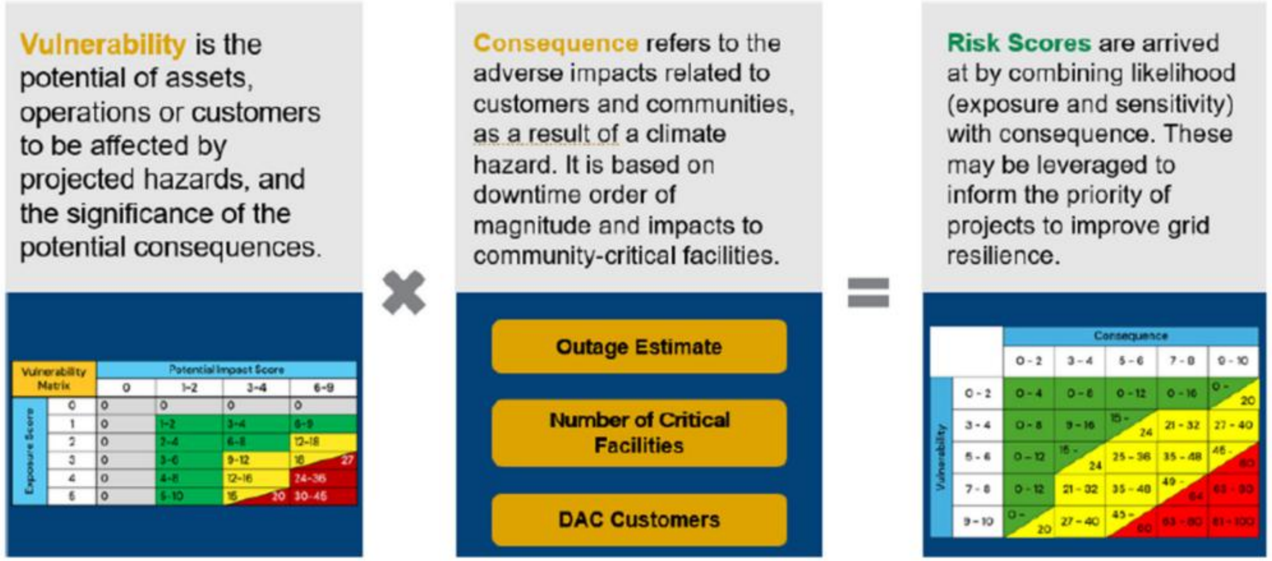
Stated Plans for Future Integration | **Enhanced Reliability Analysis** | Resilience Integration in Distribution System Plans

- Utilities can analyze worst performing circuits using reliability data focusing on major storms and/or major event days.
- Examples:
  - Tampa Electric considers performance for both extreme weather and blue-sky days (TEC, 2022).
  - ConEd computes a Network Reliability Index for selecting worst-performing circuits for sectionalization in its Primary Feeder Resiliency program, which aims to mitigate risks associated with projections of increases in extreme heat events (ConEd, 2023b).

Threat Assessments

Stated Plans for Future Integration | Enhanced Reliability Analysis | Resilience Integration in Distribution System Plans

- Some risk assessments are more quantitative and can yield a risk score
- DSPs and resilience plans reflect different types of risk (e.g., wildfire ignition, power interruption, flooding, extreme heat or cold)
- Example: Xcel Energy CO



Substation Transformer	Heat Risk Score (out of 100)	Flood Risk Score (out of 100)
Bt.	8.3	6.9
B.C.	0	0
B.T.	7.7	0
C.	13.9	22.3
Ch.	1.0	0
E.	12.0	19.6
Ed.	14.0	0
F.	0.4	0
G.	3.2	0
M.	11.7	0
Me.	1.2	0
R.	7.7	0

Source: Xcel Energy CO (2024)

Threat Assessments

Stated Plans for Future Integration | Enhanced Reliability Analysis | **Resilience Integration in Distribution System Plans**

- Vulnerability assessments examine the impact of threats to utility operations and processes – in addition to physical grid assets
- Examples:
  - Duke Energy resilience and adaptation report includes a risk score for various process areas related to DSP, such as load forecasting and capacity planning (see upper figure).
  - National Grid assesses distribution operations and planning functions across various threats. It finds that high temperatures have a potential impact on load forecasting and capacity planning (see lower figure).

Table 3. 2050 projected vulnerability priority ratings for asset and operations planning groups.

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

Source: Duke Energy (2023)

Table 15. Identified climate hazards with potential impacts on operations and planning functions

OPERATIONS AND PLANNING FUNCTIONS	High Temperature	High Winds	Inland Flooding	Ice
Emergency Response	✓	✓	✓	✓
Vegetation Management		✓	✓	✓
Workforce Safety and Methods	✓	✓	✓	✓
Reliability Planning	✓	✓	✓	✓
Load Forecasting	✓			
Capacity Planning	✓			

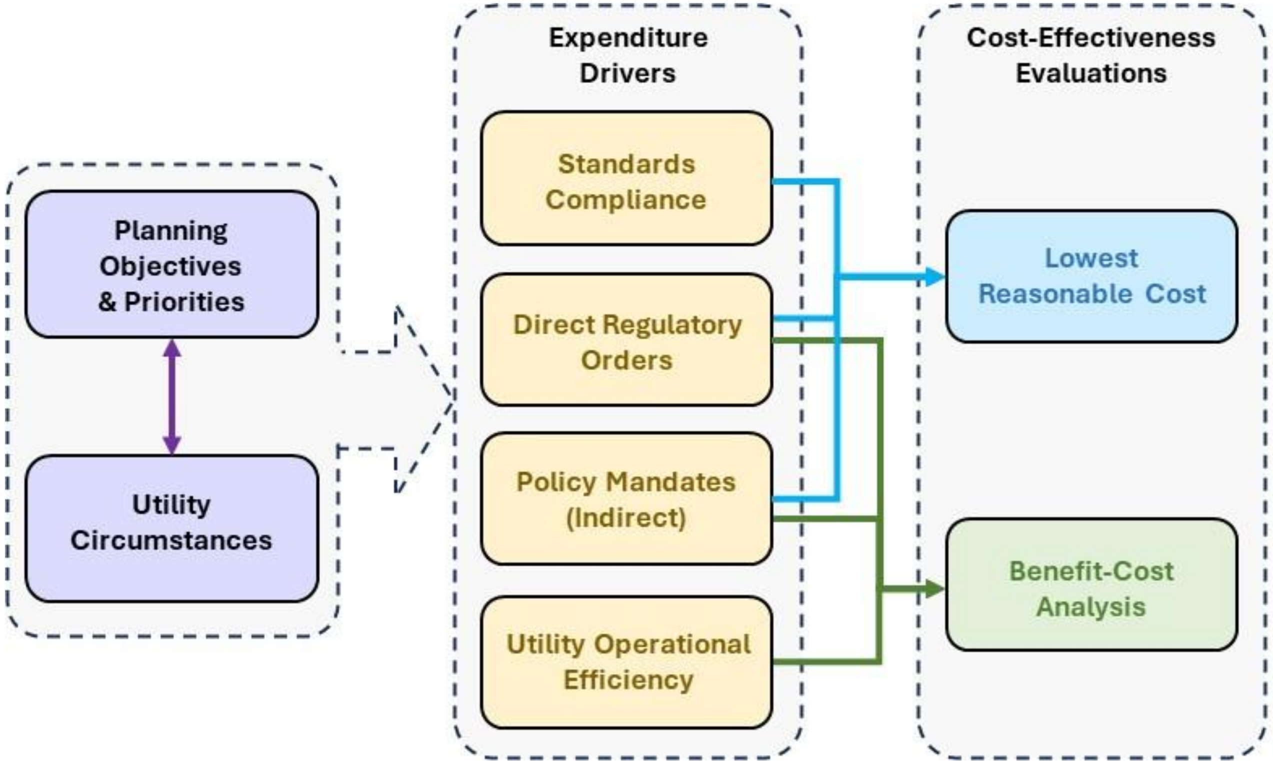
Source: National Grid (2023)

Solution Identification and Prioritization

Identify and prioritize potential solutions to mitigate threat risk.

DSP leverages various analytical methods to support decision making for grid investments.

- Lowest reasonable cost
- Benefit-cost analysis (BCA)
- Risk spend efficiency (RSE)
- Value spend efficiency (VSE)



De Martini et al. 2025

Solution Identification and Prioritization

Stated Plans for Future Integration	Enhanced Reliability Analysis	Resilience Integration in Distribution System Plans

- Hawaiian Electric
  - 2023 Integrated Grid Plan outlines future resilience planning efforts beyond its current "no-regrets" hardening investments
  - Utility acknowledges that it lacks formal resilience valuation methods and plans to guide future system hardening efforts by defined metrics and BCA once it determines resilience performance targets and adopts quantitative decision-making tools.
- Consolidated Edison
  - Investment prioritization is influenced by risk scores, but the utility does not yet have a set methodology for comparing resilience investments.

IEEE Utility Integrated Planning Task Force aims to "develop industry consensus value frameworks and models to support utilities in integrated planning and investment decision-making processes"

Solution Identification and Prioritization

Stated Plans for Future Integration	Enhanced Reliability Analysis	Resilience Integration in Distribution System Plans

Eversource

- Investigated outage data during major storms in past 4 years
- Methodology prioritizes highest criticality events (many customers impacted, multiple events, and long duration events)
- Root cause analysis
  - From 2019-2022, 25% of major event customer minutes interrupted (CMI) were related to reclosers and breakers' operations
- Solutions
  - Impacted zones grouped in 3 tiers of criticality
  - Highest criticality items paired with highest impact solutions
  - Impact of resilience mitigation quantified as impact on all-in SAIDI

SAIDI improvements (%) and per mile costs of each resilience mitigation

Tier	Criteria	Measure	All-in SAIDI Improvement	Cost ($M/mile)
I	Impacted zones with 300,000 or more CMI per event on average	Undergrounding	98%	4
II	Impacted zones with less than 300,000 and more than 150,000 CMI per event on average	Aerial Cable	82%	2.2
III	Impacted zones with less than 150,000 average CMI per event—with bare wire	Bare wire to tree wire conversion	50%	1.1
	Impacted zones with less than 150,000 average CMI per event—with insulated wire	Resilience Tree Work (RTW)	35%	0.1

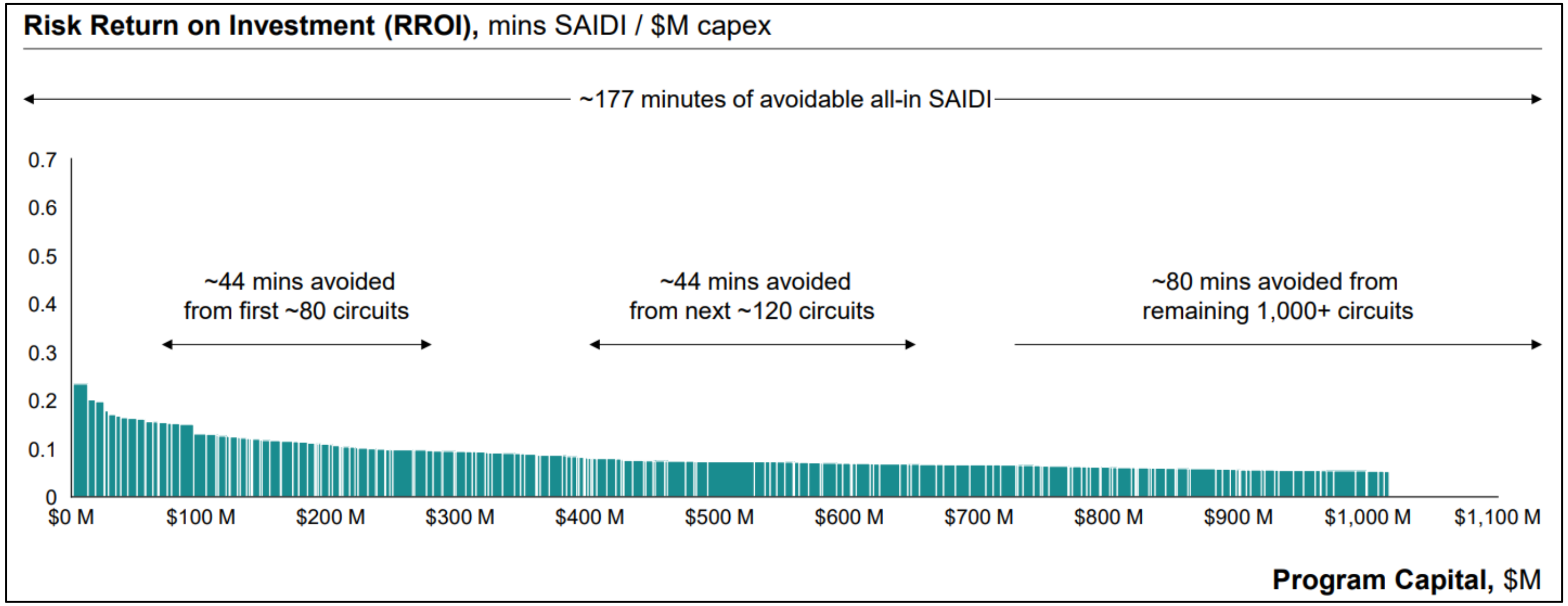
Source: Eversource (2024)

Solution Identification and Prioritization – Risk Return on Investment

Stated Plans for Future Integration	Enhanced Reliability Analysis	Resilience Integration in Distribution System Plans

Louisville Gas & Electric and Kentucky Utilities

- Solution portfolio developed by ordering solutions from highest to lowest risk return on investment and establishing resilience performance targets



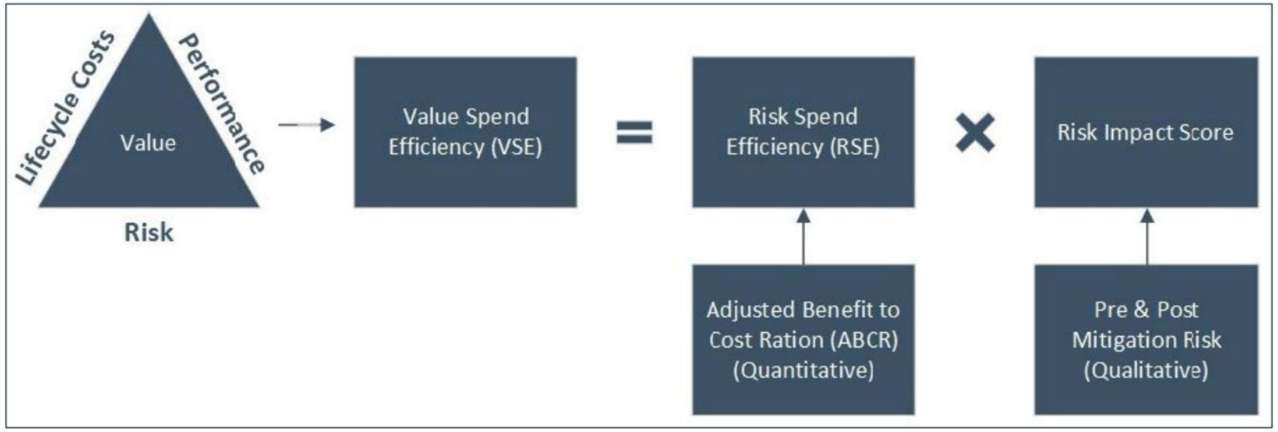
Source: LG&E and KU (2025)

Solution Identification and Prioritization – Value Spend Efficiency

Stated Plans for Future Integration	Enhanced Reliability Analysis	Resilience Integration in Distribution System Plans

Portland General Electric (PGE)

- DSP includes a section referring to the utility's Wildfire Mitigation Plan (WMP), where PGE employs a VSE approach to compare pre- and post-mitigation wildfire risk, considering additional difficult-to-monetize qualitative impacts
- DSP refers to utility's approach to optimizing cost-effectiveness of ignition risk mitigation (detailed in WMP)
- PGE uses VSE to prioritize investments that achieve the greatest benefit per dollar spent across programs such as vegetation management, system hardening, Public Safety Power Shutoffs
- VSE framework builds on RSE approach in the WMP by incorporating additional Risk Impact Scores associated with difficult-to-monetize qualitative impacts, such as wildfire impacts on watersheds



PGE's Value Spend Efficiency model

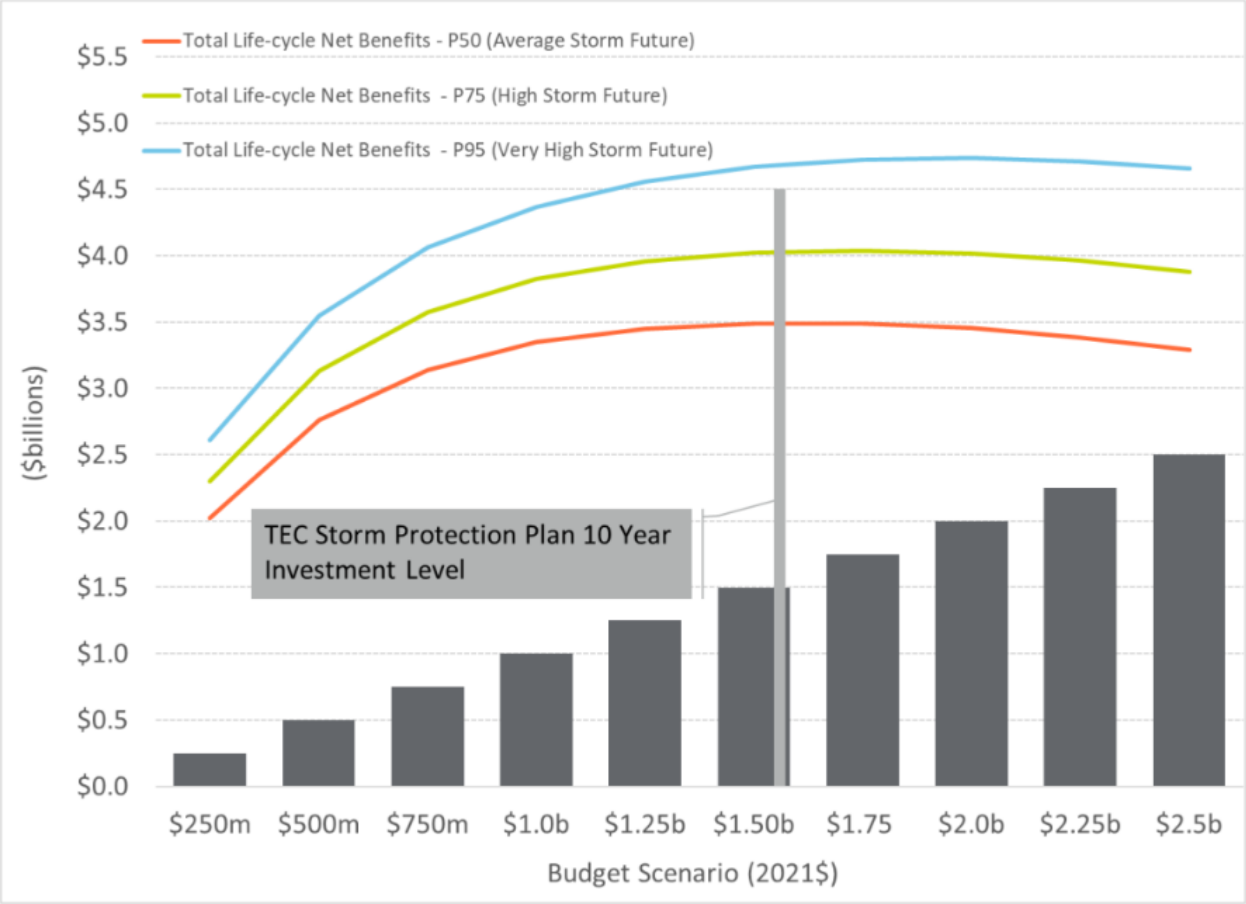
Source: [PGE Wildfire Mitigation Plan (2024)]

Solution Identification and Prioritization – BCA

Stated Plans for Future Integration	Enhanced Reliability Analysis	Resilience Integration in Distribution System Plans

Tampa Electric Company (TEC)

- Prioritized its 800 distribution circuits based on reliability performance and priority customer count to identify target circuits for improvement using benefit-cost ratio (BCR)
- Reliability performance assessed for both extreme weather and blue-sky days
  - Higher weighting factor assigned to performance under extreme weather conditions
- Resilience benefits
  - CMI 50-year benefit
  - Restoration cost 50-year NPV benefit
- Scenarios (weighted to favor extreme weather)
  - Average Storm Future
  - High Storm Future
  - Extreme Storm Future



Source: TEC (2022)

Consideration of Other Grid Needs

Determine investment plan and implementation process to efficiently address multiple grid needs.

- DSP considers multiple grid needs, including capacity expansion (load growth), reliability, resilience, customer resources, and other state objectives
- Timing considerations are important for efficient and successful implementation
  - Supply chain issues, funding and staffing constraints, and specialty equipment and personnel
  - Balancing longer-term, systemic grid needs with immediate reliability and resilience gaps
  - Aligning implementation schedules to satisfy multiple objectives

Consideration of Other Grid Needs

Stated Plans for Future Integration	Enhanced Reliability Analysis	Resilience Integration in Distribution System Plans

- Southern California Edison 2026-28 WMP: When implementing major wildfire mitigation projects, SCE also evaluates whether impacted circuits also need capacity upgrades due to load growth or other factors, completing both efforts together in a coordinated, cost-effective way. (SCE, 2025)
  - Consistent with CPUC decision[*] requiring utilities to submit Advice Letters by the end of 2025 describing their methodology for referencing Distribution Planning Processes when designing projects in other workstreams
- Appalachian Power Company: “…continuing to deliver safe, reliable, and affordable energy in the future power system will require an integrated approach between transmission, distribution, and generation resource planning. … Resilience and safety are enhanced with better visibility over future EV deployment and distributed generation at distribution circuit level to allow the planners to plan for multiple load conditions and increase hosting capacity to integrate more green energy generation.” (APCo, 2022)

[*] D.24-10-030

Consideration of Other Grid Needs

Stated Plans for Future Integration	Enhanced Reliability Analysis	Resilience Integration in Distribution System Plans

DTE Electric – Global Prioritization Model

- Valuing and balancing multiple objectives
- Formal prioritization framework applied consistently across all investments
- Investments receive a score (0–100) across multiple dimensions
  - In most cases, scoring is based on BCR
- SAIDI and SAIFI reduction
- Major event risk mitigation from substation outage events is included as a weighted, quantifiable factor

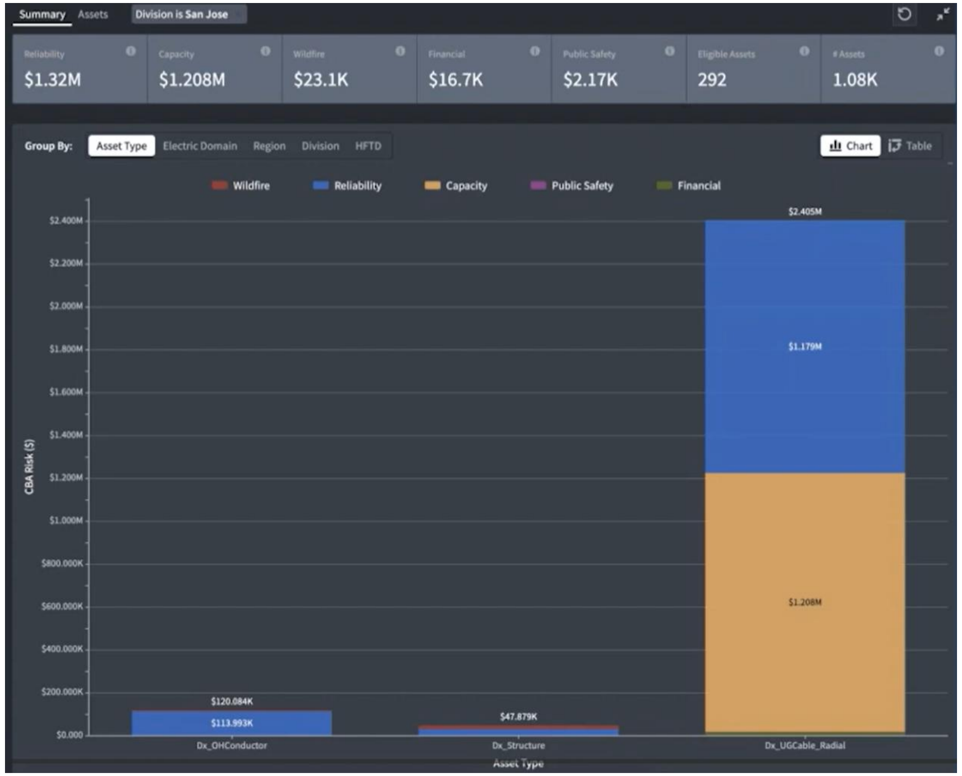
DTE Electric's investment prioritization framework components

Impact Dimension	Drivers	Weight
Reduce Electrical Hazards	• Reduction in wire down events • Reduction in secondary network cable manhole events	3
Overload Relief	• Elimination of overloaded equipment	
SAIDI	• Reduction in duration of outage events	
SAIFI	• Reduction in frequency of outage events	
Regulatory Compliance	• MPSC staff's recommendation (March 30, 2010 report) on utilities' pole inspection program • Docket U-12270 – Service restoration under normal conditions within 8 hours • Docket U-12270 – Service restoration under catastrophic conditions within 60 hours • Docket U-12270 – Service restoration under all conditions within 36 hours • Docket U-12270 – Same circuit repetitive interruption of fewer than five within a 12-month period	2
Major Event Risk	• Reduction in extensive substation outage events that lead to a large amount of stranded load for more than 24 hours	
Capacity Relief	• Elimination of system capacity constraints	
Investment in EJ Communities	• Percent of customers impacted by investment in EJ communities	
O&M Avoidance	• Trouble event reduction and truck roll reduction • Preventive maintenance investment reduction	1
Capital Avoidance	• Trouble event reduction and truck roll reduction • Reduction in capital replacement either during equipment failures or avoided planned capital work	

Source: DTE (2023)

Consideration of Other Grid Needs

Stated Plans for Future Integration	Enhanced Reliability Analysis	Resilience Integration in Distribution System Plans



PG&E's System Needs Analysis Platform for aggregating monetized asset risks

Source: Energy Central webinar

Pacific Gas & Electric

- Prioritizes projects across multiple objectives based on risk scores including wildfire, reliability, capacity, public safety, and financial risks
- Process consolidates and monetizes asset risk data in a common platform across three electric domains (distribution circuits, substations, and transmission lines)
- Risk values normalized and aggregated by asset type, then aggregated at circuit level
- Mapping benefits and costs of multiple grid improvement programs to specific circuits enables utility to manage as a single investment what would otherwise be treated as multiple separate projects

Consideration of Other Grid Needs

Stated Plans for Future Integration	Enhanced Reliability Analysis	Resilience Integration in Distribution System Plans

- Coordination of short-term solution with longer-term capital investments
  - Hawaiian Electric: Using microgrids as near-term resilience solution until longer-term system hardening projects are underway; once hardened assets are in place, microgrids will continue to play a complementary role by addressing residual risks (i.e., reducing outage impacts that may still occur despite system hardening)
  - Dominion: Using microgrids as a near-term resilience solution while longer-term system hardening projects are underway
- Coordinated implementation is more cost-effective
  - DTE: Coordinating near- and long-term hardening solutions by focusing on no-regrets investments that address the oldest infrastructure first; future investments focus on longer-term capacity and other advanced grid needs

Metrics

Measure performance of investments to improve resilience.

- Attribute metrics
  - System characteristics that contribute to or describe aspects of the resilience of a system or community
  - Reflect the ability of the electrical system and its customers to anticipate a hazard, withstand the hazard, adapt to hazard impacts, and recover from the hazard to a normal operating state
- Performance metrics
  - Impacts of resilience investments on system performance—generally, measures of expected or actual reduction of negative impacts from hazard events
  - Measure the effectiveness of resilience investments

Metrics

Stated Plans for Future Integration	Enhanced Reliability Analysis	Resilience Integration in Distribution System Plans

- IEEE 1366-2022 defines reliability indices. Utilities normally calculate and report standard reliability indices annually, aggregating performance over an entire year, and generally exclude MEDs.
  - SAIDI, SAIFI, CAIDI, MAIFI are commonly reported.
  - Less-common metrics focus on impacts to individual customers.
- In contrast, resilience metrics tend to focus on notable events that occur at specific times within a year (e.g., over a day or week).
- Many utilities use traditional reliability metrics and apply them to MEDs for planning purposes.
- Some utilities have separate designations for major events and may apply reliability metrics to these times and locations.

Examples of Reliability Metrics Applied to Major Storms and/or MEDs to Measure Resilience	
Interruption Events	Customer Interruptions
	Customer Minutes Interrupted
Interruption Frequency	System Average Interruption Frequency Index (SAIFI)
	Momentary Average Interruption Frequency Index (MAIFI)*
Interruption Duration	System Average Interruption Duration Index (SAIDI)
	Customer Average Interruption Duration Index (CAIDI)*
	Percent of interruptions lasting longer than X hours
Customer-Focused	Customers Experiencing Multiple Interruptions ($CEMI_n$)
	Customers Experiencing Long Interruption Durations (CELID)

**MAIFI and CAIDI are less common for applying to major events to measure resilience. These events generally result in interruptions that are longer than 5 minutes (the cutoff for "momentary" interruptions) and which have a distribution with a long tail to the right, making CAIDI less useful as a measure of average interruption duration.*

Metrics

Stated Plans for Future Integration | Enhanced Reliability Analysis | Resilience Integration in Distribution System Plans

- Utilities can perform granular assessments of specific events on specific circuits
- Utilities and industry organizations are developing and experimenting with resilience-focused metrics and indices
  - Network Resiliency Index (ConEd, 2023)
  - IEEE Storm Resilience Metric (IEEE, 2020)
  - Time to restore from peak customers interrupted to 95% restoration (National Grid, 2024)
  - Time to restore X% of customers (LBNL, 2024)
  - Percent of customers restored within X hours of a major storm
- Combinations of metrics can provide a more thorough understanding of performance than standalone metrics

Key Dimensions of Granularity

- Start and end of event or interruption
- Interruption cause
  - IEEE Standard 1782-2022 provides a structured approach to identify and categorize causes of interruptions to enable consistent reporting and analysis.
- Interruption location
  - Circuit, substation, or other location
- Conditions
  - Major Storm
  - Red Flag Warning
  - High Wind Warning

Case Studies

Example Strategies for Integrating Distribution and Resilience Planning

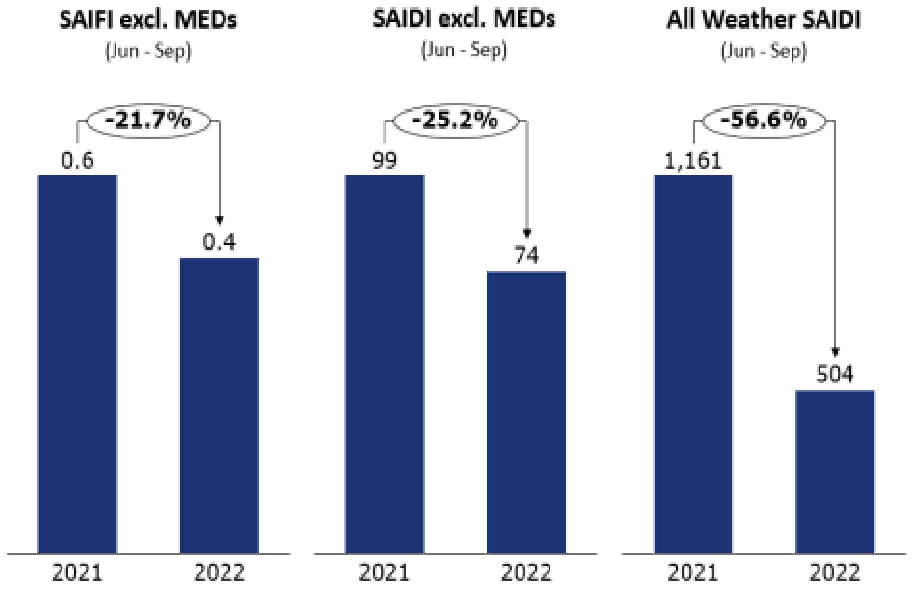
- Pole hardening
  - Utilities can harden poles to withstand resilience events, such as high wind speeds. Pole replacement is an opportunity to upgrade other distribution system assets (e.g., reclosers) at the same time, lowering the cost of such improvements.

- Microgrids
  - Group of interconnected loads and generating resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid
  - Can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode
  - Utilities can support development and implementation of microgrids by administering incentive programs and grants, providing technical and planning support, entering into partnership agreements with customers or third-party developers, and establishing specific tariffs to compensate microgrid customers for energy sales and other services provided to the grid.

Pole Hardening Case Study 1 – DTE

- DTE's pole hardening strategy is a multi-phased approach that shifts resources from reactive outage response to proactive system resilience
- Long-cycle proactive hardening
  - Targets aging infrastructure via planned inspection (10-year cycle) and modernization
  - Includes upgrading equipment (e.g., higher class poles, fiberglass crossarms) to enhance storm resilience, with the 4.8 kV hardening program significantly accelerated
- Short-cycle targeted response
  - Addresses immediate, localized reliability issues and repeated outages
  - Strategically informed by Pre-Storm Season Strengthening, which uses storm vulnerability data to prioritize circuits for hardening

Pre-Storm Strengthening Reliability Improvements for Short-Cycle Maintenance Programs



Source: DTE (2023)

Pole Hardening Case Study 2 – Pepco (DC)

- Planning integrates projects that increase capacity with projects that improve reliability and resilience
- Utility breaks down distribution system investments into capacity expansion and system performance projects.
- Relevant report components
    1. System Planning for existing and future electric system needs to provide reliable electric service to customers and support load growth in a cost-effective manner
    2. Productivity Improvement Plan (PIP) reports on operating performance of transmission and distribution system and measures to improve service reliability
- Focus is on coordination between capacity expansion and PIP
    - Example: 4kV to 13kV feeder conversion to improve reliability while increasing capacity to enable GER interconnection and load growth for transportation

Microgrids Case Study – New Jersey

- Town Center Microgrid Design Incentive Program
- Implementation
  - Phase I (Completed)
    - New Jersey Board of Public Utilities (NJBPU) awarded ~$2 million to 13 public entities to study potential locations for microgrids
  - Phase II (Active)
    - Provides incentives for detailed design of microgrids to move projects toward procurement and financing
    - BPU awarded a total of $4 million in incentives to eight eligible applicants that completed Phase I.
    - Focus is on microgrids that can serve a cluster of critical municipal facilities (e.g., hospitals, police/fire headquarters, shelters) within a single municipal boundary, ensuring they can operate reliably during grid outages and cost-effectively during normal operations

Microgrids Case Study – New Jersey

NJBPU provided the evaluation criteria for microgrid feasibility studies, including criteria for resilience, GER integration, air pollution reduction, peak demand reduction, and critical facilities support.

Evaluation of Applications (100 points total)	
General project characteristics (20 points)	• Overall description • FEMA Category III and IV critical facilities included • Community support during grid outages
Technical characteristics (40 points)	• Project readiness • Integration of resources and loads • Communication and control protocols and cyber security measures • Degree of resilience • Incorporation of technologies to reduce air pollution • Ability to reduce peak demand
Financing and business model (40 points)	• Reasonableness of estimated costs • Portion of cost requested from NJBPU • Source of funding for applicant’s portion of design cost • Reasonableness of business and financial models proposed • Reasonableness of project cost allocation • Degree of involvement of electricity and gas distribution companies

Source: NJBPU (2021)

Applicants submitted feasibility studies, describing proposed projects according to the multiple objectives defined by the evaluation criteria.

Relevant Highlights of Feasibility Studies

- Degree of resilience
  - Avoided customer interruption costs (Cape May, Middletown)
  - Local voltage and VAR support, short-term substation relief, and circuit-by-circuit grid restoration services – potentially via contract with the utility (Hudson County)
  - Flexibility in handling restoration of service during an outage, as utility can prioritize resources to other circuits (Highland Park)
- Integration of resources and loads
  - Integration of existing behind-the-meter diesel or natural gas standby generators into the microgrid to be used as load modifiers, reserve capacity, or backup power sources during extended outages (Cape May, Galloway)
  - Utilization of existing utility distribution infrastructure (feeders and distribution assets) to deliver power between microgrid customers (Atlantic City, Galloway, Hoboken)
- Critical facilities and community support centers served by microgrids include public safety and emergency response, healthcare and medical facilities, essential utilities and infrastructure, public shelter, warming centers, food and water distribution points, and places for cellphone charging.

Emerging Practices

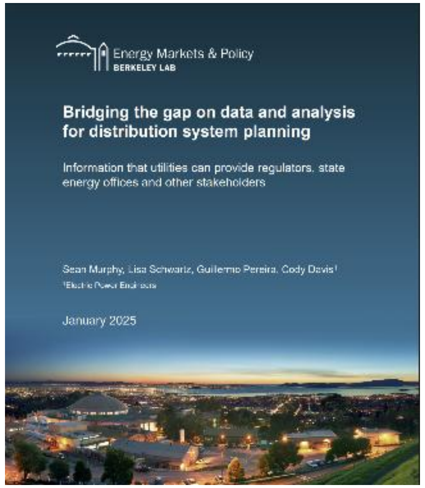
Typology Component	Description
Strategy	• Specify objectives to assess and prioritize planned distribution system investments and provide a roadmap for achieving objectives
Data	• Use consistent data sources and scenarios across planning functions • Use technology for enhanced situational awareness (visibility and control) • Move beyond historical weather data to anticipate more extreme weather conditions
Threat Assessments	• Assess impacts of threats to planning processes (e.g., capacity planning and load forecasting) as well as physical infrastructure
Solution Identification and Prioritization	• Systematically prioritize investments based on risk reduction, RSE, VSE, and BCR • Make explicit connections between planning processes when some types of resilience planning occurs through a separate proceeding (e.g., wildfire mitigation plans)

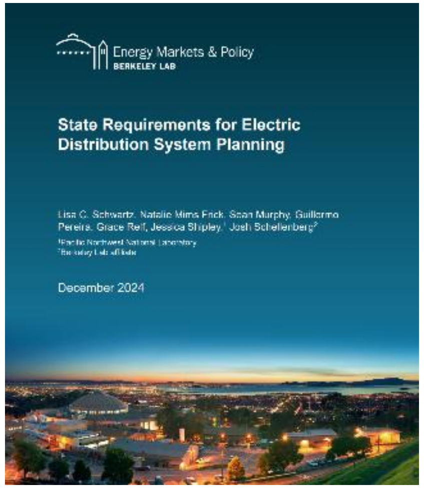
Consideration of Other Grid Needs	• Explore frameworks for comparing risk reduction value across multiple planning criteria, including resilience
	• Efficiently complete multiple types of work on the same circuit:
	    • Group all planned grid projects by circuit to optimize project selection and workflow
	    • Integrate hardening investments with standard planning and capacity upgrade cycles
	• Balance longer-term, systemic grid needs with immediate reliability and resilience gaps
	• Evaluate non-wires alternatives (e.g., storage) to defer or avoid traditional infrastructure upgrades to reduce costs and to mitigate resilience risks in locations prone to prolonged interruptions

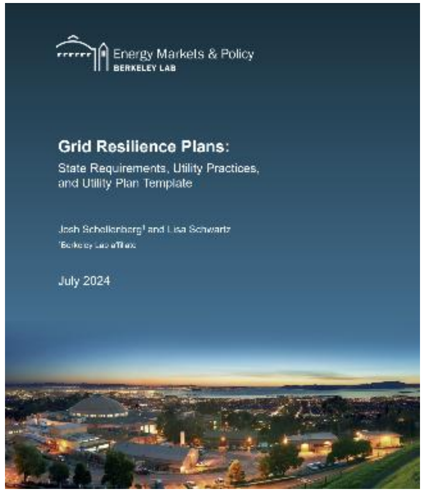
Metrics	• Use combinations of metrics to provide a more comprehensive view of resilience investment impacts than standalone metrics • Collect and analyze power interruption data with as much granularity as possible for analysis and interpretation. • Obtain baselines of key metrics to enable ex-post analyses that measure effectiveness of grid investments

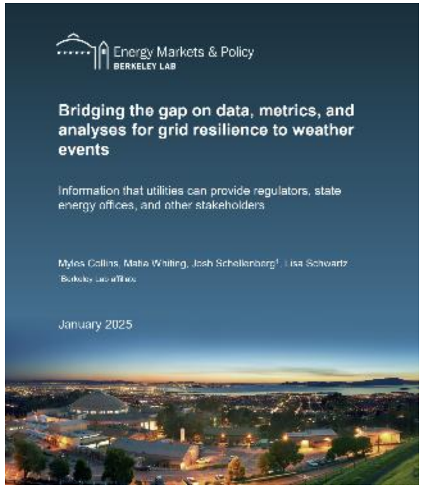
Additional Resources

- Bridging the Gap on Data and Analysis for Distribution System Planning
- State Requirements for Electric Distribution System Planning (includes a review of filed utility plans for leading practices)
- Grid Resilience Plans: State Requirements, Utility Practices, and Utility Plan Template
- Bridging the Gap on Data, Metrics, and Analyses for Grid Resilience to Weather Events
- Interruption Cost Estimate (ICE) Calculator – Online tool for estimating interruption costs and/or the benefits associated with reliability improvements
- Power Outage Economics Tool (POET) – Economic model to estimate economic impacts of widespread, multi-day outages across an entire region









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Extra Slides

Reliability Indices

Metric	Definition	Interpretation
SAIFI	System Average Interruption Frequency Index	Total number of interruptions that an average customer experiences over some time period
SAIDI	System Average Interruption Duration Index	Total number of minutes that an average customer is without power over some time period
CAIDI	Customer Average Interruption Duration Index	Time required to restore service for an average customer over some time period
MAIFI	Momentary Average Interruption Frequency Index	Total number of momentary interruptions (< 5 minutes) that an average customer experiences over some time period
$CEMI_n$	Customers Experiencing Multiple Interruptions	Ratio of customers experiencing *n* sustained interruptions to the total number of customers served
$CEMM_n$	Customers Experiencing Multiple Momentaries	Ratio of customers experiencing *n* momentary interruptions to the total customers served
$CEMSMI_n$	Customers Experiencing Multiple Sustained Interruptions and Momentary Interruptions	Ratio of individual customers experiencing *n* or more of both sustained interruptions and momentary interruption events to the total customers served
CELID-s; CELID-t	Customers Experiencing Long Interruption Durations	Ratio of individual customers that experience interruptions with durations longer than or equal to a given time: • (*s*), where the time is a single interruption • (*t*), defined as the total time a customer has been interrupted

Case Studies: Pole Hardening

Increased Pole-Hardening Standards Mentioned as Resilience Strategy						
Company	Type of Plan and Plan Link	State	Timeline Status			
			Increase class	Switch materials	Bolster Inspection	Fire paint / mesh
Black Hills Colorado Electric (2025)	Distribution System Plan	Colorado	-	-	Implemented	-
HECO (2023)	Integrated Grid Plan	Hawaii	Evaluating	Evaluating	-	Implemented
Ameren (2024)	Multi-Year Integrated Grid Plan	Illinois	Implemented	Implemented	-	-
ComEd (2024)	Multi-Year Integrated Grid Plan	Illinois	Implemented	Implemented	-	-
Eversource (2024)	Electric Sector Modernization Plan	Massachusetts	Uncertain	Uncertain	Implemented	-
DTE Electric (2023)	Distribution Grid Plan	Michigan	Uncertain	Implemented	-	-
UPPCO (2025)	Distribution Investment and Maintenance Plan	Michigan	Implemented	-	-	-
Northern States Power Company (2024)	Distribution Plan	Michigan	Implemented	Implemented	Implemented	-

Timeline Legend
Uncertain
Evaluating
Planned
Implemented

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