

Bridging the gap on data, metrics, and analyses for grid resilience to weather events

Myles Collins, Matia Whiting and Lisa Schwartz, Berkeley Lab

Public Webinar

February 19, 2025

This work was funded by the U.S. Department of Energy's Grid Deployment Office under Contract No. DE-AC02-05CH11231.



Today's webinar

- We'll discuss a new Berkeley Lab [report](#) by:
 - ▣ Myles Collins
 - ▣ Matia Whiting
 - ▣ Josh Schellenberg
 - ▣ Lisa Schwartz (PI)
- The U.S. Department of Energy's Grid Deployment Office provided funding for the study.
- On this webinar, all participants are in listen-only mode.
- You can use the Q&A box to make a comment or ask a question. We'll moderate Q&A following the presentation.
- Slides are posted to the [project website](#).
- We'll post a recording of the webinar at this website soon.

Resilience: the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions



Bridging the gap on data, metrics, and analyses for grid resilience to weather events

Information that utilities can provide regulators, state energy offices, and other stakeholders

Myles Collins, Matia Whiting, Josh Schellenberg¹, Lisa Schwartz

¹Berkeley Lab affiliate

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This work was supported by the U.S. Department of Energy's Grid Deployment Office under Lawrence Berkeley National Laboratory Contract No. DE-AC02-05CH11231.



Agenda

- Objectives and scope (*Lisa Schwartz*)
- Methodology and framework (*Myles Collins*)
- State requirements, vulnerability assessment, and hazard exposure (*Matia Whiting*)
- Data, metrics, and analyses in utility resilience plans, findings and emerging best practices (*Myles Collins*)
- Moderated Q&A



Motivation, Scope, and Methodology



Objectives and Scope

- States and utilities are aiming to improve grid resilience to address threats posed to electric systems from increasingly severe weather events.
 - ▣ Planning activities to improve grid resilience are at a relatively nascent stage.
 - ▣ There is no industry-wide consensus on the metrics, data, and analyses that are most effective to improve decision-making related to grid resilience investments.
- Study objectives
 - ▣ Help bridge the gap between the grid resilience data, metrics, and analyses that utilities use and the information utilities provide to utility regulators, state energy offices, and other stakeholders that engage in grid resilience planning
 - ▣ Help state regulators identify, describe, request, and use utility data and analyses to inform their decisions on utility resilience plans and cost recovery requests for investments
 - ▣ Help stakeholders understand why certain information is needed and what information the utility can provide
- Scope
 - ▣ Focus on resilience to events resulting from severe weather and climate conditions
 - ▣ Other hazards, such as earthquakes and threats to physical security and cybersecurity, are not within the scope of this report.
 - ▣ Builds on earlier report, [Grid Resilience Plans: State Requirements, Utility Practices, and Utility Plan Template](#), which summarized state requirements for grid resilience plans across a variety of hazards, identified emerging best practices, and provided a template for utility filings.



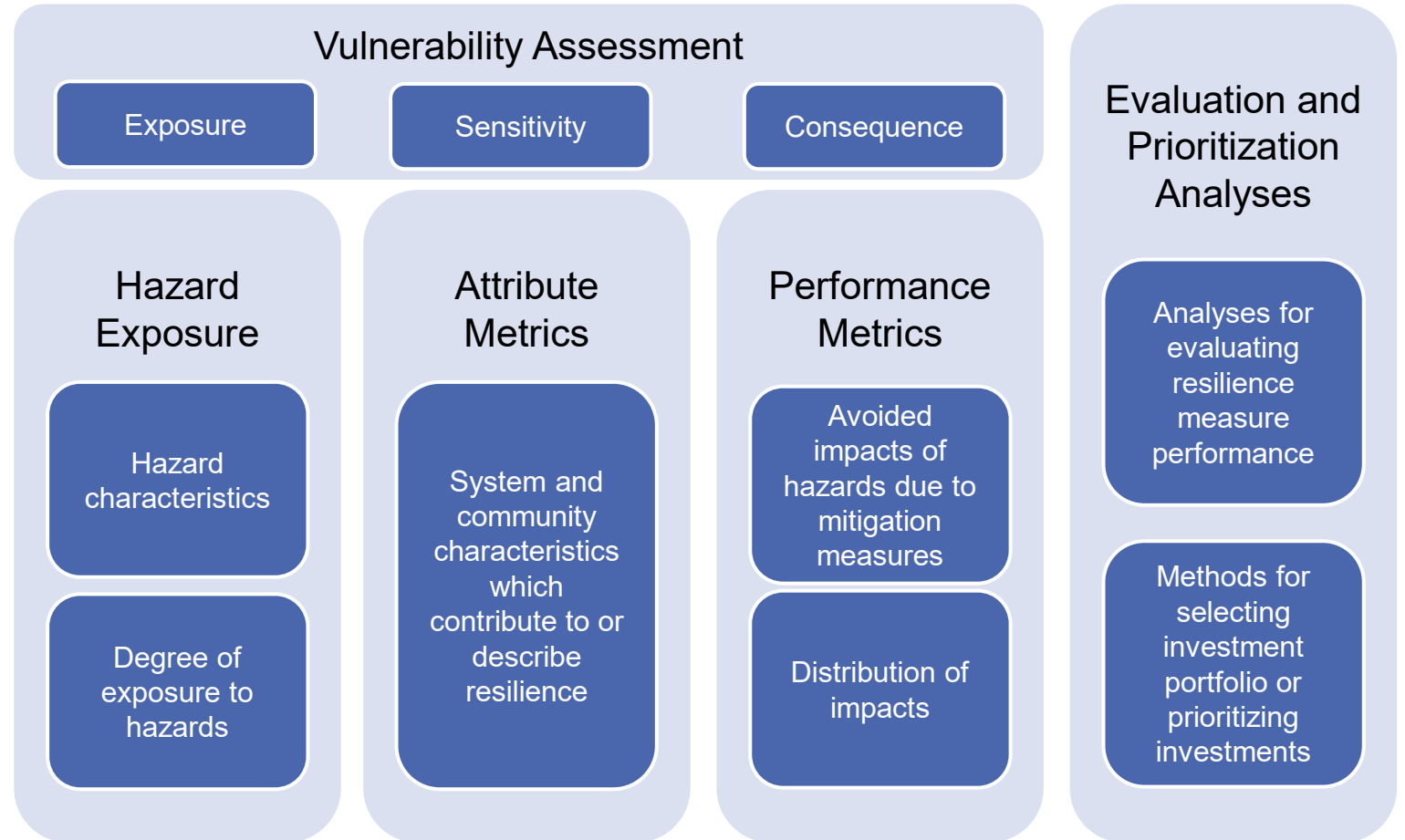
Methodology

- Reviewed state resilience planning requirements in 15 states and one city
- Reviewed 43 utility resilience plans, academic literature, and materials from industry resilience initiatives and working groups
- Conducted interviews with staff at utilities, public utility commissions, and state energy offices



Framework

- The report presents data, metrics, and analyses that utilities can provide state regulators and stakeholders.
- Categories in the report align with frameworks found in the literature and in utility resilience plan filings.

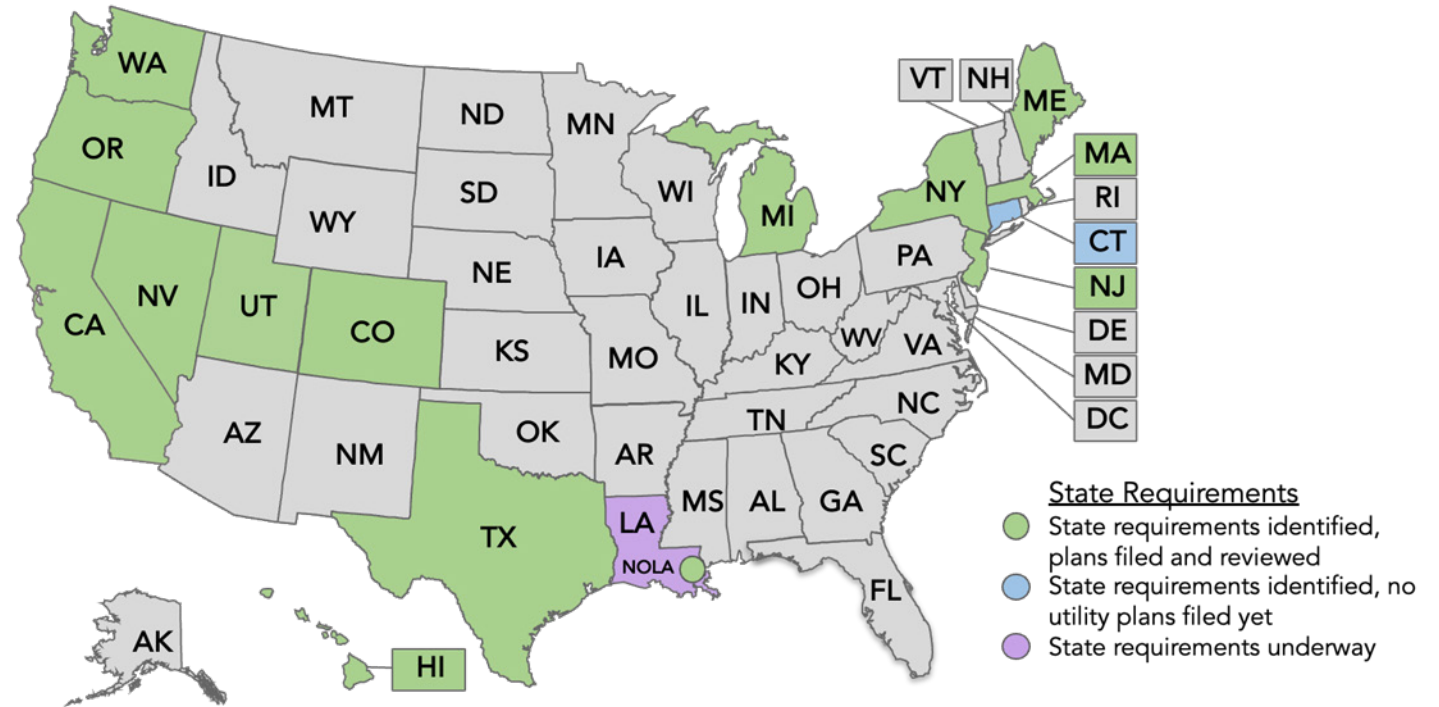


State Requirements



State Requirements (1)

- A growing number of states are establishing requirements for electric utilities to file grid resilience plans.
 - ▣ As of September 2024, 15 states and one city



State Requirements (2)

- Multiple hazards
 - ▣ General system resilience – HI, LA, TX
 - ▣ Climate change resilience and vulnerability – CA, ME, NY
 - ▣ Infrastructure modernization – MA, NJ
- Storm protection
 - ▣ CT, FL, MI, New Orleans
- Wildfire mitigation
 - ▣ CA, NV, OR, UT, WA

Legend	
●	Required and specific
●	Required and high-level
●	Recommended and high-level

State	Plan	Vulnerability Assessment	Hazard Exposure	Attribute Metrics	Performance Metrics	Evaluation & Prioritization Analyses
Ensemble of Hazards						
California	Climate Vulnerability Assessment, Risk-based Decision-making Framework	●	●	●	●	●
Colorado	Distribution System Plan	●	●		●	
Hawaii	Natural Hazard Mitigation Plan	●	●	●	●	●
Maine	Climate Change Protection Plan		●			
Massachusetts	Electric-sector Modernization Plan		●		●	
New Jersey	Infrastructure Investment Program				●	●
New York	Climate Change Vulnerability Study and Resilience Plan	●	●		●	●
Texas	T&D System Resiliency Plan		●	●	●	●
Severe Storms						
Connecticut	Resilience Plan	●	●	●	●	●
Florida	Storm Protection Plan			●	●	●
Louisiana (only New Orleans)	System Resiliency and Storm Hardening Plan	●	●			●
Michigan	Distribution System Plan		●		●	
Wildfire						
California	Wildfire Mitigation Plan	●	●	●	●	
Nevada	Natural Disaster Protection Plan	●	●	●	●	
Oregon	Wildfire Mitigation Plan	●	●	●	●	●
Utah	Wildland Fire Protection Plan		●	●	●	●
Washington	Wildfire Mitigation Plan		●	●		●



State Requirements (3)

- Categories of analyses & metrics
 - ▣ Vulnerability assessment, hazard exposure, prioritization/evaluation analysis
 - ▣ Attribute metrics, performance metrics
- Most commonly required: hazard exposure analysis (in plan) and performance metrics (after plan filing)
- Flexibility and specificity varies, e.g.:
 - ▣ CA CAVAs – required and specific
 - ▣ TX System Resiliency Plan required/ recommended and high level

Legend	
●	Required and specific
●	Required and high-level
●	Recommended and high-level

State	Plan	Vulnerability Assessment	Hazard Exposure	Attribute Metrics	Performance Metrics	Evaluation & Prioritization Analyses
Ensemble of Hazards						
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Colorado	Distribution System Plan	●	●		●	
Hawaii	Natural Hazard Mitigation Plan	●	●	●	●	●
Maine	Climate Change Protection Plan		●			
Massachusetts	Electric-sector Modernization Plan		●		●	
New Jersey	Infrastructure Investment Program				●	●
New York	Climate Change Vulnerability Study and Resilience Plan	●	●		●	●
Texas	T&D System Resiliency Plan		●	●	●	●
Severe Storms						
Connecticut	Resilience Plan	●	●	●	●	●
Florida	Storm Protection Plan			●	●	●
Louisiana (only New Orleans)	System Resiliency and Storm Hardening Plan	●	●			●
Michigan	Distribution System Plan		●		●	
Wildfire						
California	Wildfire Mitigation Plan	●	●	●	●	
Nevada	Natural Disaster Protection Plan	●	●	●	●	
Oregon	Wildfire Mitigation Plan	●	●	●	●	●
Utah	Wildland Fire Protection Plan		●	●	●	●
Washington	Wildfire Mitigation Plan		●	●		●

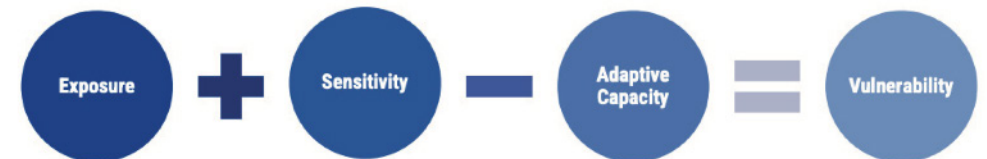
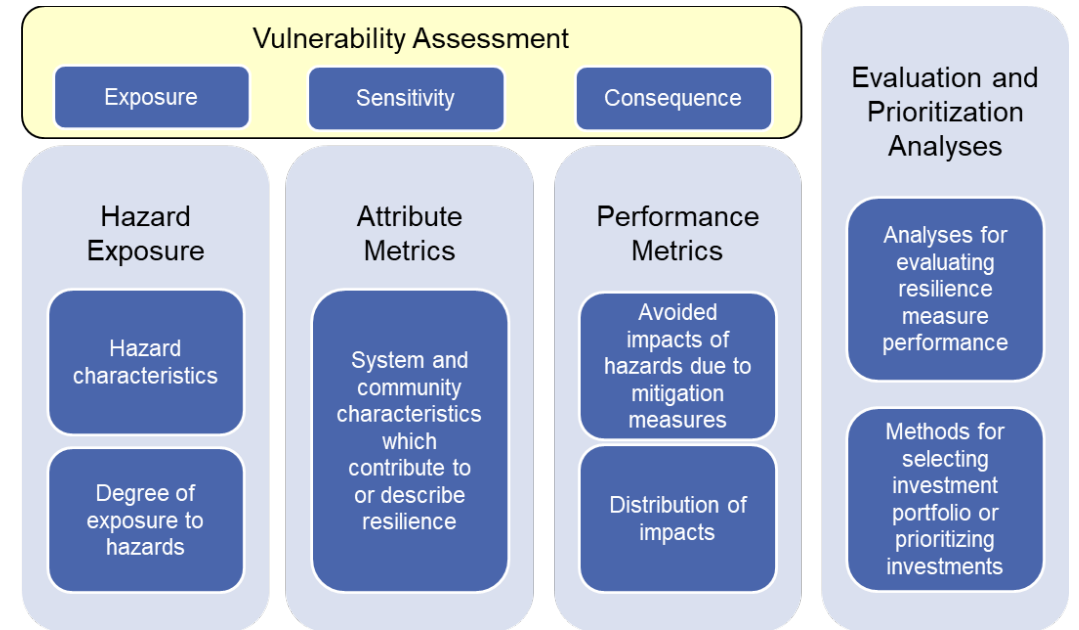


Data, Metrics, and Analyses in Utility Resilience Plans



Vulnerability Assessments

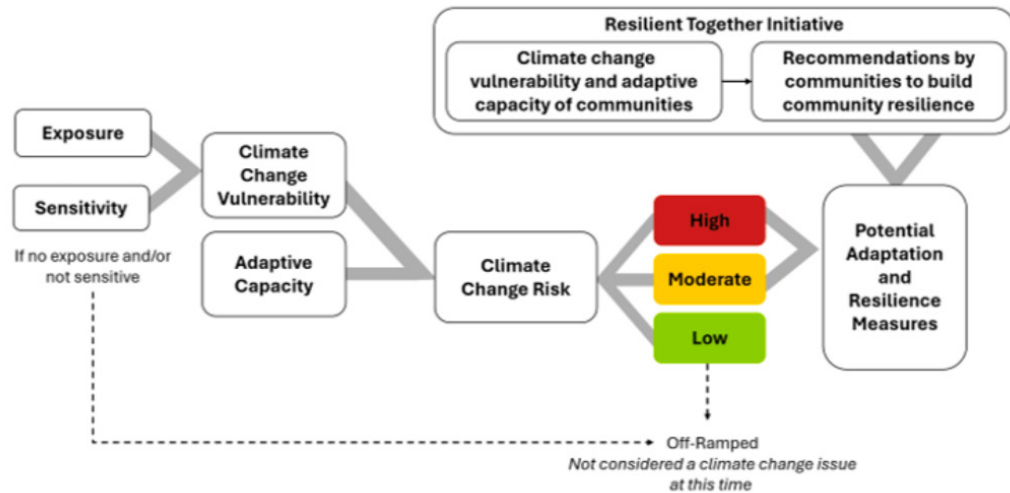
- Vulnerability assessments include the following elements:
 - ▣ *Hazard characterization* – Hazard analysis relative to infrastructure and process areas
 - ▣ *Exposure* – Degree to which utility assets could face a given hazard, based on asset location and climate information (historical, projected)
 - ▣ *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.



[City of Seattle](#) (2023)

Vulnerability Assessment Examples

- Vulnerability assessments in the utility resilience plans combined quantitative and qualitative assessments to identify high, medium, and low vulnerabilities to extreme weather hazards for specific utility assets or processes.
- Example: PG&E CAVA (2024), Rochester Gas and Electric (RG&E) and New York State Electric and Gas (NYSEG)



Source: PG&E Climate Adaptation and Vulnerability Assessment (2024)

RG&E and NYSEG Vulnerability Rating Rubric

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

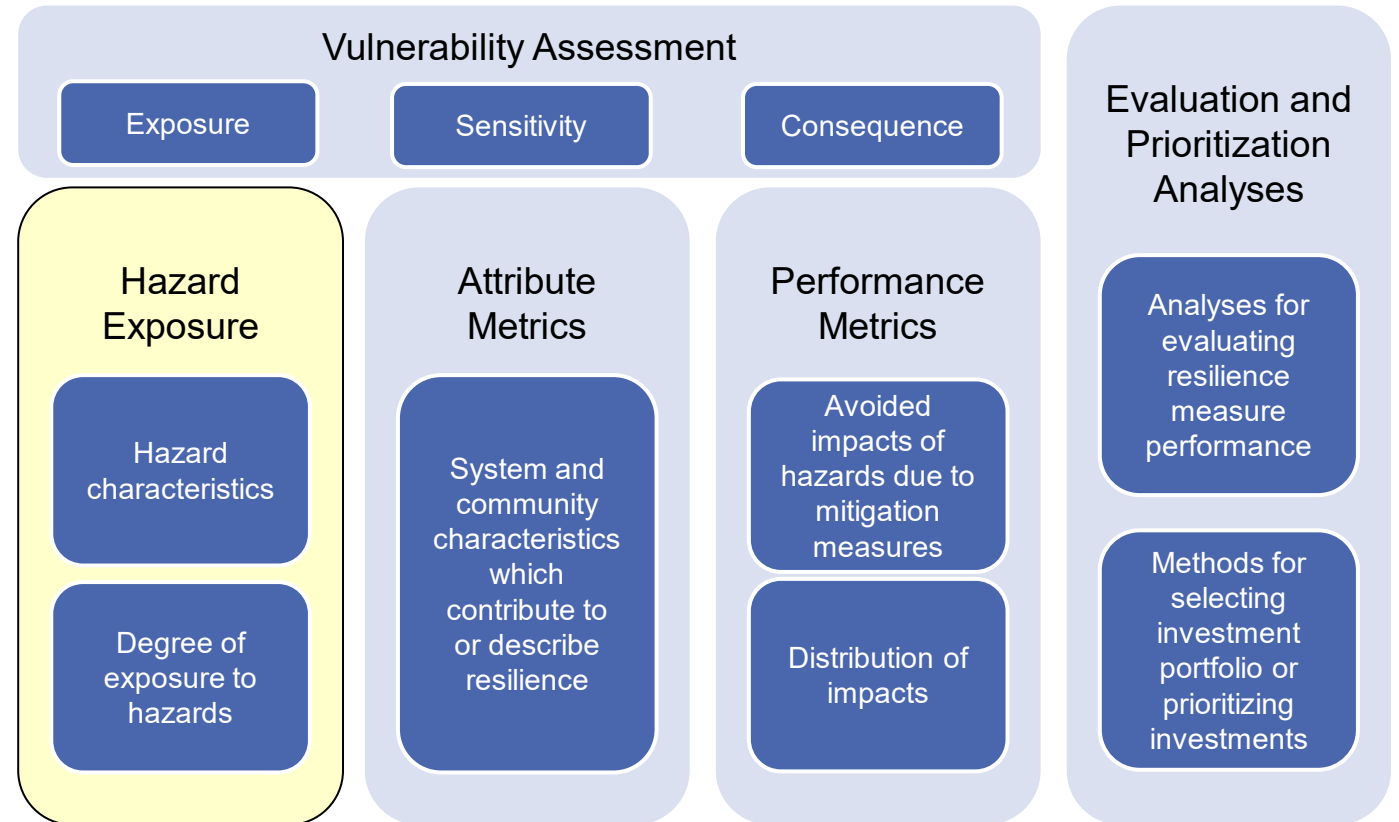
RG&E and NYSEG Transmission Asset Vulnerability Ratings

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) Climate Vulnerability Assessment (2023)

Hazard Exposure

- Hazard characteristics
 - ▣ Hazard data variables
 - ▣ Future climate scenarios
 - ▣ Analysis timeframe
 - ▣ Data sources
- Exposure data



Hazard Characteristics

- Hazard data variables
 - ▣ Informed by regional hazards, state guidance, and relevant thresholds
- Future climate scenarios
 - ▣ Informed by state guidance and risk tolerance
- Timeframe
 - ▣ Informed by state guidance, asset lifespans, and data limitations
- Data sources
 - ▣ Historical and projected
 - ▣ Nationwide downscaled gridded climate data, state and local climate data, event databases, locally-constructed federal data

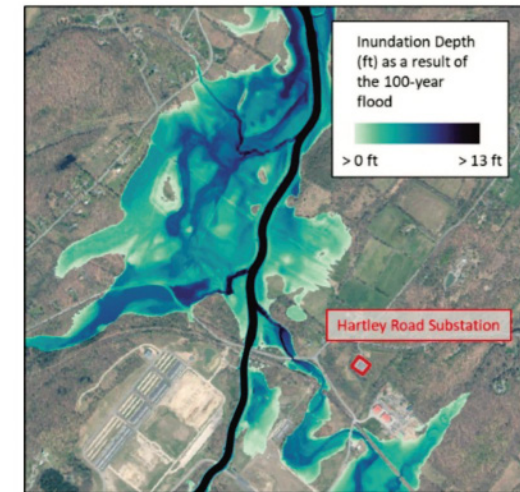
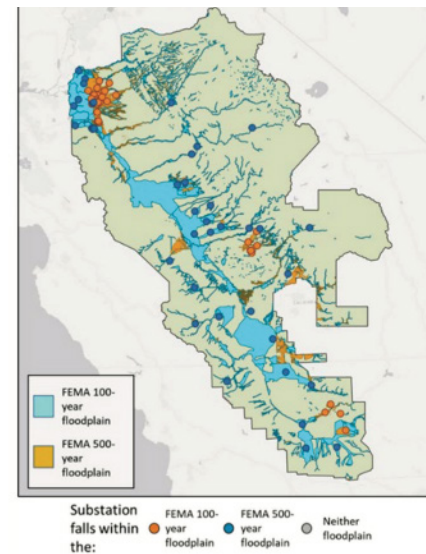
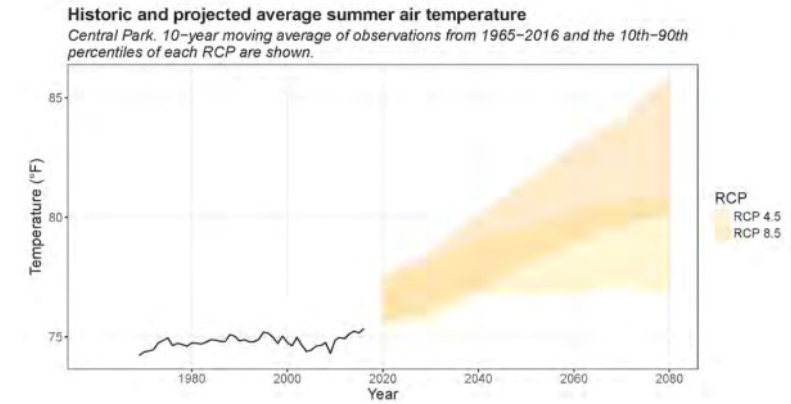
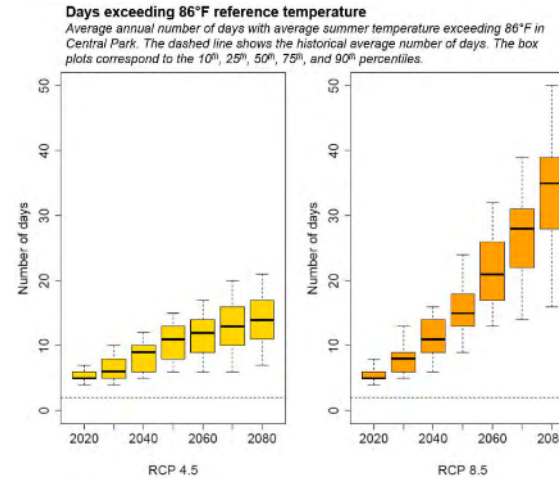


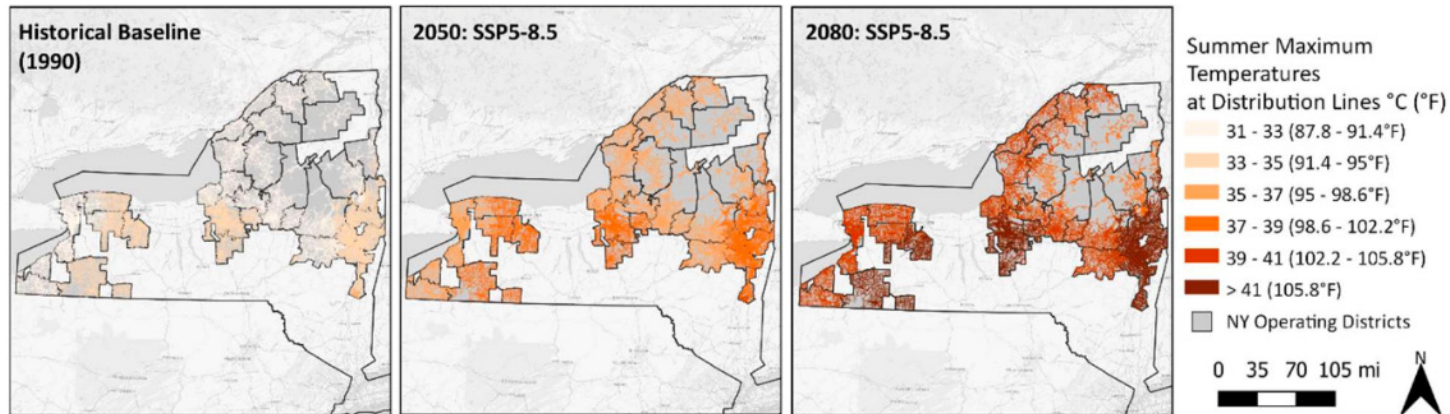
Figure 11. 100-year inland flood depths in an example floodplain adjacent to Hartley Road Substation, located in Orange County

Top Row
Source: Con Edison Climate Change Vulnerability Study (2019)

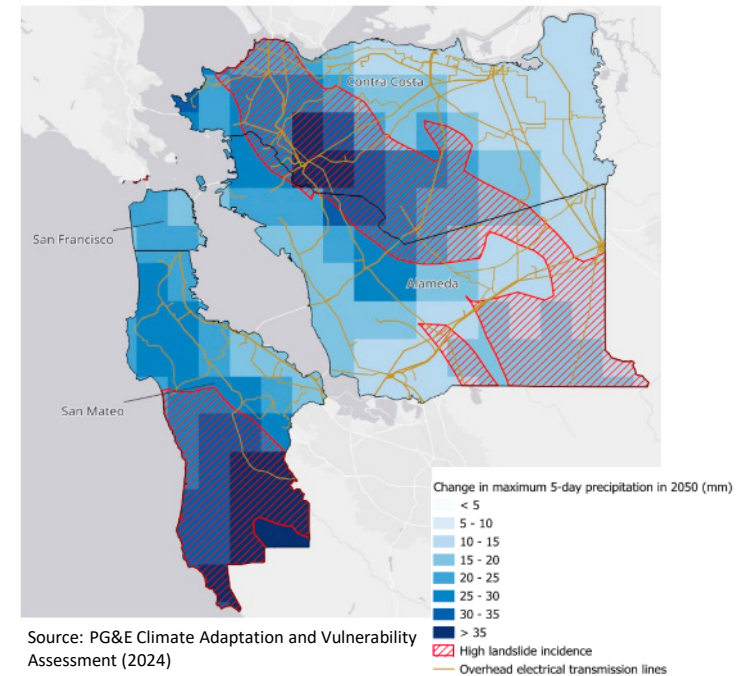
Bottom Row
Source: PG&E Climate Adaptation and Vulnerability Assessment (2024) and O&R Climate Change Vulnerability Study (2023)

Exposure Data

- Describe the degree to which assets may experience specific climate hazards
- Utilities typically generated exposure data using geospatial asset and hazard data and analyzed it on an asset-hazard combination-specific basis.
- Allows utilities to identify which components of their system are most exposed to potentially disruptive climate hazards, enabling more targeted resilience efforts.
- Most resilience plans that addressed exposure presented findings as maps.



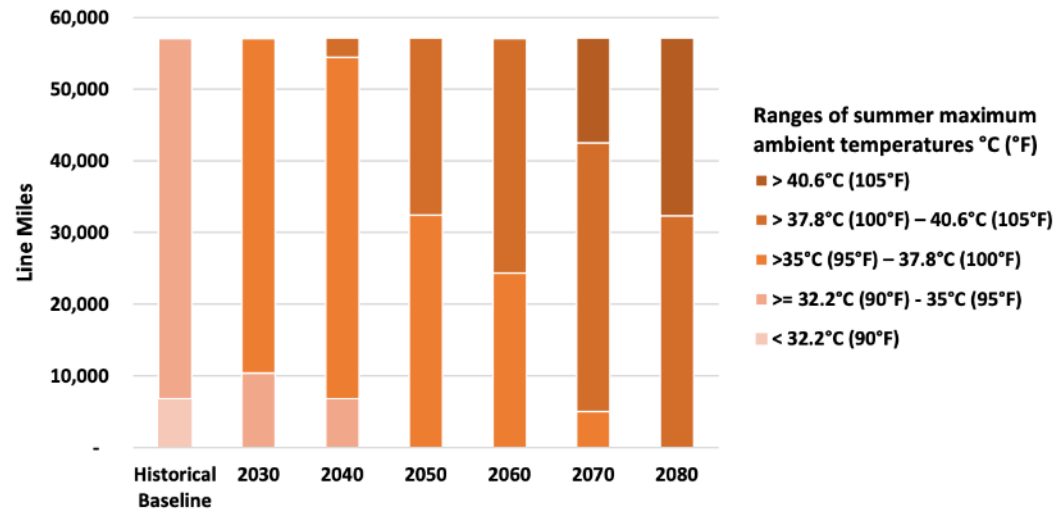
Source: National Grid Climate Vulnerability Assessment (2023)



Source: PG&E Climate Adaptation and Vulnerability Assessment (2024)

Exposure Data (2)

- Exposure data may be presented visually (maps and graphs) or statistically (summary tables)

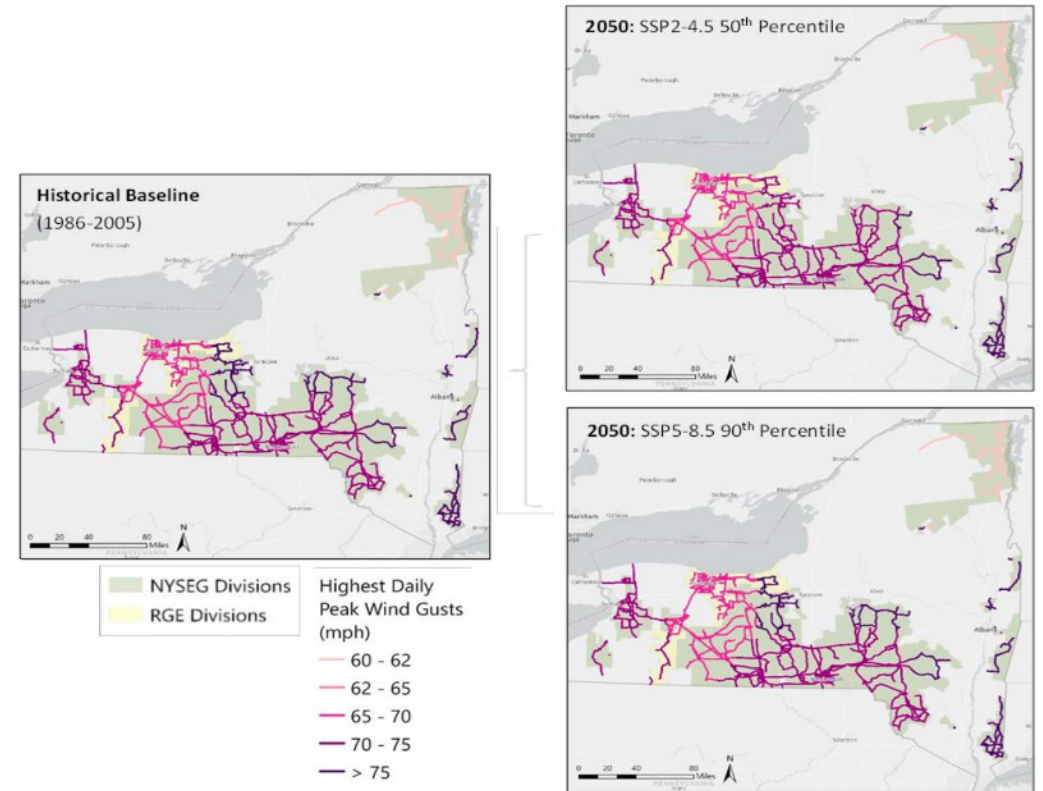


Source: National Grid Climate Vulnerability Assessment (2023)

Table 5.2. PG&E Pad-Mount Distribution Transformer Counts Exposed to Coastal Flooding

Region	Baseline	2030	2050	2080
Bay Area	107 (0.08%)	1,501 (1.12%)	1,942 (1.45%)	3,598 (2.69%)
Central Valley	25 (0.02%)	754 (0.56%)	786 (0.59%)	1,420 (1.06%)
Sierra	6 (0.004%)	26 (0.02%)	29 (0.02%)	58 (0.04%)
North Coast	161 (0.12%)	306 (0.23%)	424 (0.32%)	743 (0.55%)
Central Coast	22 (0.02%)	62 (0.05%)	115 (0.09%)	490 (0.37%)
Total	321 (0.24%)	2,649 (1.98%)	3,296 (2.46%)	6,309 (4.71%)

Source: PG&E Climate Adaptation and Vulnerability Assessment (2024)

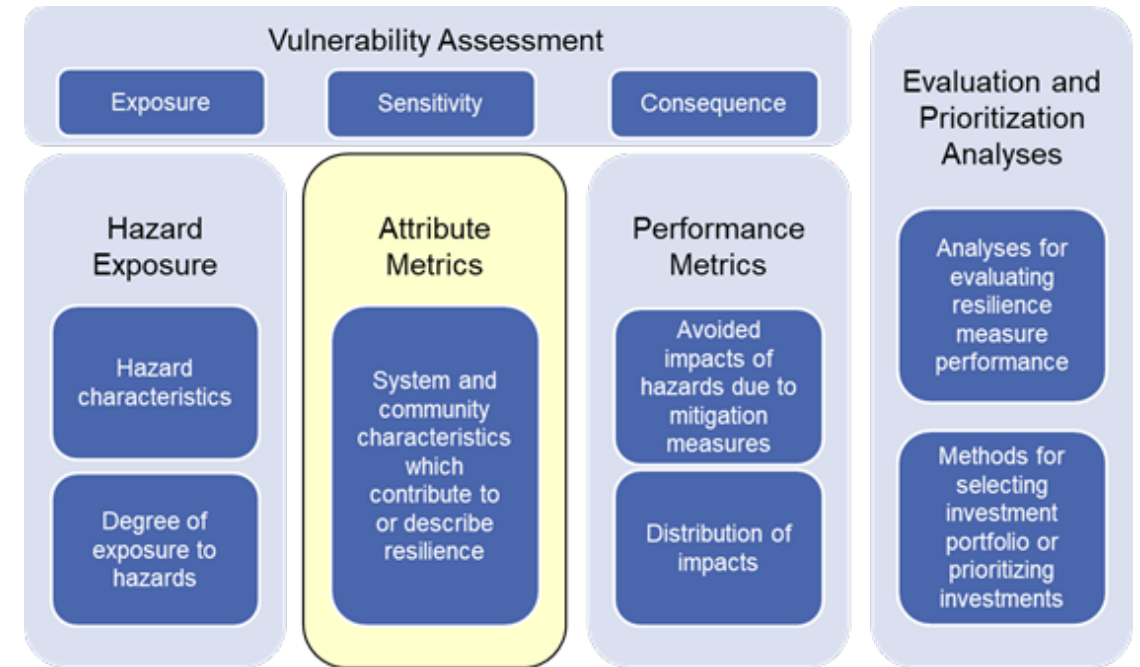


Source: AVANGRID Climate Vulnerability Assessment (2023)

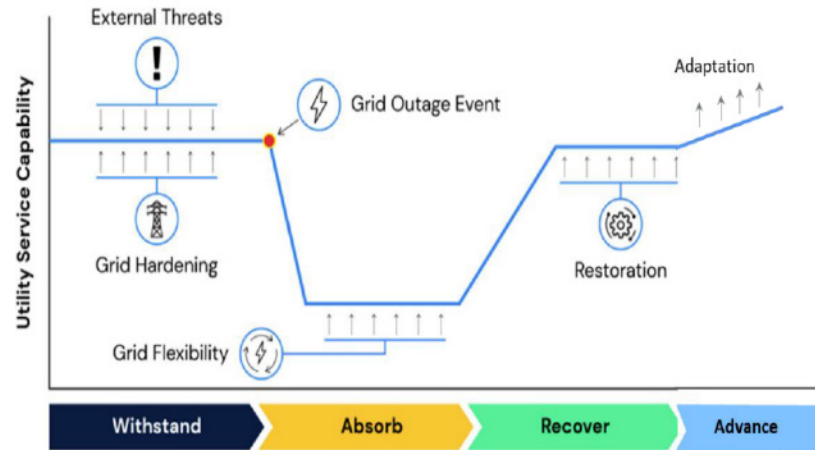
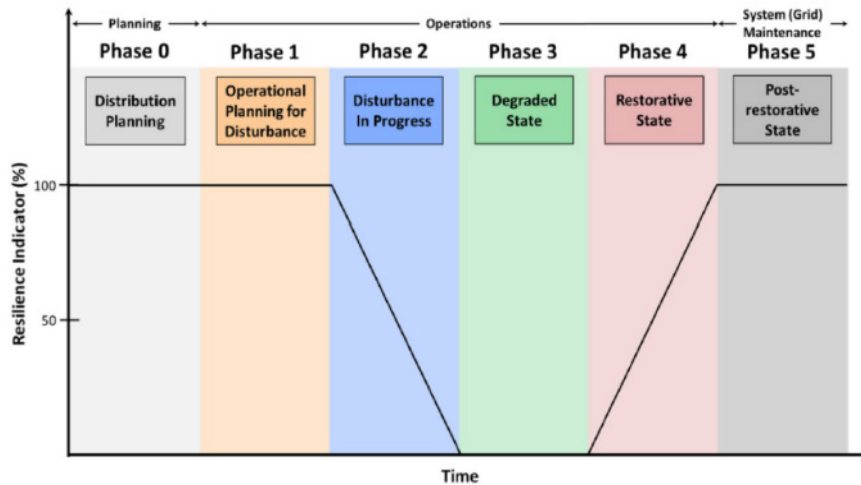
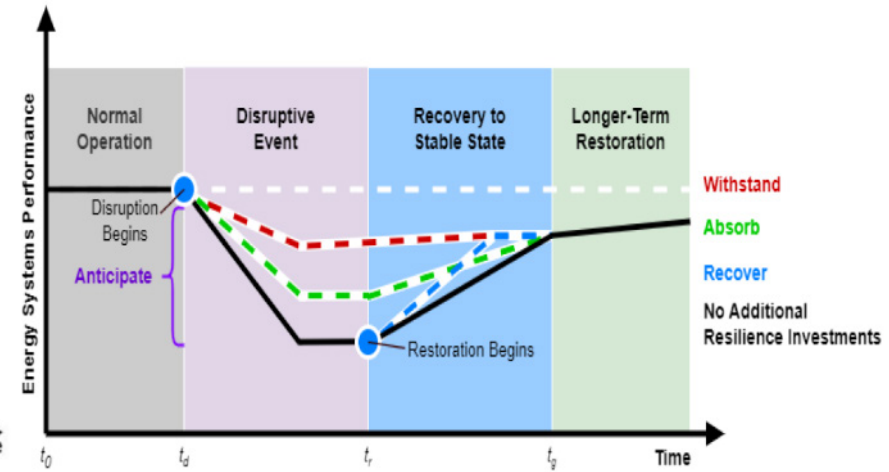
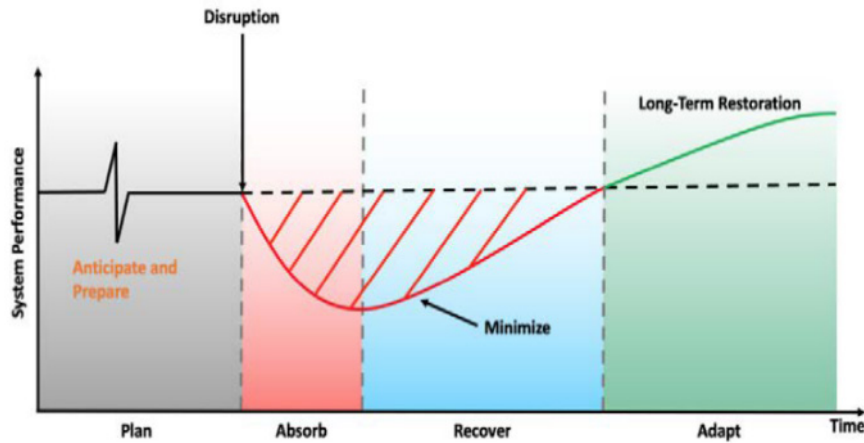


Attribute Metrics

- 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
- By tracking attribute metrics, utilities can connect infrastructure performance to tangible asset characteristics and hardening progress and, in doing so, assess both the components of their system that are more resilient and those that need improvement.



Phases of Resilience



Sources: From Leddy et al., (2023), Keen et al. (2024), EPRI (2023), RG&E & NYSEG (2023)

Attribute Metrics

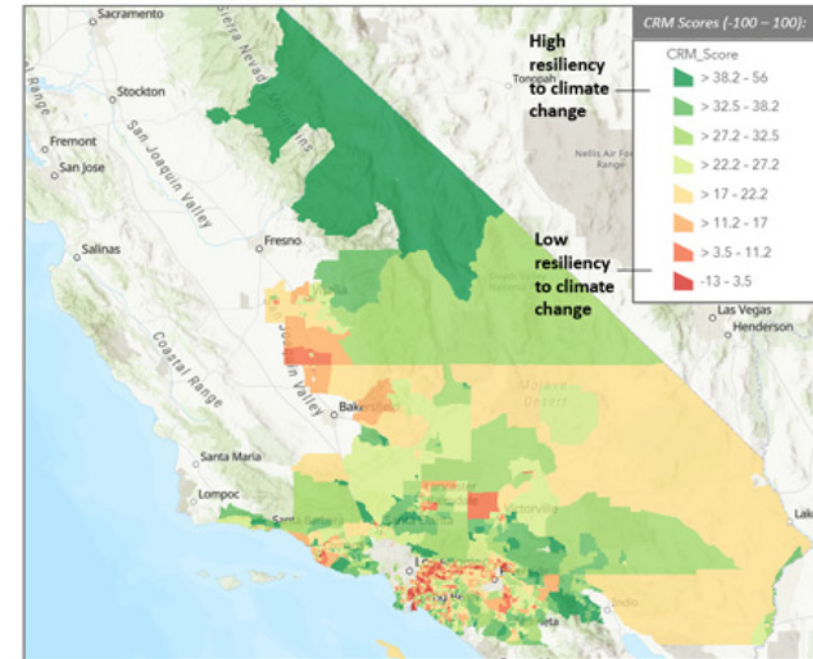
- Report categorizes attribute metrics into four resilience phases to align with the definition of resilience

Resilience Phase	Description	Metric Type
Anticipate	The likelihood or characteristics of potential impacts caused by a hazard.	Potential for hazards to damage assets
		Potential for assets to damage surroundings
Withstand	The electrical system's capacity to avoid being affected by a hazard.	Asset condition
		Asset ratings
		Asset hardening status
Adapt	The ability of the grid to respond to asset damage or of the community to change behavior to minimize impacts to customers.	Automation and topology
		Emergency power
		Social indicators
		Community resilience
Recover	The ability to restore normal grid operation after a disruption.	Preparedness
		Accessibility
		Power restoration



Attribute Metrics – Example

Resilience Phase	Description	Metric Type
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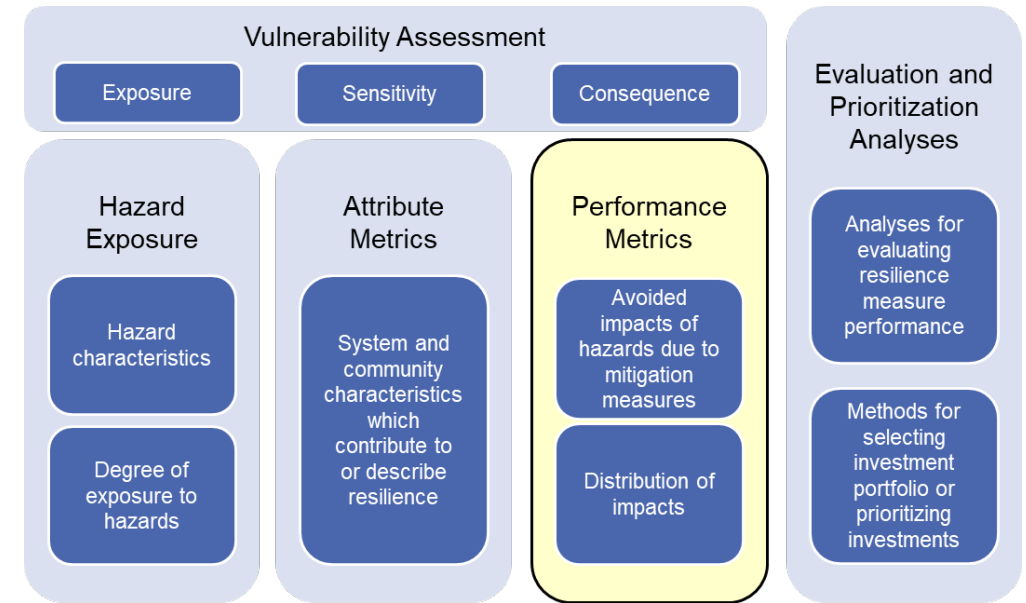
Community Resilience Metric Scores for Southern California Edison Territory

Source: [Southern California Edison](#) (2022)



Performance Metrics

Category	Description
Electrical Service	Metrics describe power interruptions in terms of frequency, duration, location, cause, customers affected, and other variables.
Asset Damage or Failure	Metrics describe infrastructure impacts in non-monetary terms, such as counts of damaged utility structures.
Response and Restoration	Metrics describe response and recovery from a hazard event, such as the time to restore power to some or all of a utility service territory.
Monetary Impact	Metrics describe the cost of impacts and include capital costs of damaged assets, operations and maintenance (O&M) costs for restoration and recovery, costs incurred by customers as a result of power interruptions, and economy-wide impacts from power interruptions.
Customer Communications and Engagement	Metrics describe the effectiveness of utility outreach regarding a storm or interruption event.



Additional Dimensions of Performance Metrics
Critical Infrastructure Electrical Service
Public Safety Power Shutoffs
Distributional Impacts



Electrical Service

Examples of Metrics	
Interruption Events	Interruptions
	Customer Minutes Interrupted
Interruption Frequency	SAIFI (with and without MEDs)
	MAIFI (with and without MEDs)
Interruption Duration	SAIDI (with and without MEDs)
	CAIDI (with and without MEDs)
	Percent of interruptions lasting longer than X hours
Customer-Focused	Customers Experiencing Multiple Interruptions (CEMI _n)
	Customers Experiencing Long Interruption Durations (CELID)
Additional Metrics	Circuit Performance Indicator (RMP, 2019)
	IEEE Storm Resilience Metric (IEEE, 2020)
	Expected Unserved Energy

Key dimensions of granularity for interruption data

- Start and end times
- Cause
 - ▣ IEEE Standard 1782-2022 provides a structured approach to identify and categorize causes of interruptions to enable consistent reporting and analysis.
- Location
 - ▣ Circuit, substation, or other location



Electrical Service – Example of Granular Data Reporting

Utility X
 Table No. 5
 Date Modified

Notes:
 5 Transmission lines refer to all lines at or above 65kV, and distribution lines refer to all lines below 65kV.
 Data from 2015 - 2021 should be actual numbers. 2022 and 2023 should be projected. In future submissions update projected numbers with actuals

Table 5: Risk event drivers							Actual number of risk events					
Risk event category	Metric type	#	Risk event driver	Line Type	HFTD Tier	Are risk events tracked for ignition driver? (yes / no)	Q1 2022	Q2 2022	Q3 2022	Q4 2022	Q1 2023	Q2 2023
Unplanned Outage	13. Object contact	13.f.d.0	Other	Distribution	Non-HFTD							
Unplanned Outage	13. Object contact	13.f.d.2	Other	Distribution	HFTD Tier 2							
Unplanned Outage	13. Object contact	13.f.d.3	Other	Distribution	HFTD Tier 3							
Unplanned Outage	13. Object contact	13.f.t.0	Other	Transmission	Non-HFTD							
Unplanned Outage	13. Object contact	13.f.t.2	Other	Transmission	HFTD Tier 2							
Unplanned Outage	13. Object contact	13.f.t.3	Other	Transmission	HFTD Tier 3							
Unplanned Outage	13. Object contact	13.g.d.0	Unknown	Distribution	Non-HFTD							
Unplanned Outage	13. Object contact	13.g.d.2	Unknown	Distribution	HFTD Tier 2							
Unplanned Outage	13. Object contact	13.g.d.3	Unknown	Distribution	HFTD Tier 3							
Unplanned Outage	13. Object contact	13.g.t.0	Unknown	Transmission	Non-HFTD							
Unplanned Outage	13. Object contact	13.g.t.2	Unknown	Transmission	HFTD Tier 2							
Unplanned Outage	13. Object contact	13.g.t.3	Unknown	Transmission	HFTD Tier 3							
Unplanned Outage	14. Vegetation contact	14.a.d.0	Vegetation contact	Distribution	Non-HFTD							
Unplanned Outage	14. Vegetation contact	14.a.d.2	Vegetation contact	Distribution	HFTD Tier 2							
Unplanned Outage	14. Vegetation contact	14.a.d.3	Vegetation contact	Distribution	HFTD Tier 3							
Unplanned Outage	14. Vegetation contact	14.a.t.0	Vegetation contact	Transmission	Non-HFTD							
Unplanned Outage	14. Vegetation contact	14.a.t.2	Vegetation contact	Transmission	HFTD Tier 2							
Unplanned Outage	14. Vegetation contact	14.a.t.3	Vegetation contact	Transmission	HFTD Tier 3							
Unplanned Outage	15. Equipment / facility failure or damage	15.a.d.0	Anchor/guy	Distribution	Non-HFTD							
Unplanned Outage	15. Equipment / facility failure or damage	15.a.d.2	Anchor/guy	Distribution	HFTD Tier 2							
Unplanned Outage	15. Equipment / facility failure or damage	15.a.d.3	Anchor/guy	Distribution	HFTD Tier 3							
Unplanned Outage	15. Equipment / facility failure or damage	15.a.t.0	Anchor/guy	Transmission	Non-HFTD							
Unplanned Outage	15. Equipment / facility failure or damage	15.a.t.2	Anchor/guy	Transmission	HFTD Tier 2							
Unplanned Outage	15. Equipment / facility failure or damage	15.a.t.3	Anchor/guy	Transmission	HFTD Tier 3							
Unplanned Outage	15. Equipment / facility failure or damage	15.b.d.0	Capacitor bank	Distribution	Non-HFTD							
Unplanned Outage	15. Equipment / facility failure or damage	15.b.d.2	Capacitor bank	Distribution	HFTD Tier 2							
Unplanned Outage	15. Equipment / facility failure or damage	15.b.d.3	Capacitor bank	Distribution	HFTD Tier 3							
Unplanned Outage	15. Equipment / facility failure or damage	15.b.t.0	Capacitor bank	Transmission	Non-HFTD							
Unplanned Outage	15. Equipment / facility failure or damage	15.b.t.2	Capacitor bank	Transmission	HFTD Tier 2							
Unplanned Outage	15. Equipment / facility failure or damage	15.b.t.3	Capacitor bank	Transmission	HFTD Tier 3							
Unplanned Outage	15. Equipment / facility failure or damage	15.c.d.0	Conductor	Distribution	Non-HFTD							
Unplanned Outage	15. Equipment / facility failure or damage	15.c.d.2	Conductor	Distribution	HFTD Tier 2							
Unplanned Outage	15. Equipment / facility failure or damage	15.c.d.3	Conductor	Distribution	HFTD Tier 3							
Unplanned Outage	15. Equipment / facility failure or damage	15.c.t.0	Conductor	Transmission	Non-HFTD							

California Office of Energy Infrastructure Safety
 Energy Safety Data Guidelines – Wildfire Mitigation Data Tables Template



Asset Damage or Failure / Response and Recovery

Asset Damage or Failure Metrics

Examples of Metrics	
Asset Damage	Critical facility asset damage from resilience events
	Asset damages from resilience events
Asset Performance	Overloaded equipment as a result of a resilience event
	Failed equipment as a result of a resilience event
	Failed hardened equipment as a result of a resilience event
Asset Repair and Replacement	Asset replacement and repair rates after major events

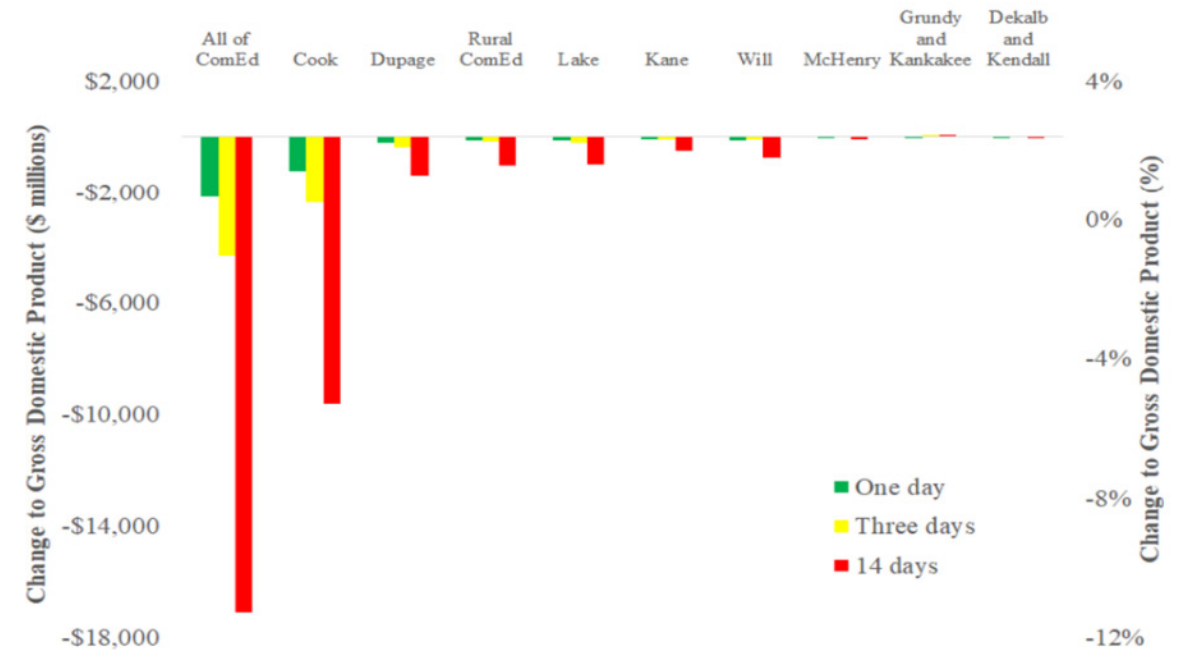
Response and Recovery Metrics

Examples of Metrics	
Response	Resource engagement during an event
	Restoration efforts
	System inefficiencies during event response
	Emergency response measures
Restoration	Downed wire response
	Time to Restore X% of Customers (or CR-X)
	Time to restore from peak customers interrupted to 95% restoration (JIC, 2024)
	Percent of Customers Restored within X hours of a Major Storm



Monetary Impact Metrics and Example

Examples of Metrics	
Utility Costs	Value of assets damaged and destroyed by major events
	Post-event O&M restoration costs
Customer Interruption Costs	Cost per event
	Cost per average kW
	Cost per unserved kWh
Economy-wide Impacts	Gross output
	Gross (regional) Domestic Product
	Change in household consumption



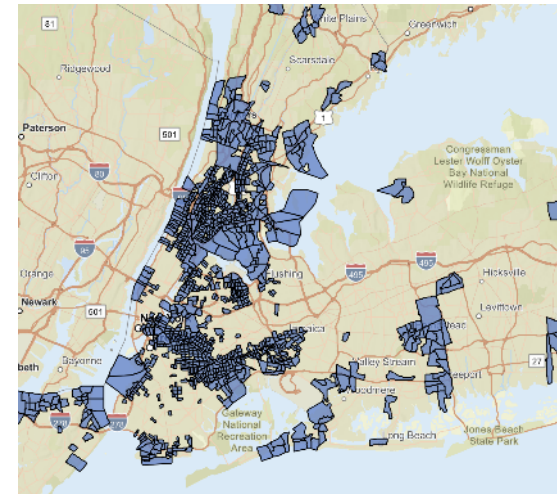
Change in Overall Gross Domestic Product for All of ComEd's Service Territory

Source: Larsen et al. (2024)

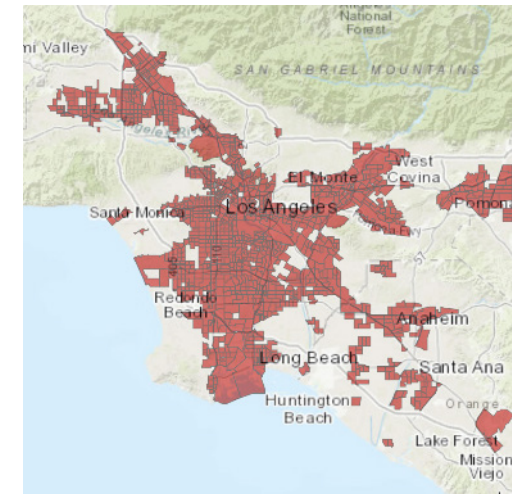


Performance Metrics – Additional Dimensions

- ❑ **Critical facilities:** Infrastructure which is essential for the health, safety, and economic well-being of a population (e.g., hospitals, fire stations, emergency operation centers, public drinking water facilities, sewer and wastewater facilities)
- ❑ **Public Safety Power Shutoffs:** Intentional de-energization of portions of the grid to reduce the risk of a wildfire caused by a utility asset
- ❑ **Distributional impacts:** Census tracts designated by state governments for meeting a certain set of criteria



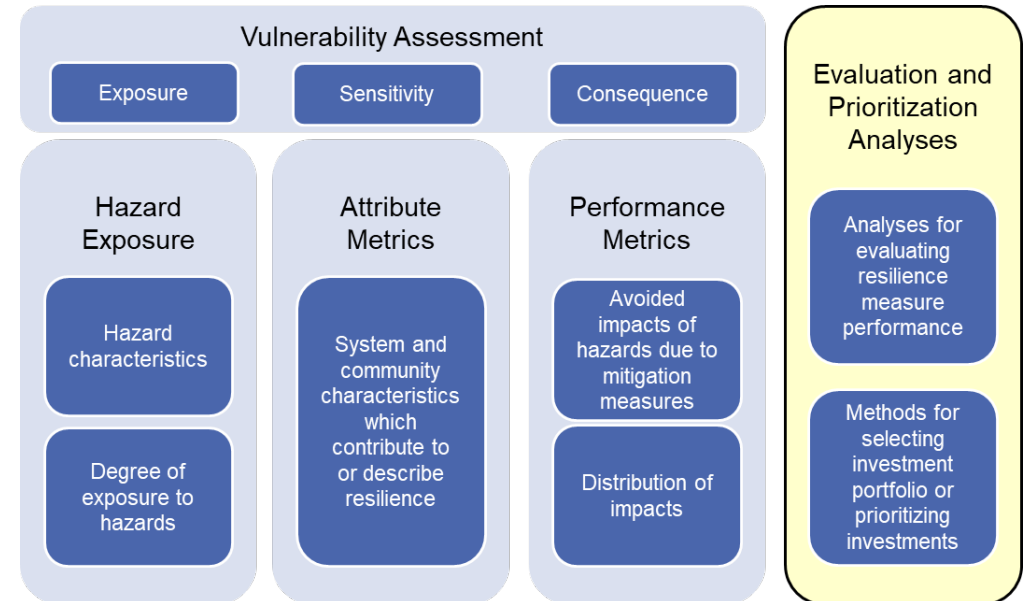
Source: [NYSERDA](#)



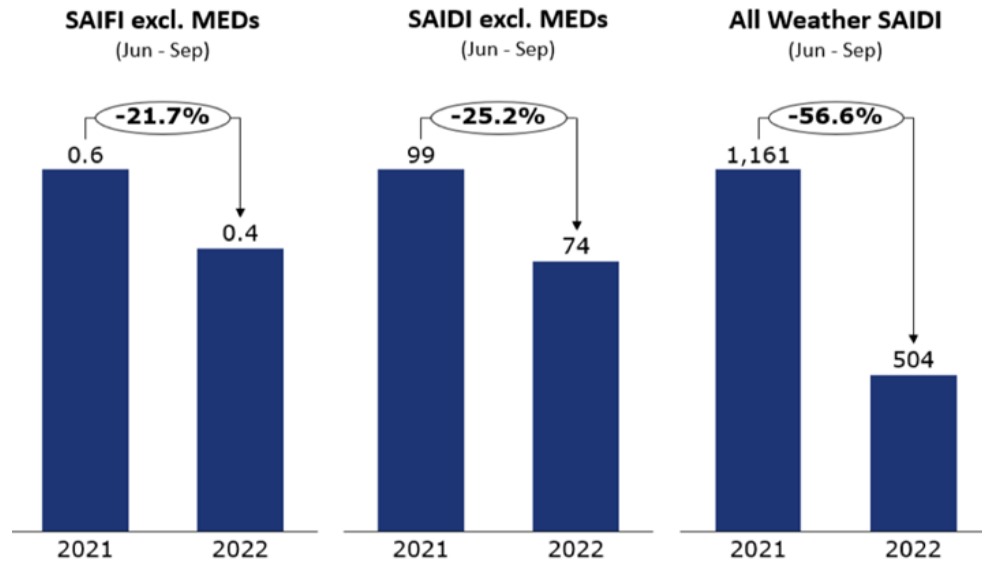
Source: [OEHHA](#)

Evaluation and Prioritization Analyses

- Ex Post Analyses
 - Compare performance of the electric grid before and after implementing resilience measures
 - Helpful for assessing the effectiveness of deployed measures
- Ex Ante Analyses
 - Estimate the effect that resilience measures will have on performance metrics
 - Often leverage information learned in ex post studies about statistical associations between hazard events, resilience measures, and negative outcomes to the grid
- Prioritization Analyses
 - Identify, assess, and prioritize resilience solutions that mitigate vulnerabilities to extreme weather hazards



Ex Post Analysis Examples



DTE Electric: Performance Improvements from Short Cycle Preventative Maintenance Programs

	Hurricane Wilma	Hurricane Irma
Hurricane Strength (Category)	3	4
Customer Outages (Millions)	3.2	4.4
Distribution Poles Replaced	>12,400	<2,900 ¹³
Total Days to Restore	18	10
Average Days to Restore	5.4	2.1

Transmission Facilities	Hurricane Wilma	Hurricane Irma	Improvement
Line Section Outages	345	215	38%
Substation Outages	241	92	62%
Structures Failed	100	5	95%

FPL: Ex Post Analysis of Distribution Pole and Transmission Facility Performance during Hurricanes

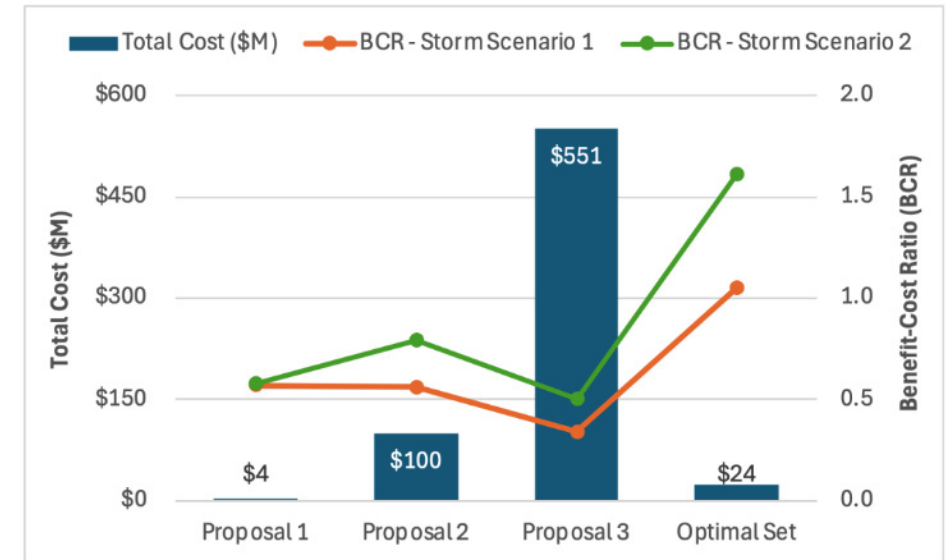
Timeframe	SAIDI		SAIFI		MAIFI	
	Non RFW	RFW Day	Non RFW	RFW Day	Non RFW	RFW Day
2019-2020	0.29897	0.32451	0.00182	0.00250	0.00545	0.00345
2021-2023	0.29167	0.33027	0.00176	0.00211	0.00505	0.00601
% Difference	Negligible	2%	Negligible	Negligible	Negligible	74%

PGE: Ex Post Analysis of Systemwide Reliability Performance (June 1-October 31) on RFW and Non-RFW Days (Excluding MEDs)



Prioritization Analyses and Example

Analysis Category	Explanation	Key Planning Indicators	Methods & Tools	Utility Plan Examples
Benefit-Cost Analysis (BCA)	Compares and prioritizes resilience measures based on present value of monetized benefits and costs	Benefit-Cost Ratio	Interruption Cost Estimate (ICE) Calculator, Power Outage Economics Tool (POET)	Entergy New Orleans (2023), TECO (2022), United Illuminating (2022), Xcel Energy (2019)
Risk-Based Analysis	Estimates cost-effectiveness based on risk reduction benefits (calculated by probability and associated consequences) and costs for a specific solution	Risk-Spend Efficiency, Value-Spend Efficiency	Bowtie Method, Geospatial Analysis	Duke Energy Florida (2022), FPU (2022), Idaho Power (2023), NV Energy (2023), Oncor (2024), Pacific Power (2023), PGE (2023), RMP (2023)
Multi-Criteria Assessment	Compares benefits that are difficult to quantify or monetize, using composite indices, or that may not be effectively highlighted in financial analysis	Composite Indices	Index Calculation, Weighting	Con Edison (2023b), Consumers Energy (2023), DTE Electric (2023), National Grid (2023b), NYSEG (2023), O&R (2023b), PGE (2022), RG&E (2023)



United Illuminating Resilience Plan BCA Results

Source: Summary of United Illuminating (2022) Results



Key Findings and Emerging Best Practices



Key Findings

- Resilience planning presents unique challenges for utilities, regulators and stakeholders.
- Utility methods for approaching risk and vulnerability assessments vary in nomenclature but have a similar framework.
- An increasing number of indices are in use for characterizing resilience attributes and performance.
- Utilities and regulators acknowledge the need to augment standard reliability metrics with metrics tailored to measure resilience.
- Regulators and stakeholders face a tradeoff between more granular utility data and limited resources to analyze and interpret the data.
- Utilities and states are increasingly defining and considering vulnerable populations in grid resilience planning efforts.
- Utilities and regulators are increasingly taking steps to systematically measure and track performance of resilience investments, such as measuring ex post impacts.



Emerging Best Practices

- Select or establish a clear analysis framework based on capabilities, regional preferences, and resilience objectives.
- Establish and maintain consistent definitions and accurate location data for critical facilities.
- Understand the key socioeconomic factors that define populations that are more vulnerable to adverse impacts of power interruptions and severe weather.
- Measure resilience impacts at a granular level and be consistent in tracking interruption causes.
- Advance efforts to address uncertainty associated with the likelihood and magnitude of resilience events.
- Use a combination of metrics to understand system performance.
- Conduct regular, systematic ex post (backward-looking) analyses following resilience events and apply learnings in future planning cycles.



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Extra Slides



Electrical Service Metrics

	Examples of Metrics	Description
Interruption Events	Interruptions	Count of interruption events
	Customer Minutes Interrupted	Sum of all customer minutes interrupted over a given time period
Interruption Frequency	SAIFI (with and without MEDs)	System Average Interruption Frequency Index: total number of interruptions that an average customer experiences over some time period
	MAIFI (with and without MEDs)	Momentary Average Interruption Frequency Index: total number of momentary interruptions (< 5 minutes) that an average customer experiences over some time period
Interruption Duration	SAIDI (with and without MEDs)	System Average Interruption Duration Index: total number of minutes that an average customer is without power over some time period
	CAIDI (with and without MEDs)	Customer Average Interruption Duration Index: time required to restore service for an average customer over some time period
	Percent of interruptions lasting longer than X hours	
Customer-Focused	Customers Experiencing Multiple Interruptions (CEMI _n)	Ratio of customers experiencing n sustained interruptions to the total number of customers served
	Customers Experiencing Long Interruption Durations (CELID)	Ratio of individual customers that experience interruptions with durations longer than or equal to a given time
Additional Metrics	Circuit Performance Indicator (RMP, 2019)	$Index * [(SAIDI * WF * NF) + (SAIFI * WF * NF) + (MAIFI * WF * NF) + (Lockouts * WF * NF)]$
	IEEE Storm Resilience Metric (IEEE, 2020)	Quantifies the speed of recovery during the first 12 hours of a storm from customers losing power
	Expected Unserved Energy	Estimated quantity of electricity that would have been consumed if an interruption had not occurred



Anticipate

Metric Type	Metric Description	Utility Example
Potential for hazards to damage assets	Substations located within a FEMA 100- or 500-year floodplain	National Grid (2023a)
	Transmission line mileage located within High Fire Risk Areas	PG&E (2024)
	Environmental monitoring systems	California Office of Energy Infrastructure Safety WMP Reporting Requirements
	Weather forecasting	California Office of Energy Infrastructure Safety WMP Reporting Requirements
Potential for assets to damage surroundings	Annual probability of asset-caused ignition	PGE (2023)
	Number of asset management ignition risk- related work orders that are past due	SCE (2023)
	Number of vegetation contacts with lines in Wildfire Risk Tiers	NV Energy (2023)
	Ignition Potential Index – potential for ignition of a large wildfire given fuel and weather conditions	PGE (2023)



Withstand

Metric Type	Metric Description	Utility Example
Asset condition	Asset age	PGE (2023)
	Asset condition (inspection data – source)	California Office of Energy Infrastructure Safety WMP Reporting Requirements
	Improvements to tracking of asset condition related to joint-use poles	Duke Energy Carolinas (2023)
Asset ratings or hardening status	Total number of transformers that meet the latest temperature specification	NYSEG (2023)
	Total number of upgraded transformers	National Grid (2023)
	Total number of upgraded transmission assets	TECO (2022)
	Distribution feeders upgraded	TECO (2022)
	Conductor temperature ratings by location in the service territory	PG&E (2024)
	Line miles undergrounded for wind and ice	O&R (2023)
	Critical substation assets elevated in floodplains	PSEG Long Island (2024a)



Adapt



Recover

Metric Type	Metric Description	Utility Example
Preparedness	Collaboration on local wildfire mitigation planning	California Office of Energy Infrastructure Safety WMP Reporting Requirements
	Minimum staffing required in preparation for event response	PGE (2023)
Accessibility	Average drive time from a fire station	PGE (2023)
	Access/egress road density by HFRZ	PGE (2023)
	Asset accessibility and terrain	Entergy New Orleans (2023)
Power Restoration	Reclosers automated or remotely-controlled	Pacific Power (2023)
	Fire response time	PGE (2023)



Areas for Further Research

- Collect and analyze infrastructure failure data consistently and systematically.
- Track and analyze interruption restoration strategies and approaches to understand how they affect interruption durations.
- Track and analyze the effectiveness of preventive maintenance activities for grid assets.
- Improve physical models for how networks and assets generally fail.
- Develop publicly available resources for estimating effectiveness of resilience measures.
- Continue to advance efforts for understanding impacts of widespread, long-duration interruptions to regional economies.



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