NASEO-NARUC Training for States on Grid Resilience Planning

Nashville, Tennessee
March 21, 2024

The U.S. Department of Energy's Grid Deployment Office provided support for this training

TOM KING

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National Association of State Energy Officials

Agenda review

Morning Agenda	
8:30 am	Welcome and Agenda Review
8:45 am	Integrated to Resilience for Electricity Systems – *Krishnamoorthy*
9:15 am	Identifying Threats and Risks – *Wall*
10:15 am	Break
10:30 am	Example Vulnerability Assessment – *Klein and Weisenfeld*
11:15 am	What Should Resilience Plans Include? – *Schellenberg*
12:00 pm	Lunch

Afternoon Agenda	
12:45 pm	Exercise: Engaging Stakeholders and Building Equity – *O'Quinn and Reed*
1:30 pm	Strategies for Valuing and Prioritizing Investments – *Larsen*
2:30 pm	Mitigation and Restoration Strategies: Case Studies – *Schellenberg*
3:15 pm	Break
3:30 pm	State Criteria for Evaluating Resilience Projects – *Wall and panel*
4:30 pm	Adjourn

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NREL Transforming ENERGY

Introduction to Resilience for Electricity Systems

Presented by Gayathri Krishnamoorthy, National Renewable Energy Laboratory

Resilience Training for States
Nashville, Tennessee

March 21, 2024

Agenda

- Introducing Resilience:
    - Defining Resilience
    - Understanding Risks
    - Vulnerability, & Consequence
    - Measuring Resilience
- Mitigation and Resilience Solutions
    - Example of Stakeholder Driven Approach
- Resources for more information
- Q&A

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Introducing Resilience

Reliability		Resilience
The ability to meet the electricity needs of end-use customers, even when events reduce the amount of available electricity	Definition	The ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions
Uncertainty associated with fluctuating load and generation, fuel availability, and failure of assets under normal operating conditions	Event Characteristics	Low-probability, high-consequence events that represent black-sky operating conditions and apply stress to a system over a large scale
Seconds to hours	Outage Duration	Days to months
Concentrated area (e.g., one facility, campus, or neighborhood)	Spatial Extent	Large geographic region (e.g., states, regions, or islands)
Losses largely limited to unserved load for a subset of customers	Economic Losses	Losses arising from both lost load and cascading impacts to the economy (such as degraded water quality or delivery due to power loss)

Source: Hotchkiss, Eliza, Nick Grue, and Moriah Petty. 2023. Understanding Resilience Valuation for Energy Systems: An Overview of the NYSERDA-NREL Research Collaboration. Golden, CO: National Renewable Energy Laboratory. NREL/FS-5R00-86923

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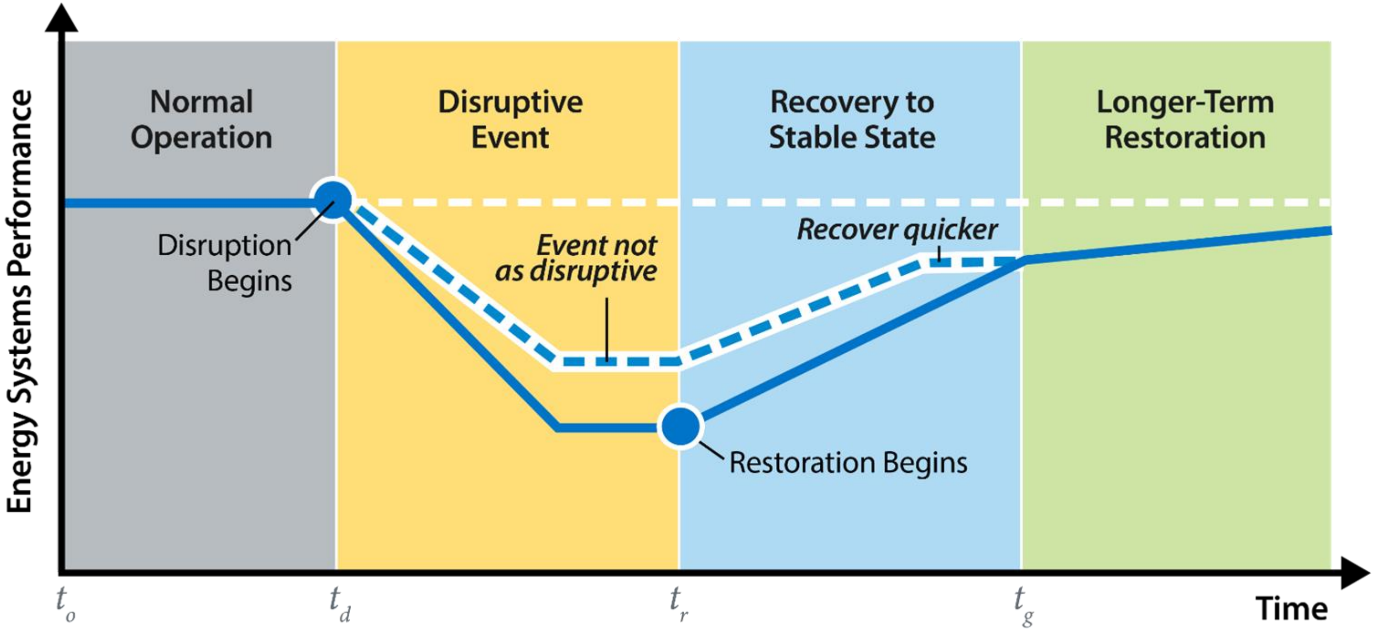
Established Resilience Definitions

The ability to anticipate, prepare for, and adapt to changing conditions and to withstand, respond to, and rapidly recover from disruptions through adaptable and holistic planning and technical solutions.[1]



Resilience can be measured as a system's performance subject to both acute shocks and chronic stresses.

Types of systems:

- Engineered system (e.g., power grid)
- Social system (e.g., communities)
- Geographically defined systems (e.g., military installation).

Types of shocks and stresses:

- Natural
- Human caused
- Systemic.

Resilience is contextual. A system resilient to one type of hazard may not be resilient to another.

[1]Hotchkiss, Eliza; Dane, Alex. 2019. Resilience Roadmap: A Collaborative Approach to Multi-Jurisdictional Resilience Planning. Golden, CO. National Renewable Energy Laboratory. NREL/TP-6A20-73509. https://www.nrel.gov/docs/fy19osti/73509.pdf.

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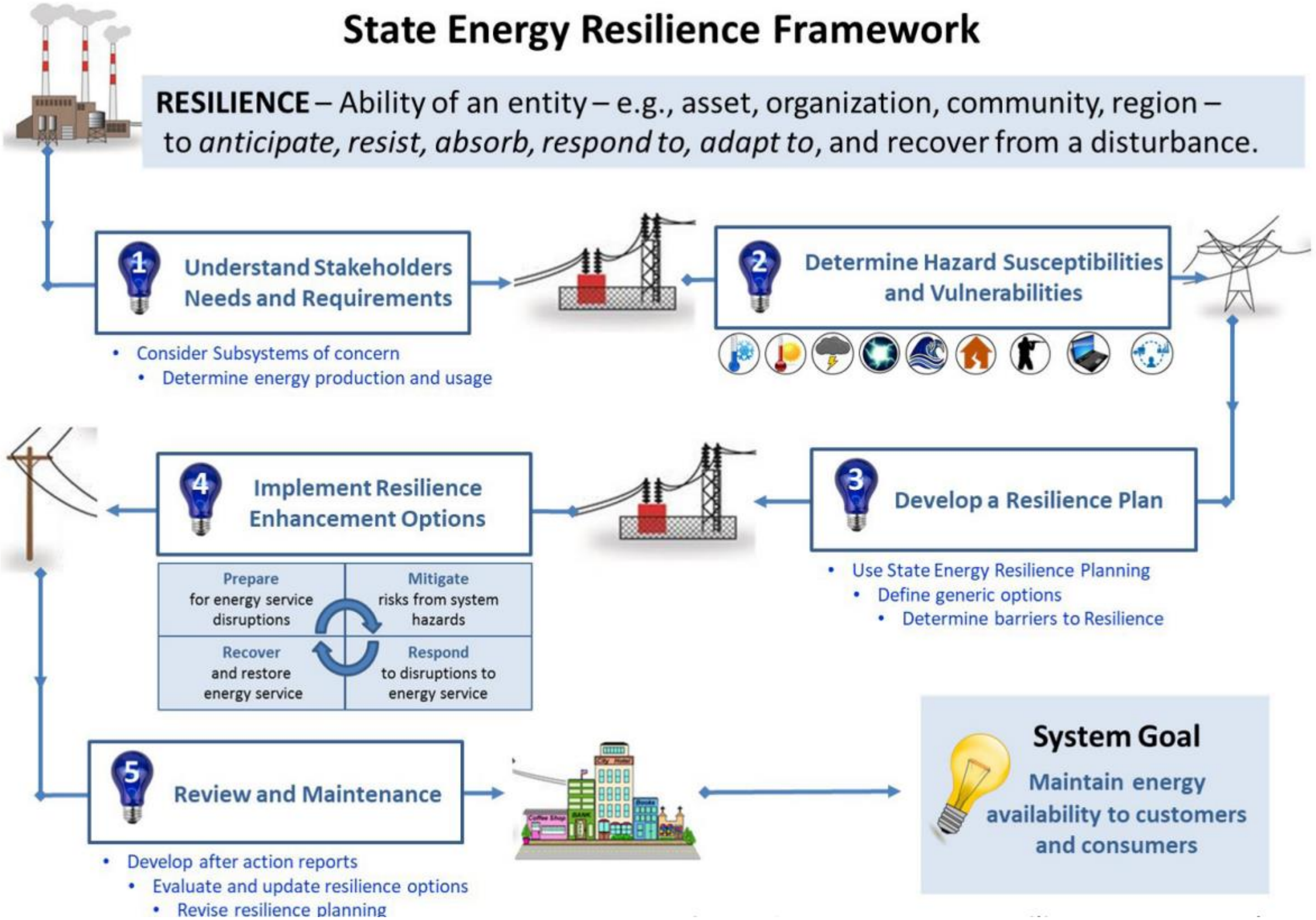
Risk Informed Approach to Resilience Assessments and Planning

Illustration by Jennifer Breen Martinez, NREL



K. Anderson, E. Hotchkiss, L. Myers, and S. Stout, "Energy Resilience Assessment Methodology," *Renewable Energy*, p. 29, 2019.

State Energy Resilience Framework, J. Phillips, M. Finster, J. Pillon, F. Petit, and J. Trail, Global Security Sciences Division, Argonne National Laboratory, December 2016, https://publications.anl.gov/anlpubs/2017/02/133591.pdf.

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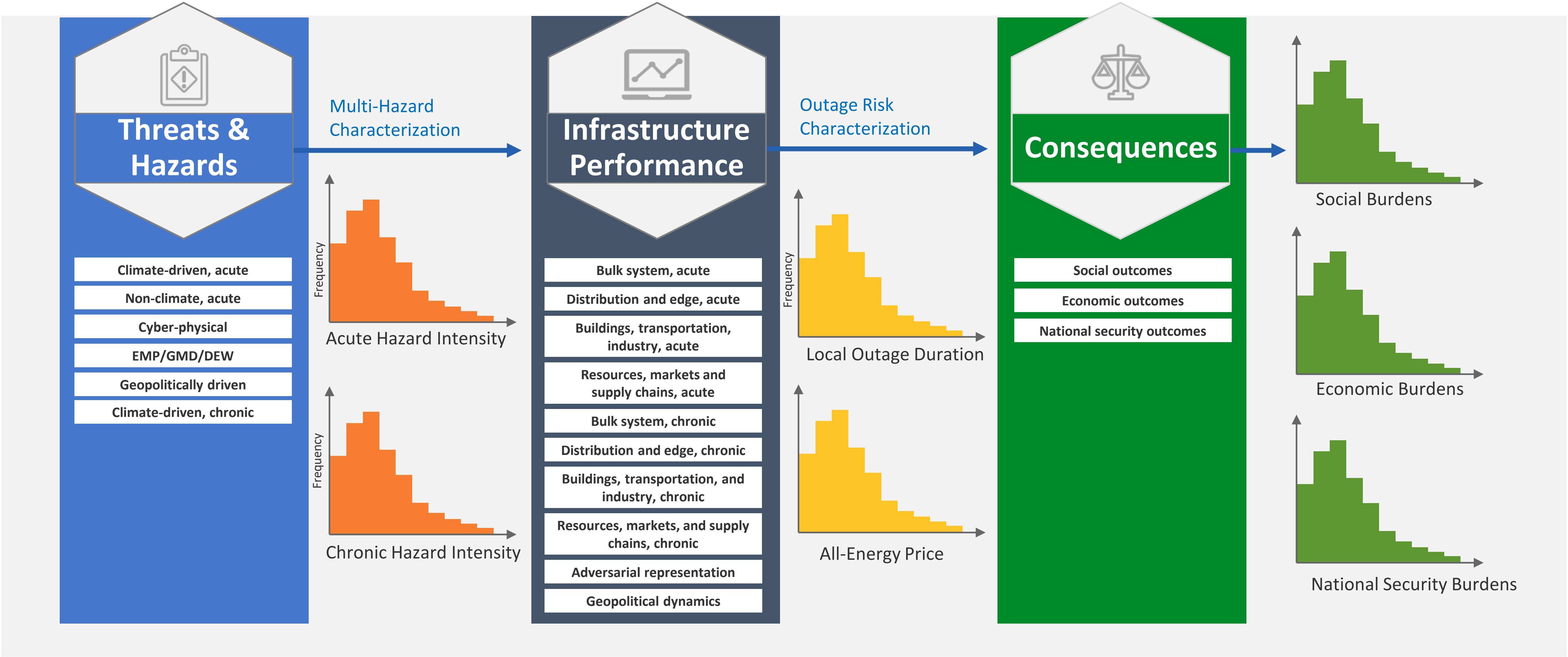
Resilience Components



Definitions

Hazard: Anything that can expose a vulnerability, either intentionally or accidentally, or that can damage, destroy or disrupt the power sector. Hazards can be natural, technological, or human caused. They are typically not within the operator's control and can include wildfires, hurricanes, storm surge, cyber-attacks and so on. Often used interchangeably with *threat*.

Threat: Something that is likely to cause damage or danger to the power sector. Often used interchangeably with *hazard*.

Vulnerability: A weakness in a system or process which, when exposed, can lead to a negative impact or consequence. Typically, vulnerabilities are within control and can be mitigated to avoid exposure.

Impact or Consequence: To have a direct effect or significant effect on something such as the power sector or components of the system.

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Hazards and Threats

Types of shocks and stresses:

- Natural
- Human caused
- Systemic

Types of systems:

- Engineered system (e.g., power grid)
- Social system (e.g., communities)
- Geographically defined systems (e.g., military installation)

Understanding Risks

- How do utilities identify high risk hazards?
  - determine the relative risk of different hazards
- How is risk defined?
  - $Risk \ = \ Probability \ x \ Vulnerability \ x \ Consequence$
- Are emerging risks considered proactively?
  - hurricanes, earthquakes, tsunamis, volcanos, wildfires, dam failure, drought, erosion, extreme heat, flood, hail, high winds, infectious disease, lightning, severe thunderstorm, space weather, tornado, and winter weather, physical attacks, and cyberattacks.

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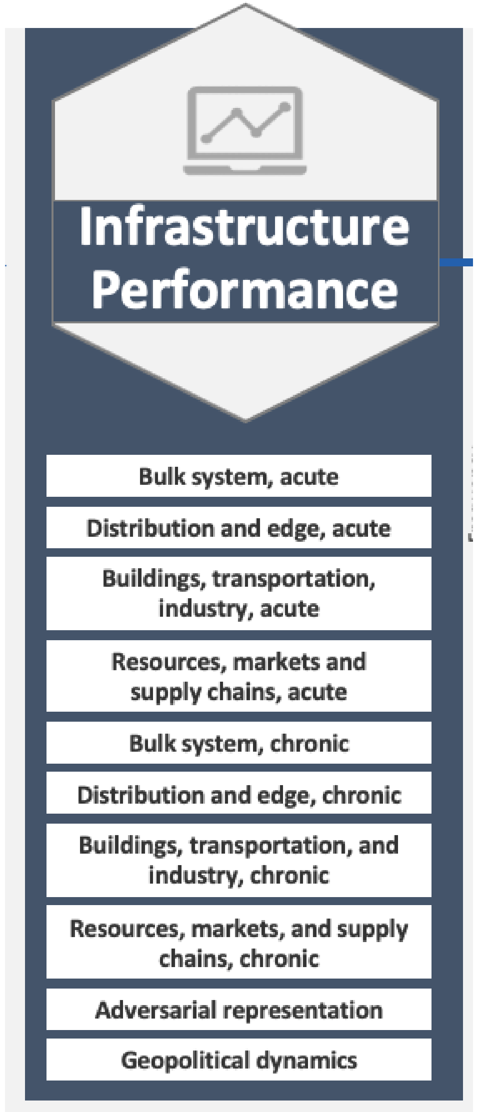
Vulnerabilities



- Power sector vulnerabilities usually fit into two categories:
  - Infrastructure
  - Process
- Both types of vulnerabilities need to be considered when assessing resilience options for the power sector
- Infrastructure vulnerabilities are often easy to address but tend to be very expensive
  - Power system hardening
  - Large infrastructure development
- Process vulnerabilities tend to be difficult to address but usually require relatively inexpensive fixes
  - Trainings
  - Development of codes and standards

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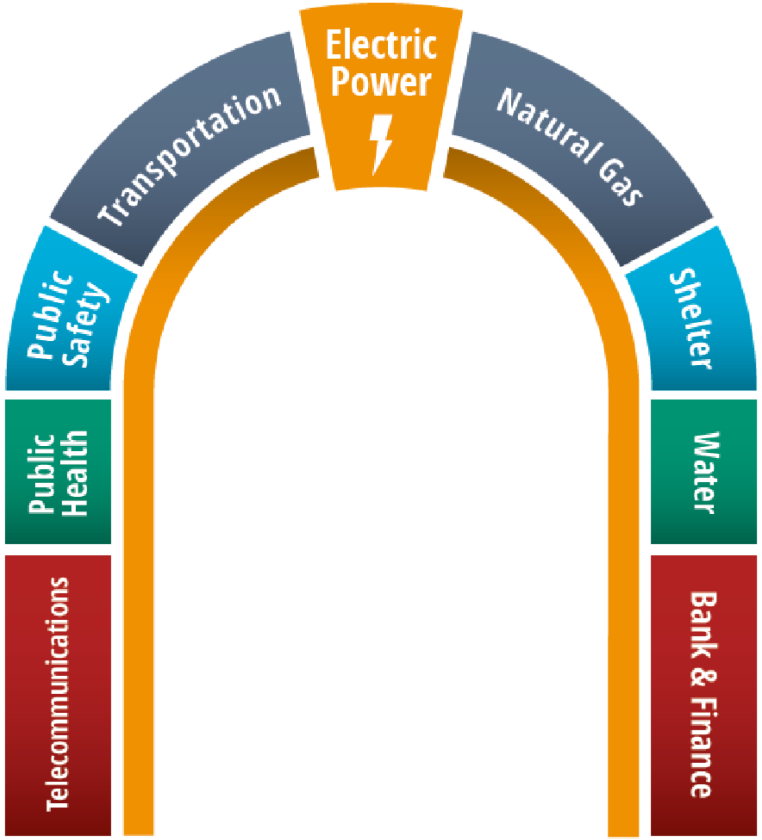
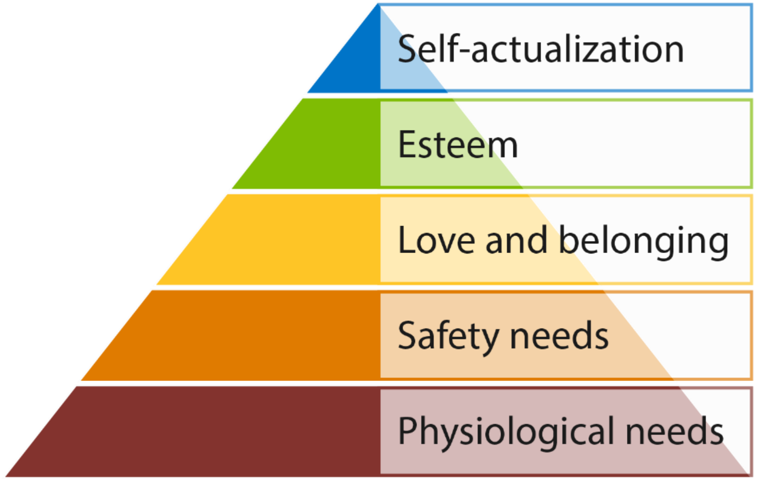
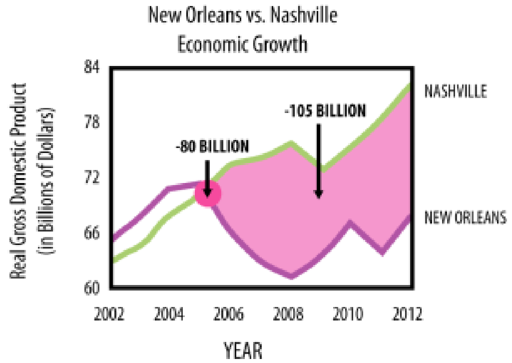
Consequences

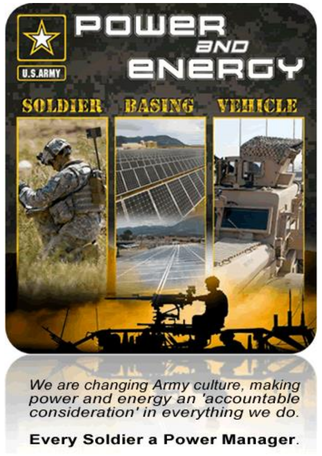
Within resilience, there are three major dimensions of consequence. These better define the externality and **lead to different internalization pathways**.



- **Society**
- **Economy**
- **National Security**







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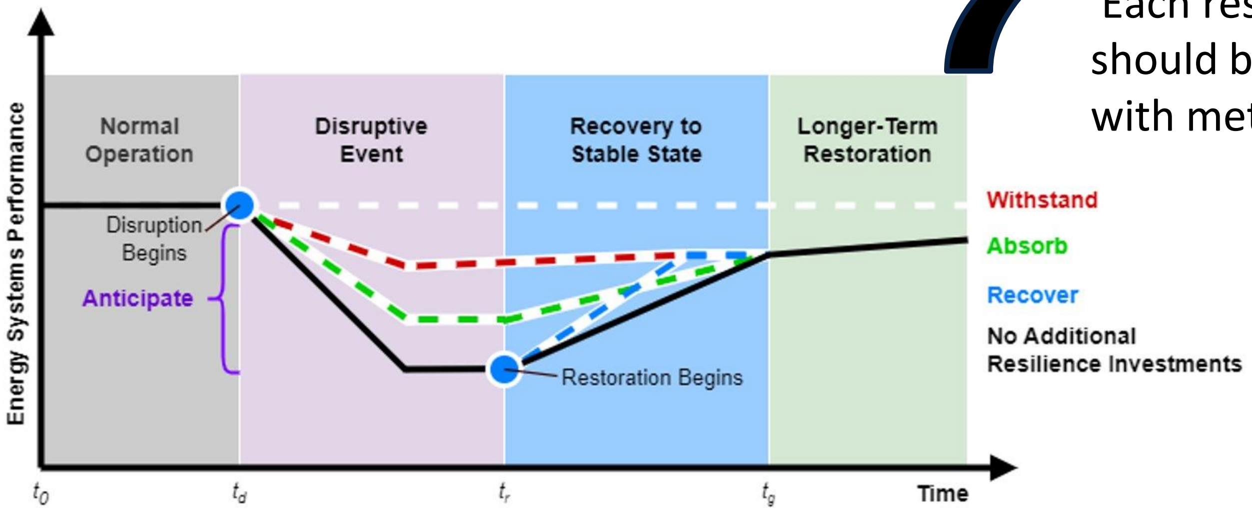
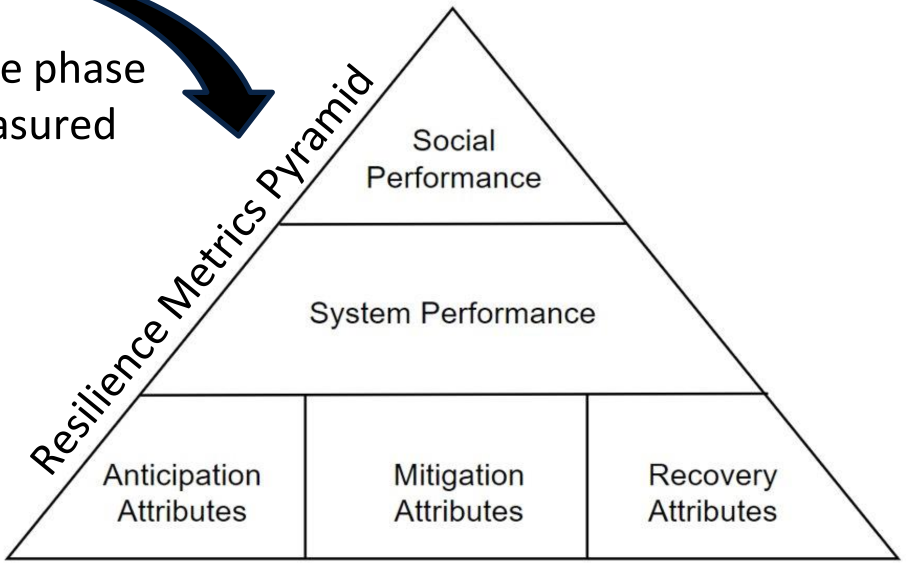
Measuring Resilience



Each resilience phase should be measured with metrics



There is no single metric for resilience and the metrics are evolving based on energy sector domain needs (e.g., generation, transmission, distribution, consumer), equity, justice, and social burden.

Murphy, Caitlin, Eliza Hotchkiss, Kate Anderson, Clayton Barrows, Stuart Cohen, Sourabh Dalvi, Nick Laws, Jeff Maguire, Gord Stephen, and Eric Wilson. 2020. Adapting Existing Energy Planning, Simulation, and Operational Models for Resilience Analysis. Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-74241. https://www.nrel.gov/docs/fy20osti/74241.pdf.

Attribute Metrics

- ❑ Are attribute metrics used to characterize system strengths and weaknesses in the face of specific hazards?
- ❑ Are attribute metrics collected that describe the system's ability to anticipate, withstand, absorb, and recover?
- ❑ Are attribute metric collected in a manner consistent with utility and industry standards?
- ❑ Are attribute metrics used to guide investment decisions?
- ❑ Data hygiene: Are data of sufficiently high resolution? Is data coverage sufficient?

Metric	Resilience Category
Asset age, location, condition	Anticipation
Asset ignition probability	Anticipation
Tree-related outages (inside/outside right-of-way, storm/non-storm)*	Anticipation
Vegetation density	Anticipation
Recorded wire downs per overhead line mile	Anticipation and withstand
Percent undergrounded	Withstand
Overhead structure wind design differential	Withstand
Fire Response Time*	Recover
Asset accessibility and terrain	Recover

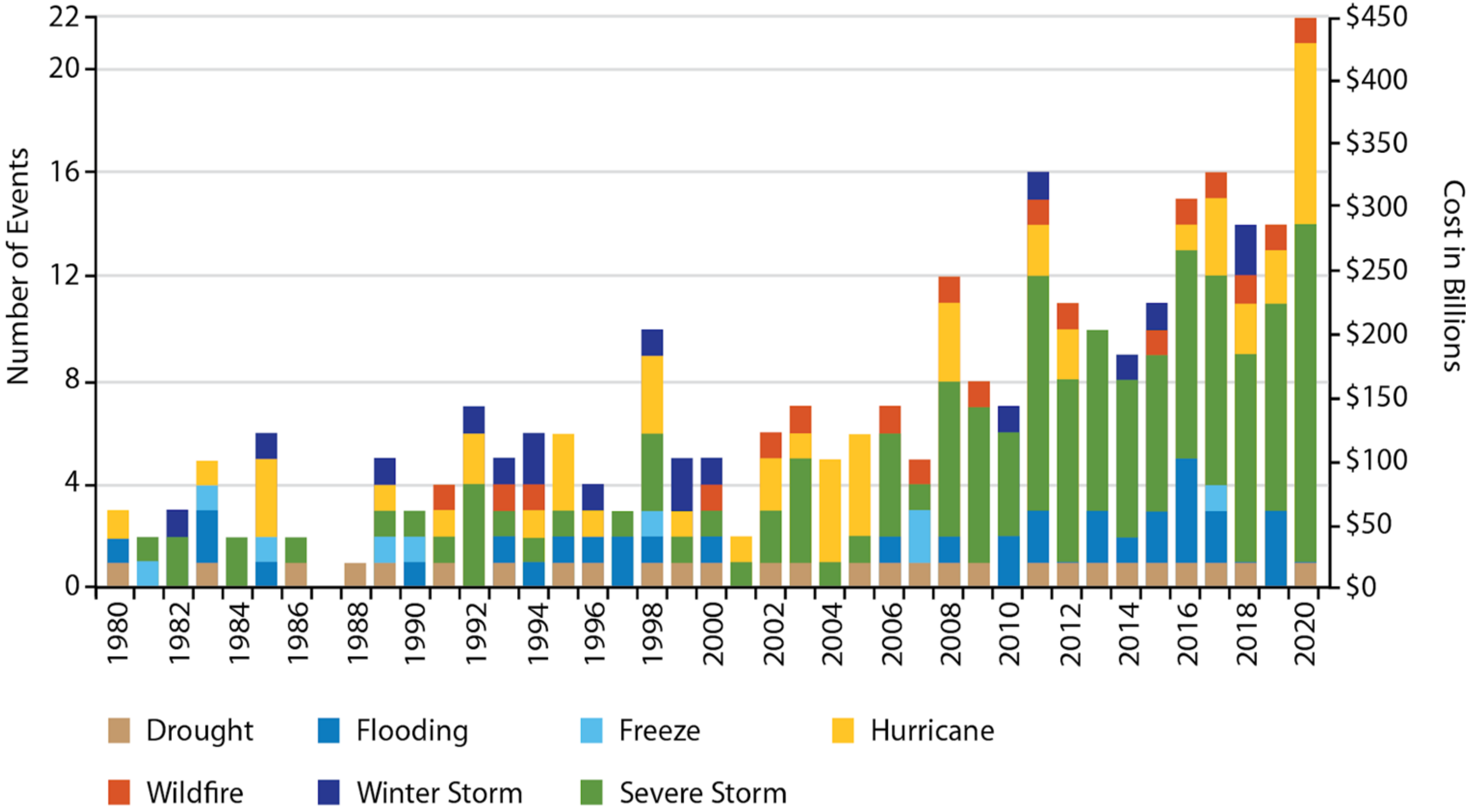
* Some attribute metrics may also be performance metrics

Performance Metrics

- Are performance metrics defined?
- Are the performance metrics used to measure how well a utility is meeting its resilience objectives?
- Are the performance metrics used to track how well a utility is meeting other objectives, such as equity, clean energy, and reliability?
- Are the resilience performance metrics applicable to all hazards or they developed specifically for one hazard?
- Data hygiene: Are data of sufficiently high resolution? Is data coverage sufficient?

Metric
Customer Minutes Interrupted
Restoration cost per event (e.g., major storm)
Storm CAIDI, SAIDI, SAIFI
SAIDI, SAIFI, CAIDI, MAIFI
Faults in High Fire Risk Areas
Number of customers de-energized during PSPS events
Percent customers notified prior to a PSPS event
Time to restoration for customers experiencing extended outages
Acreage burned

United States Billion-Dollar Disaster Events



Source: NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2021). https://www.ncdc.noaa.gov/billions/, DOI: 10.25921/stkw-7w73

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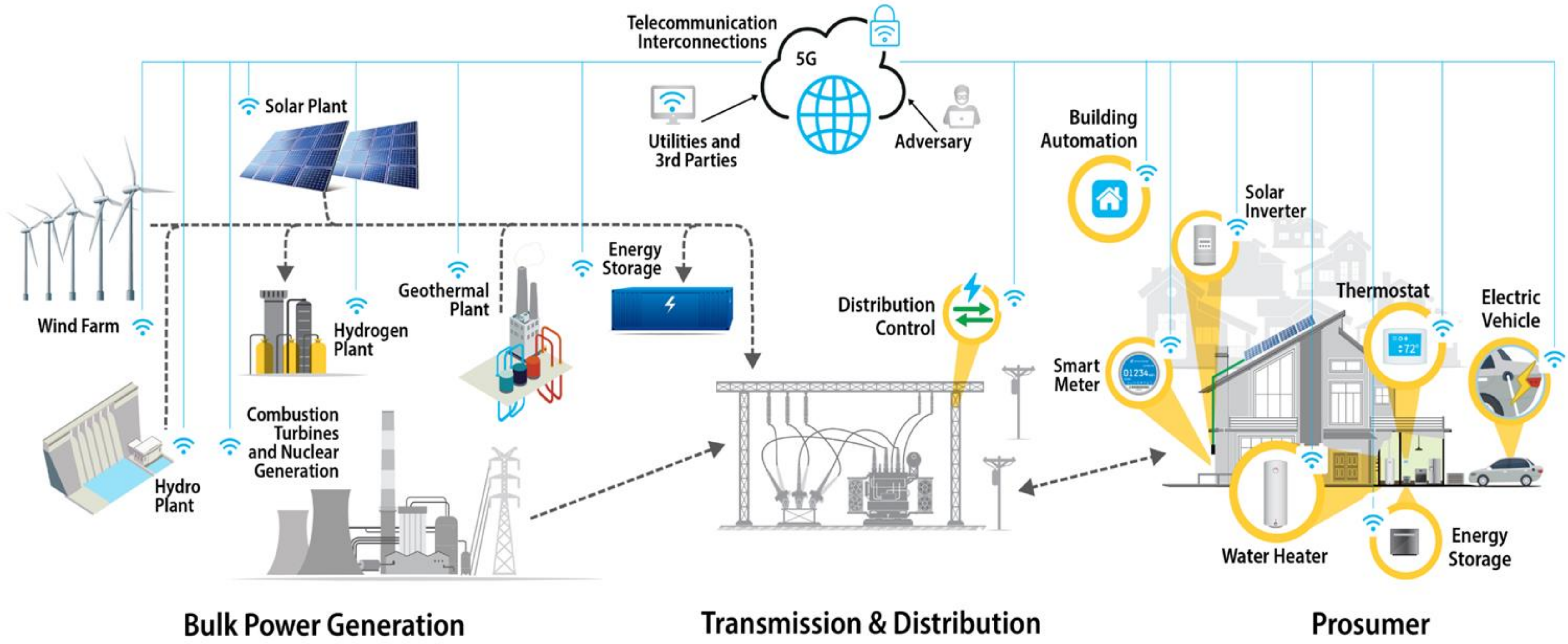

A New Frontier:

The grid is evolving to become more distributed, intelligent, and complex.

Coupled with aging infrastructure, the vulnerabilities of emerging energy systems to disruption are not yet well understood.

Resilience Solutions

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Energy

- **Energy Efficiency**
  Energy efficient buildings not only lower energy bills but can also allow occupants to shelter in place during a disruptive event. Architectural design concepts, such as passive survivability, can be incorporated to help vulnerable populations avoid life-threatening situations.

- **Distributed Energy Resources**
  Microgrids are islandable onsite energy generation (e.g., **rooftop solar**, wind, fuel cells) paired with energy storage solutions that can provide power to buildings or systems during disruptive events when the grid system may not be operational.

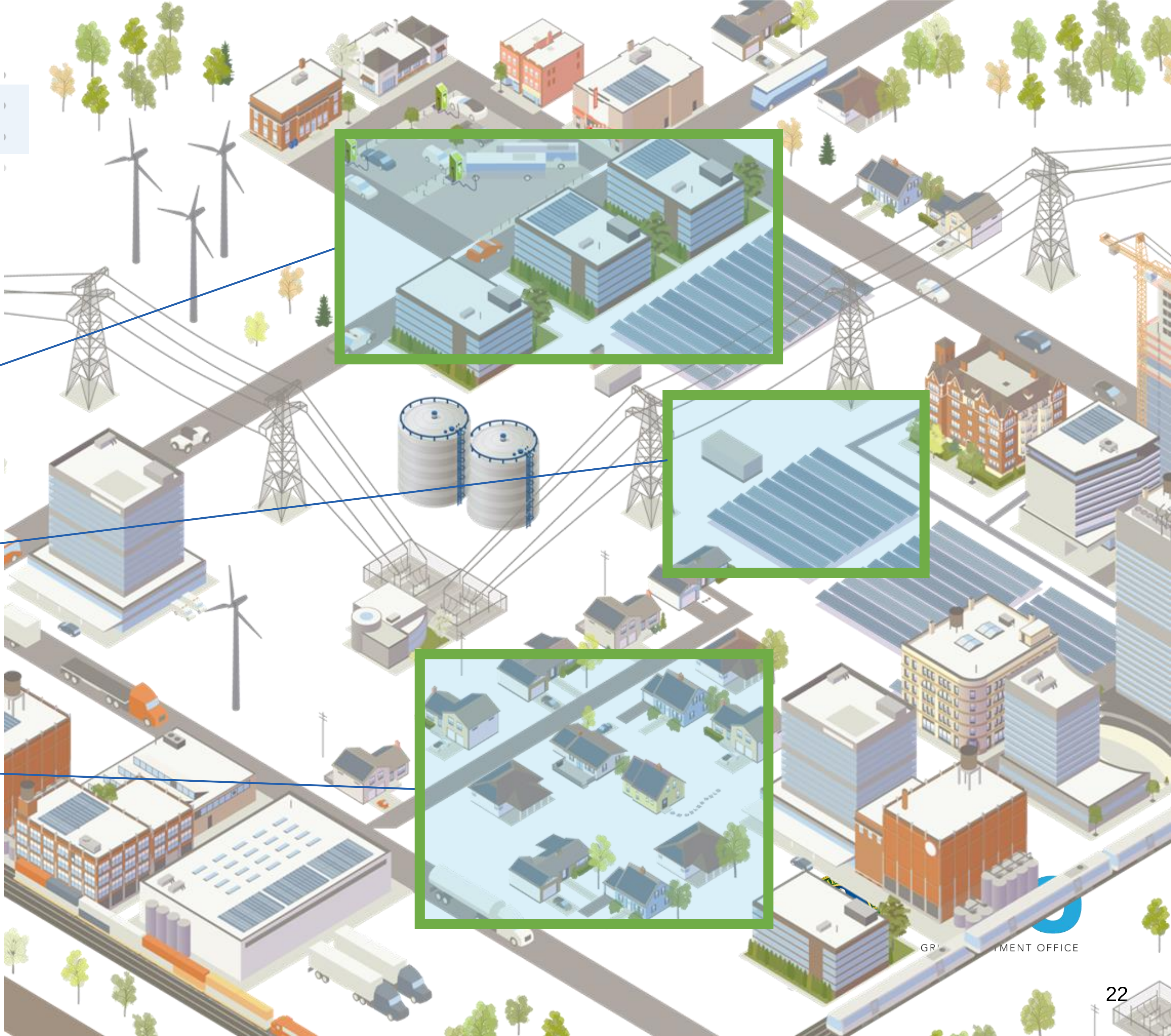

Image credit: Anthony Castellano, NREL

Transportation

- **Fuel diversity**
  Multiple modes of transportation and fuels can enhance resilience for daily needs *and* during disruptive events. Electric vehicles, walkable cities, and diversifying fuels can help meet transportation needs during disruptions.

- **Resilient infrastructure**
  Hardened infrastructure, porous pavements, and reinforced bridges can ensure that transportation routes are sustained during and after disruptive events.

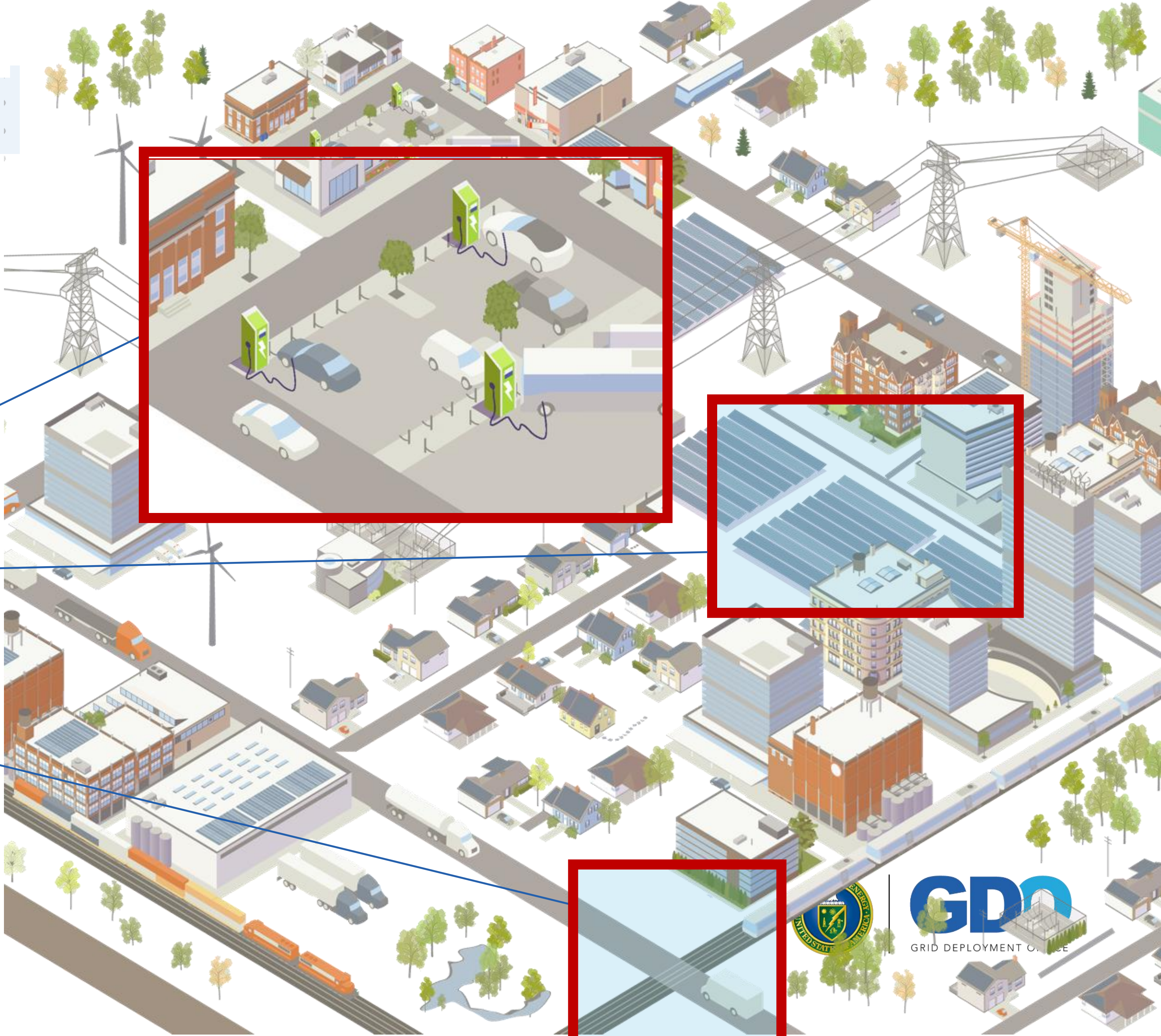

Image credit: Anthony Castellano, NREL

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Water

- **Conservation and Storage**
  Reducing the amount of water used within a building or process and having onsite water storage or a rainwater harvesting system can help meet water needs during a disruption to a municipal water supply.

- **Gravity Fed Systems**
  Using gravity to distribute water is a resilient solution because energy is not needed during normal operating conditions and disruptive events.

- **Green Infrastructure**
  Solutions such as using natural vegetation and bioswales can reduce localized flooding associated with storms and slow runoff rates.

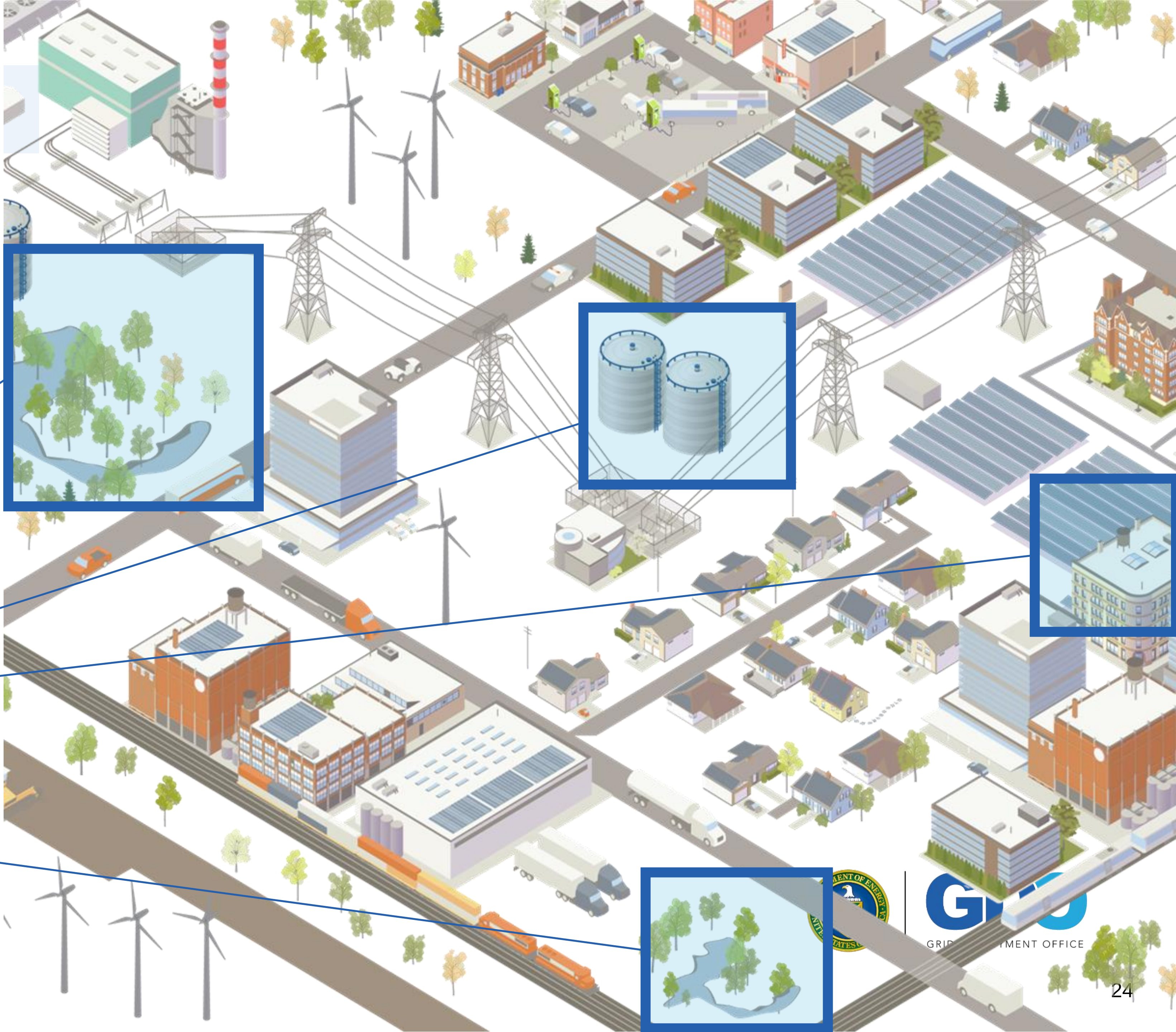

Image credit: Anthony Castellano, NREL

Information and Communication

- **Cybersecurity**
  Ensuring a secure cyber architecture is built into communications and IT networks will reduce risks associated with attacks and hacking, ensuring systems are operational.

- **Redundancy and Resourcefulness**
  Analogue backup systems and controls, redundant nodes, and trained workforce can increase the resilience of communications networks to all sorts of threats and hazards.

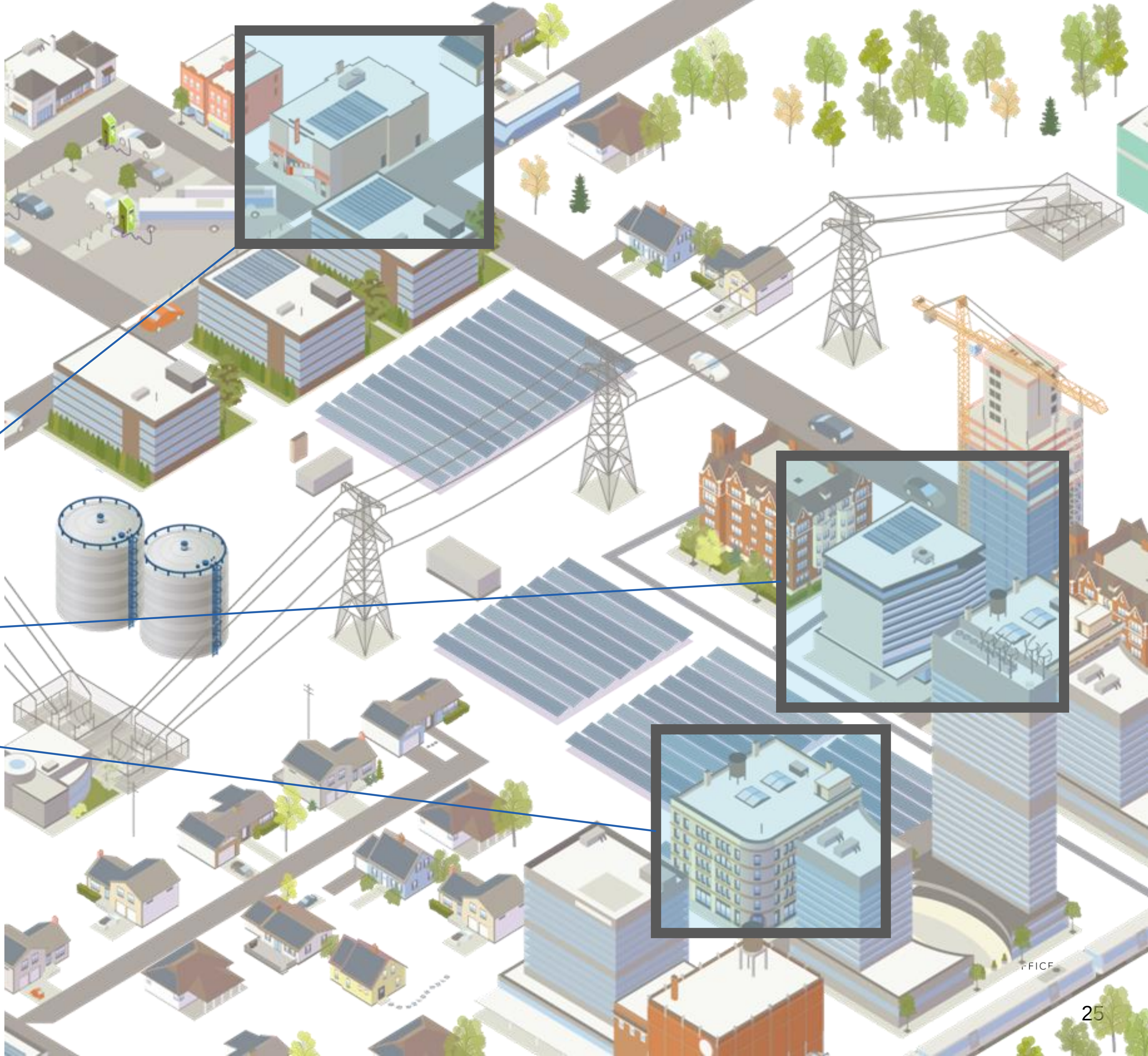

Image credit: Anthony Castellano, NREL

Questions for Utilities

- What hazards, threats, or vulnerabilities are you most concerned with for your utility, community, or state? – preliminary hazard characterization?
- What tools do you use to assess hazards, threats, and vulnerabilities?
  - Are you considering climate change and changing impacts?
  - How far in the future are you modeling?
- Have you prepared resilience plans?
  - Are those public or at least shared with state agencies?
  - How do you involve stakeholders in developing these?
- What resilience metrics are being used?
  - How do you measure progress for resilience investments?
  - How do you measure costs for resilience investments and is that data shared with the PUCs? Other state agencies?
- Are you assessing risk holistically across the entire system? Are mitigation measures assessed across the entire system?

Resources for more information

Resources

Research and Resources

- Energy Resilience Assessment Methodology: https://www.nrel.gov/docs/fy20osti/74983.pdf
- Valuing Resilience in Electricity Systems: https://www.nrel.gov/docs/fy19osti/74673.pdf
- Technical Resilience Navigator (NREL and PNNL): https://trn.pnnl.gov/
- Customer Damage Function Calculator: https://cdfc.nrel.gov/
- Energy Security and Resilience Research: https://www.nrel.gov/security-resilience/
- State Energy Resilience Framework, J. Phillips, M. Finster, J. Pillon, F. Petit, and J. Trail, Global Security Sciences Division, Argonne National Laboratory, December 2016, https://publications.anl.gov/anlpubs/2017/02/133591.pdf.

DOE Grid Deployment Office Resources

- Grid Resilience and Innovation Partnerships (GRIP) Program: https://www.energy.gov/gdo/grid-resilience-and-innovation-partnerships-grip-program
- Grid Deployment Office: https://www.energy.gov/gdo/grid-deployment-office

Contact

https://www.energy.gov/gdo/grid-deployment-office

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Thank you!

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Identifying Threats, Predicting Vulnerabilities, and Assessing the Risks

Tom Wall, Ph.D., Argonne National Laboratory

Resilience Training for States
Nashville, Tennessee

March 21, 2024

Presentation Outline

Uncertainty, Risks, and Vulnerability

- Introduction to Uncertainty & Risk
- Integrating Threat Information into Risk-Based Assessments
- Assessing Infrastructure Vulnerability

Climate Change Impacts

- Climate Science & Modeling 101
- Climate Impact Data Resources

Wrapping Up

- Questions to Ask

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Uncertainty, Risks, and Vulnerability

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Introduction to Uncertainty & Risk

Uncertainty

"…any departure from the unachievable ideal of complete determinism."
Walker et al. (2003)

- Randomness in events (aleatoric uncertainty)
- Limited knowledge (epistemic uncertainty)



Images: unsplash.com

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Introduction to Uncertainty & Risk

Risk

- Historical definition:

  …derives from random adverse events with probabilities of occurrence that can be statistically calculated.
  ~Knight, 1921 (paraphrased)

  - This suggests that risk can be viewed as a subset of uncertainty that can be quantified by statistical probability

- Modern definition:

  "…a measure of the probability and severity of adverse effects" from some event.
  ~Lowrance,1976, in Haimes, 2004

  - Risk is a function of (1) the likelihood (i.e., probability) of an event's occurrence, and (2) the consequences of that event.

Introduction to Uncertainty & Risk

- Quantitative approaches to risk & uncertainty
  - Risk = Likelihood X Consequence
  - Easiest to do when likelihood can be statistically quantified…
  - …and/or consequences can be quantified
    - E.g., Risk = 10% probability X $1M in losses
  - Frequently incorporated into engineering design standards
- Qualitative approaches to risk & uncertainty
  - Risk matrices
  - Scenario analysis (can also be used in quantitative analysis)

		Impact			
		Catastrophic	Major	Moderate	Minor
Likelihood	Very Likely	High	High	Med	Med
	Likely	High	High	Med	Low
	Medium	High	Med	Med	Low
	Unlikely	Med	Med	Low	Low
	Very Unlikely	Med	Med	Low	Low

Source: (MacArthur et al. 2012)

Functional Classification	Allowable Backwater, Annual EP	Roadway Serviceability, Annual EP	Service-ability Freeboard *	Bridge, Allowable Velocity, Annual EP	Culvert, Allowable Velocity, Annual EP
Freeway	1%	1%	2 ft	1%	2%
Ramp	1%	1%	0 ft	1%	2%
Non-Freeway, 4 or More Lanes	1%	1%	2 ft	1%	2%
Two-Lane Facility, AADT > 3000	1%	1%	1 ft	1%	2%
Two-Lane Facility, 1000 < AADT ≤ 3000	1%	4%	0 ft	1%	4%
Two-Lane Facility, AADT ≤ 1000	1%	10%	0 ft	1%	10%
Drive	1%	10%	0 ft	1%	10%

* Required serviceability freeboard is based on the difference between the edge-of-pavement and the structure-headwater elevations throughout the floodplain or watershed. Roadway serviceability should consider backwater effects from a larger downstream waterway.

DESIGN-STORM FREQUENCY FOR BRIDGE OR CULVERT

Source: (Indiana Department of Transportation, 2013

Introduction to Uncertainty & Risk

Systematically Thinking About Risk

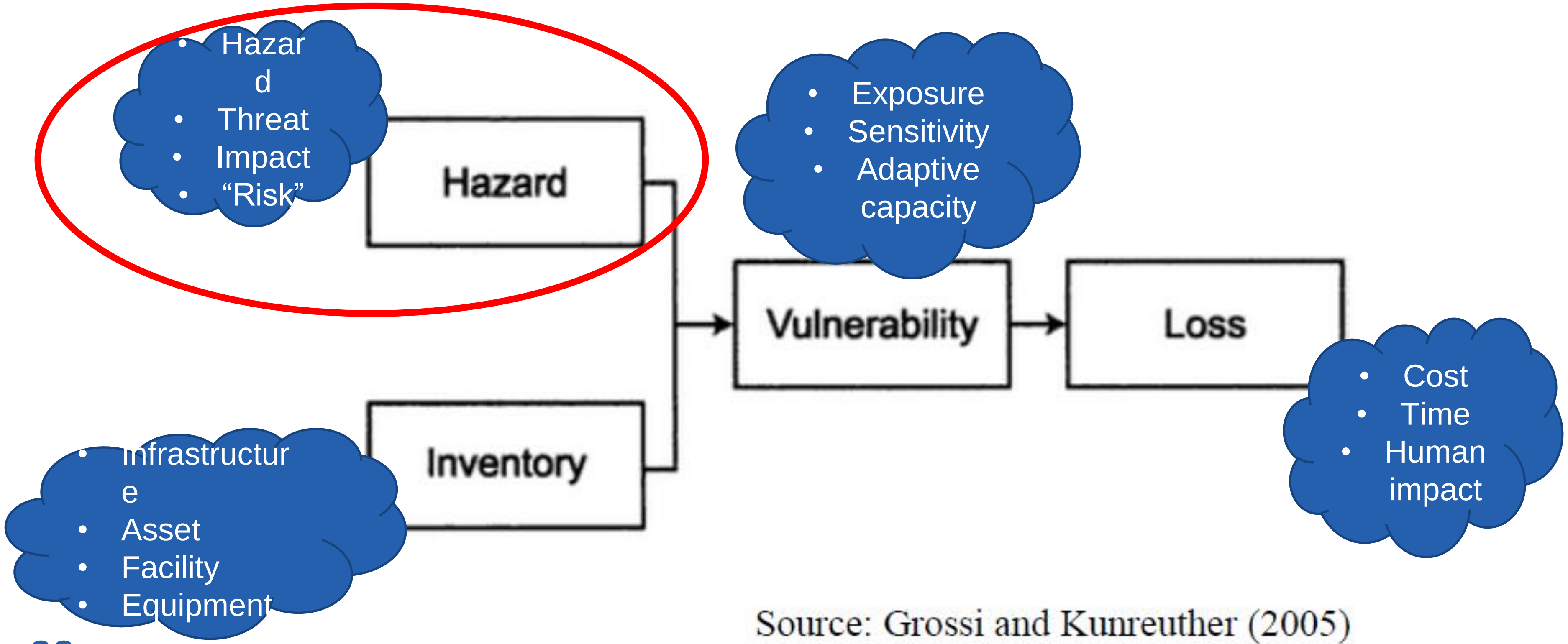
- ISO 31000:2018 – “Risk Management – Guidelines”
- Risk Assessment
  1. Risk Identification – Find, recognize and describe risks
  2. Risk Analysis – Model, quantify, measure level of risk
  3. Risk Evaluation – Prioritize; compare with the established risk criteria to determine what actions, if any at all

Image: https://www.iso.org/obp/ui/#iso:std:iso:31000:ed-2:v1:en

Integrating Threat Information into Risk-Based Assessments (1)

Infrastructure Risk – Catastrophe Model

- How does threat and hazard information fit into the construct of risk?



Source: Grossi and Kunreuther (2005)

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Integrating Threat Information into Risk-Based Assessments (2)

Probabilistic vs. Deterministic Hazard Information

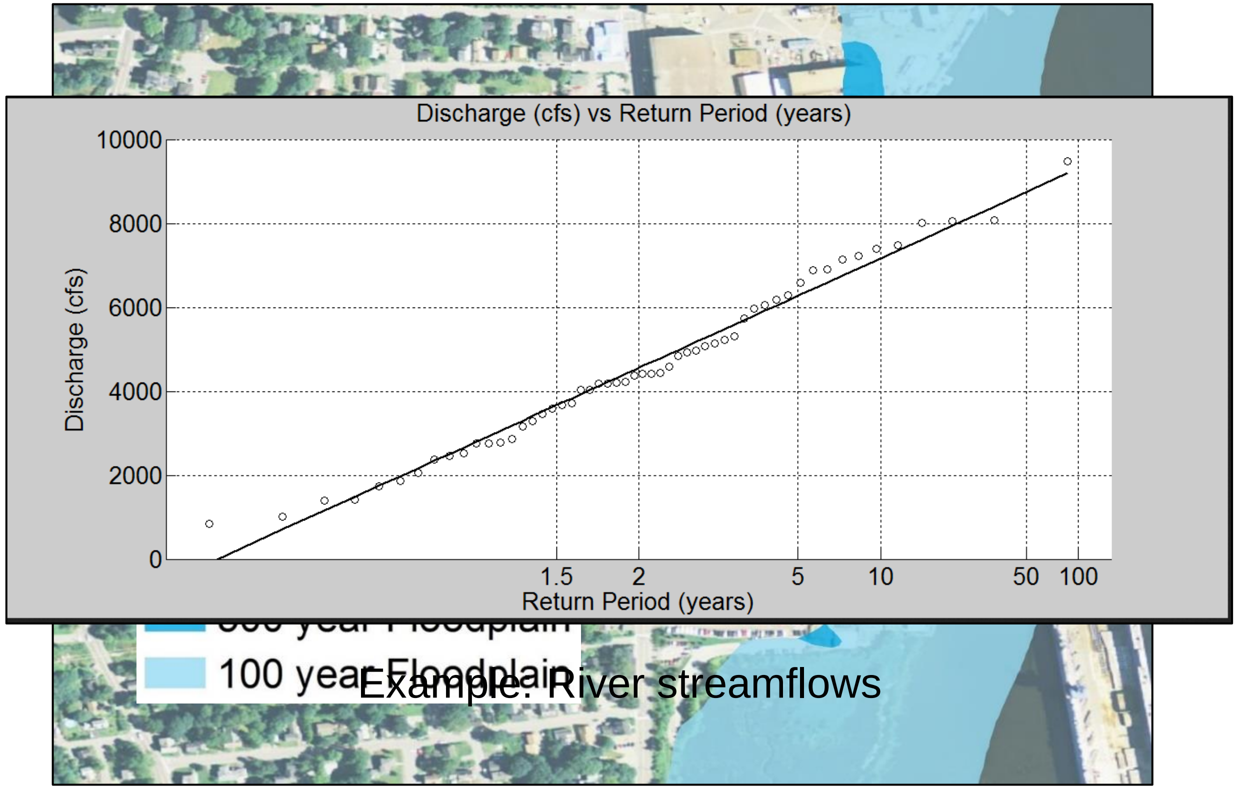
- Likelihood or probability based threat information
- Deterministic/scenario-based threat information

Example

Probability: Return intervals (e.g., flooding, storms, etc.)

$$T = N/n$$

Recurrence interval (**T**) is the number of years in record (**N**), divided by number of events (**n**)



Example: River streamflows

Image: https://serc.carleton.edu/hydromodules/steps/168500.html; Argonne National Laboratory

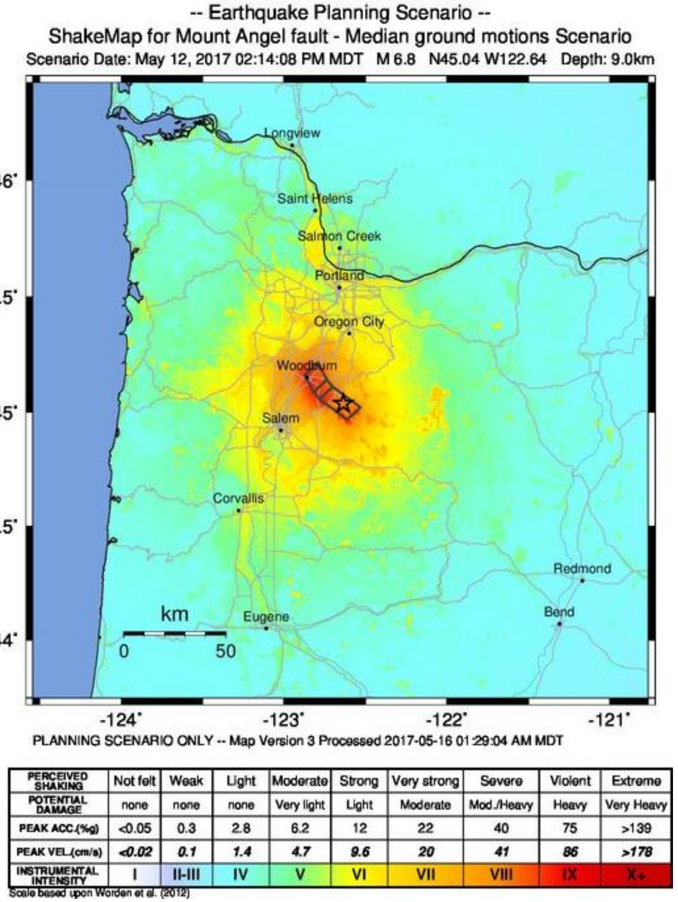
Integrating Threat Information into Risk-Based Assessments (3)

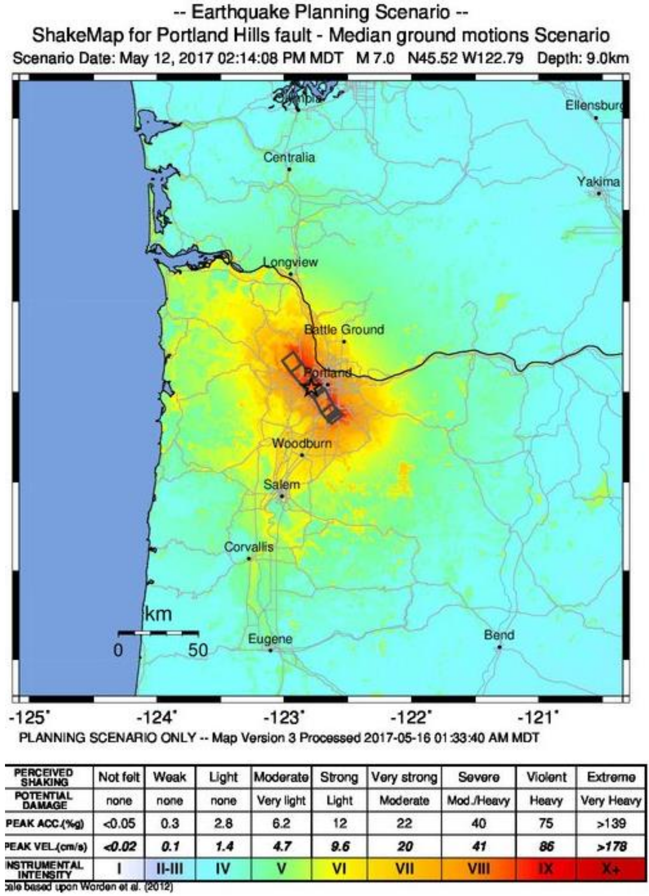
Probabilistic vs. Deterministic Hazard Information

- Likelihood or probability based threat information
- Deterministic/scenario-based threat information

Example

Scenario: Earthquake planning scenarios





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Images: https://earthquake.usgs.gov/scenarios/eventpage/bssc2014877_m7p05_se/executive; https://earthquake.usgs.gov/scenarios/eventpage/bssc2014873_m6p8_se/executive

Integrating Threat Information into Risk-Based Assessments (4)

Probabilistic vs. Deterministic Hazard Information

- Likelihood or probability based threat information
- Deterministic/scenario-based threat information

Hybrid Approach – Ensemble Scenarios

- Key feature of techniques like Robust Decisionmaking (RDM)
- Examining large numbers of scenarios moves ***toward*** a more comprehensive characterization of hazard impacts, or risk

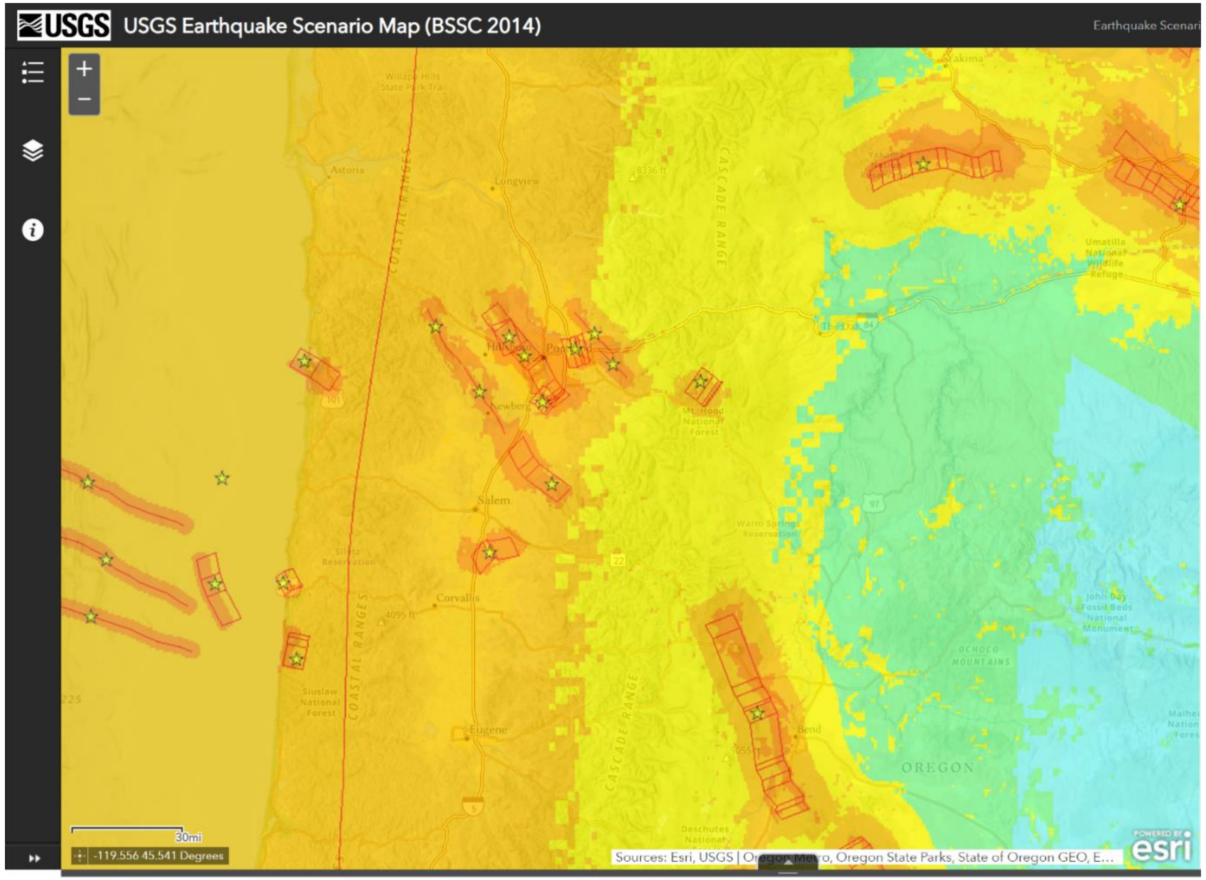

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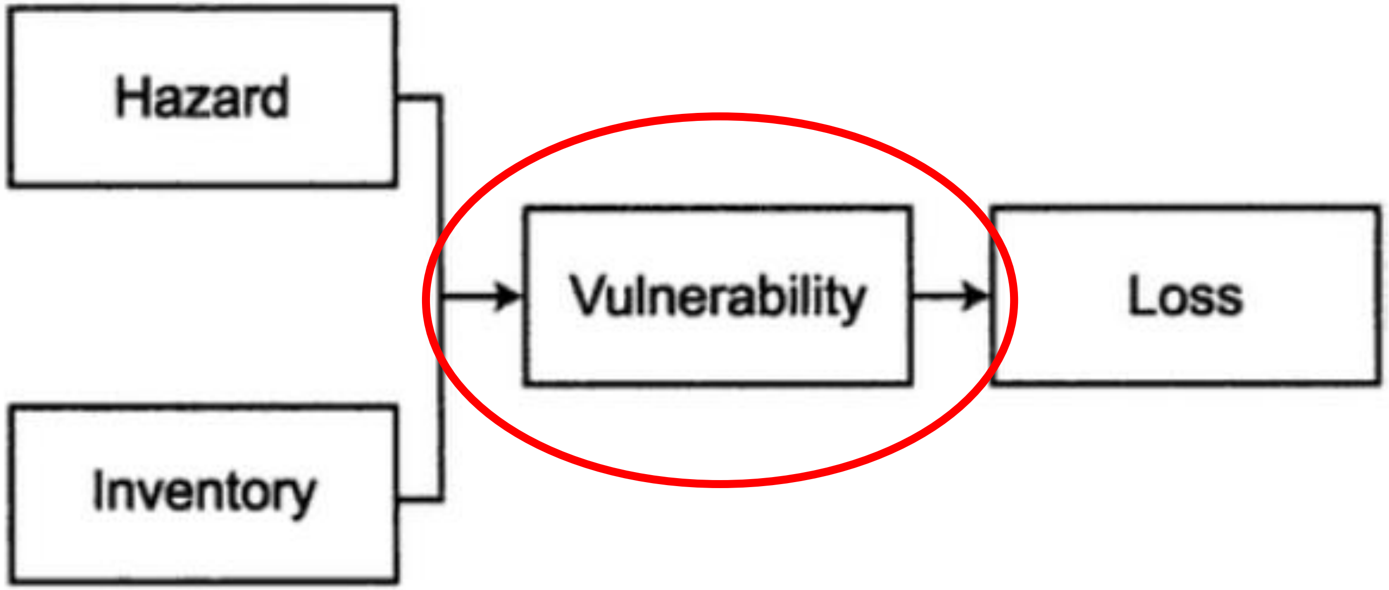
Image: https://usgs.maps.arcgis.com/apps/webappviewer/index.html?id=14d2f75c7c4f4619936dac0d14e1e468

Assessing Infrastructure Vulnerability

The Importance of Place-Based Information & Data



Source: Grossi and Kunreuther (2005)

Assessing Infrastructure Vulnerability

The Importance of Place-Based Information & Data

- UN Intergovernmental Panel on Climate Change (IPCC) definition of vulnerability

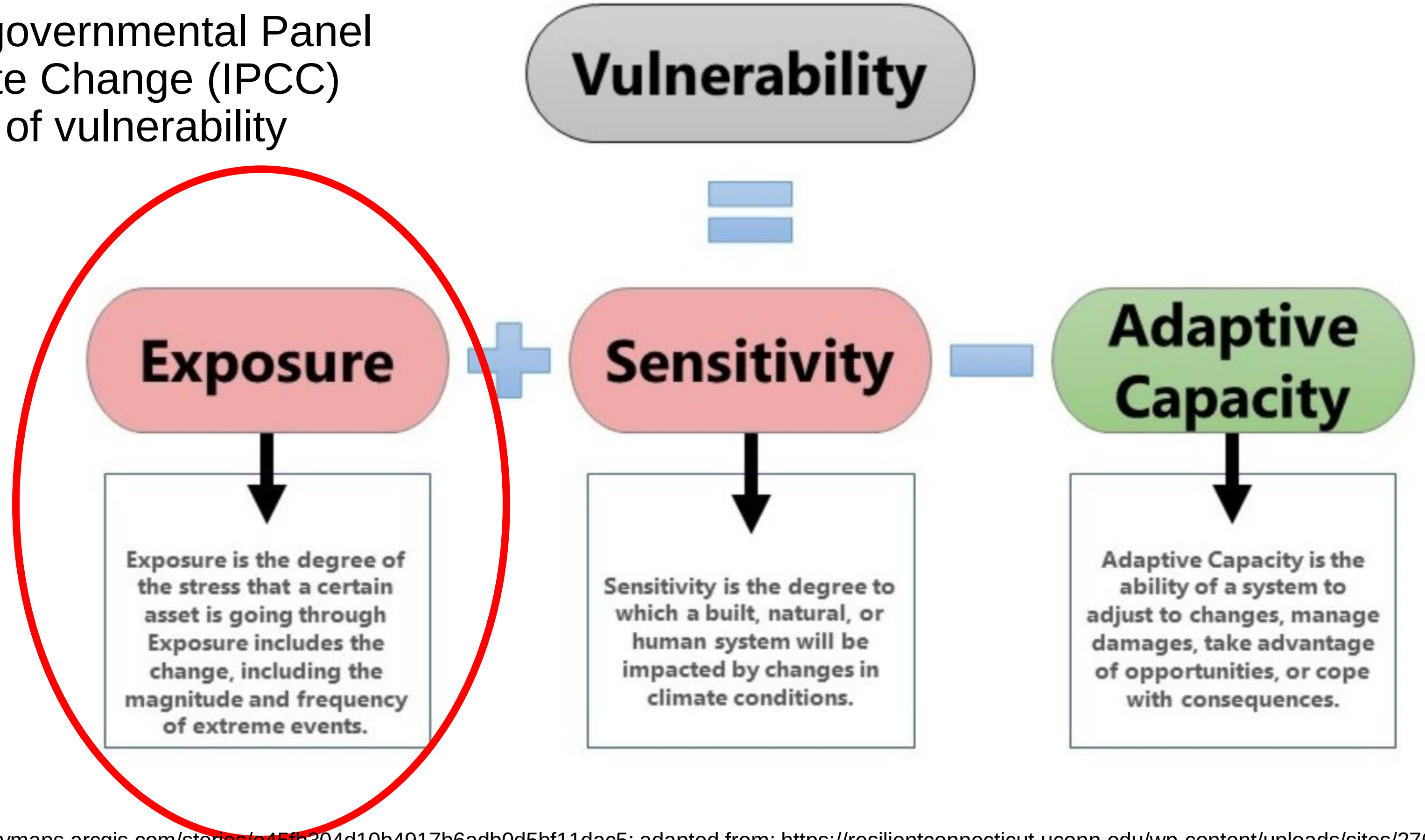


Image: https://storymaps.arcgis.com/stories/e45fb304d10b4917b6adb0d5bf11dac5; adapted from: https://resilientconnecticut.uconn.edu/wp-content/uploads/sites/2761/2021/10/CCVI-Fact-Sheet-2.pdf

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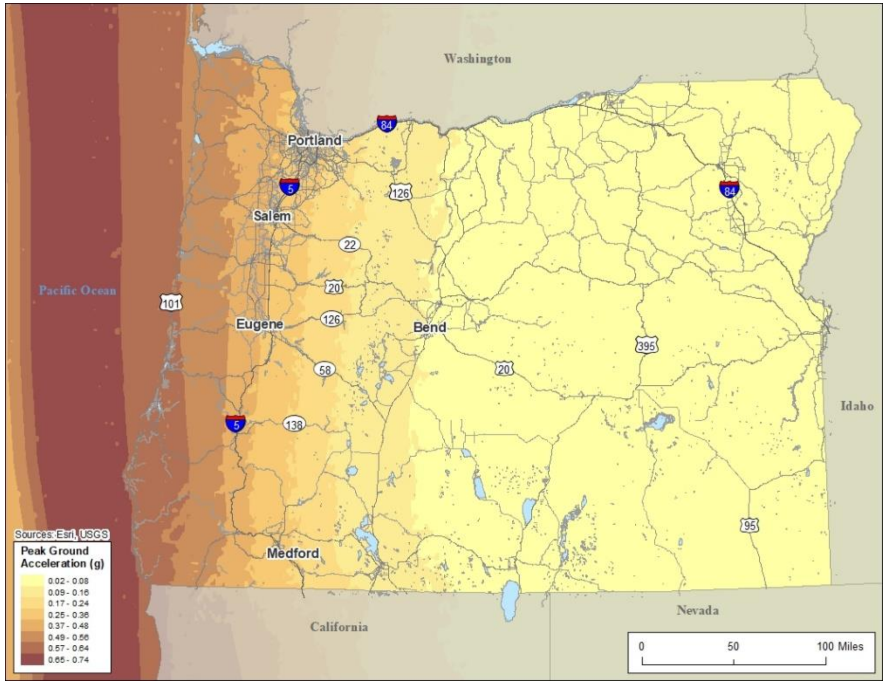
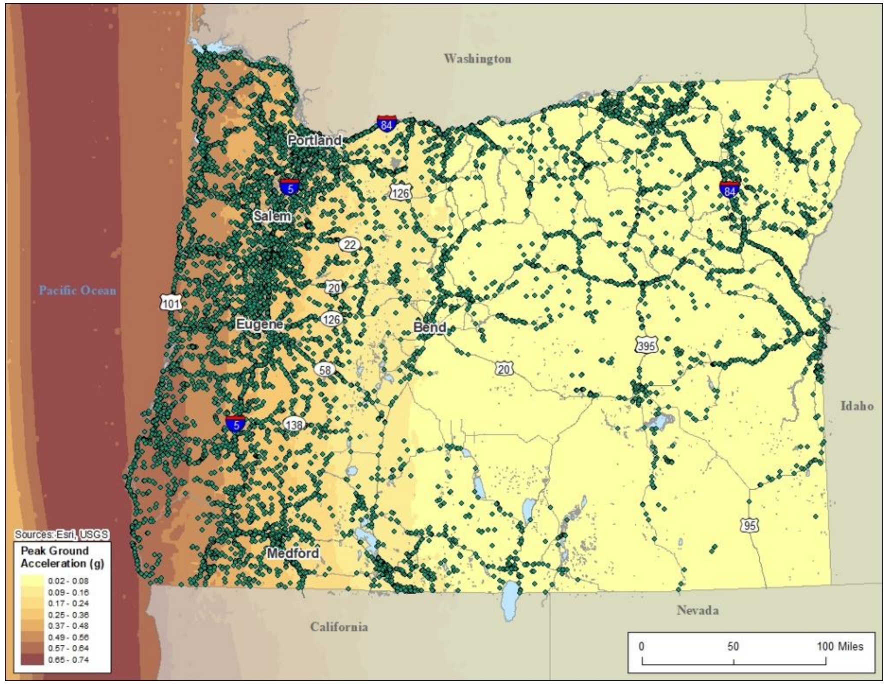
Assessing Infrastructure Vulnerability

The Important Role of GIS and Mapping Tools

- Exposure: the ***degree*** to which an asset or facility will be subjected to a certain type of hazard, threat or impact
- Hazard severity is extremely place-based, and depending on the type of hazard, may vary widely across regions





Images: Argonne National Laboratory

Assessing Infrastructure Vulnerability

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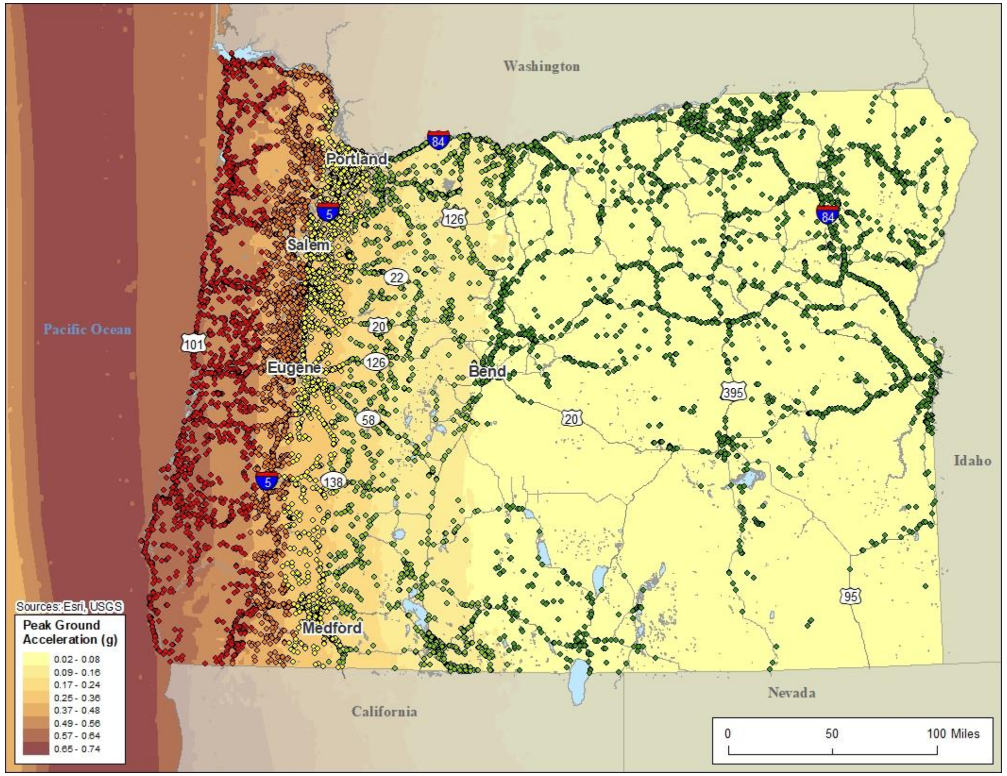
- Exposure: the ***degree*** to which an asset or facility will be subjected to a certain type of hazard, threat or impact
- Hazard severity is extremely place-based, and depending on the type of hazard, may vary widely across regions



Images: Argonne National Laboratory

- Recall: Per ISO31000:2018, *risk analysis* concerns modeling, quantifying, or measuring level of risk

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Assessing Infrastructure Vulnerability

Infrastructure Sensitivity Information

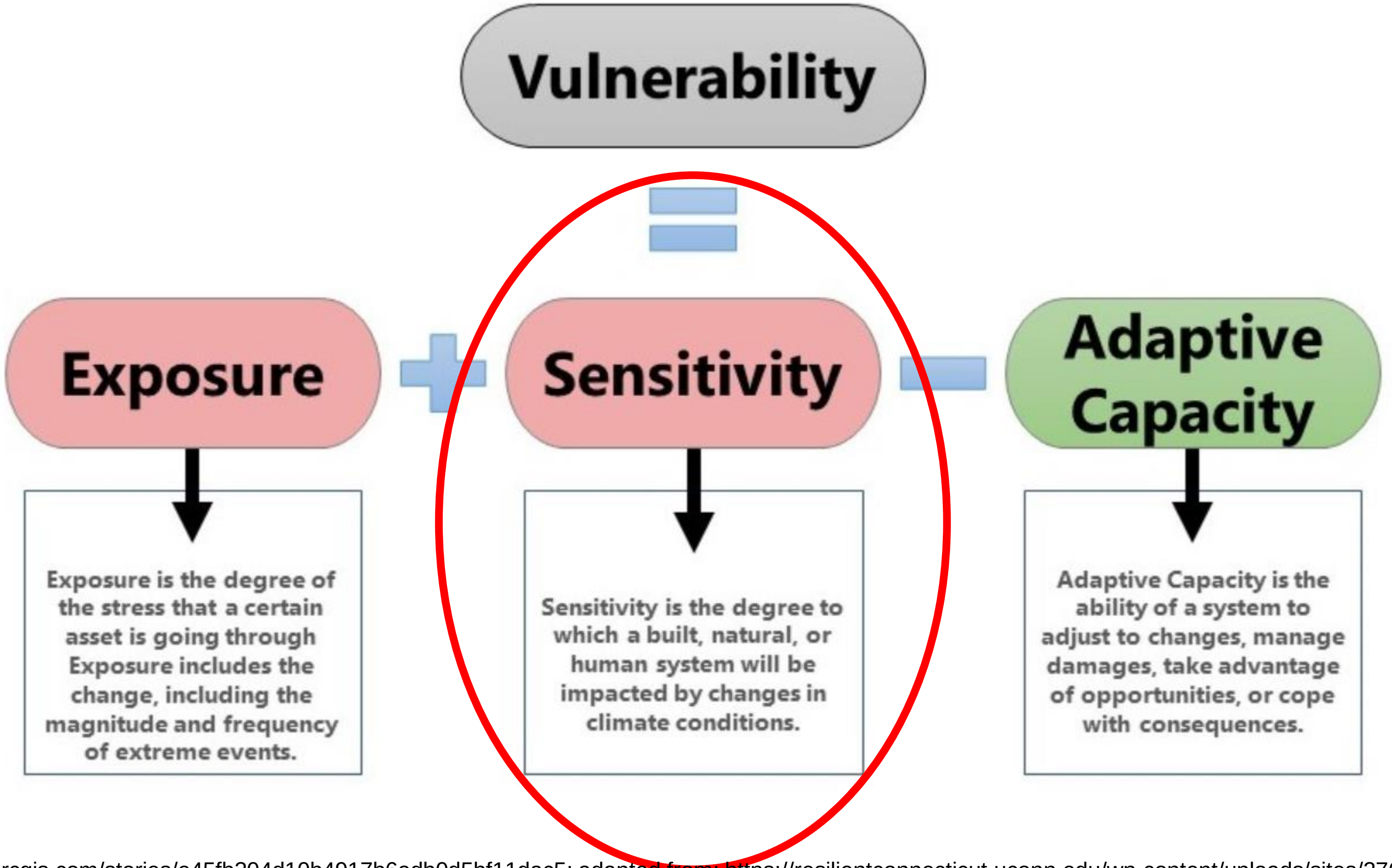

Image: https://storymaps.arcgis.com/stories/e45fb304d10b4917b6adb0d5bf11dac5; adapted from: https://resilientconnecticut.uconn.edu/wp-content/uploads/sites/2761/2021/10/CCVI-Fact-Sheet-2.pdf

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Assessing Infrastructure Vulnerability

Infrastructure Sensitivity Information

- Sensitivity: the ***degree*** to which built, natural, or human systems will be affected by a change or impact
- Not all assets or facilities, even if they are co-located, will be equally affected by an impact

Image: http://hyperphysics.phy-astr.gsu.edu/Nave-html/S09/flood.html

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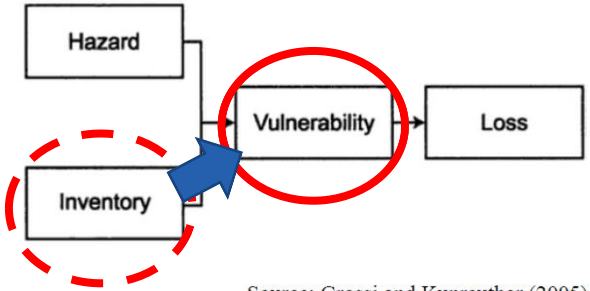
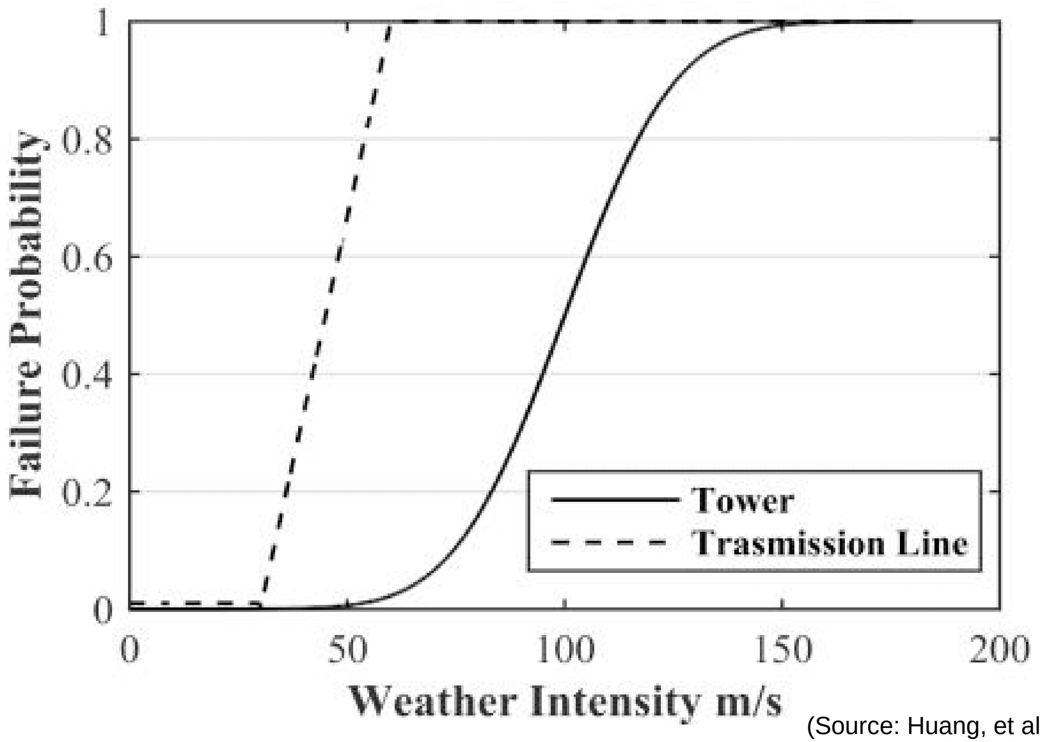
Assessing Infrastructure Vulnerability

Infrastructure Sensitivity Information

- Sensitivity: the ***degree*** to which built, natural, or human systems will be affected by a change or impact
- Not all assets or facilities, even if they are co-located, will be equally affected by an impact
- Fragility curves or response curves are a commonly used way to assess asset sensitivity to an impact



Source: Grossi and Kunreuther (2005)



(Source: Huang, et al. 2018)

Assessing Infrastructure Vulnerability

Infrastructure Adaptive Capacity

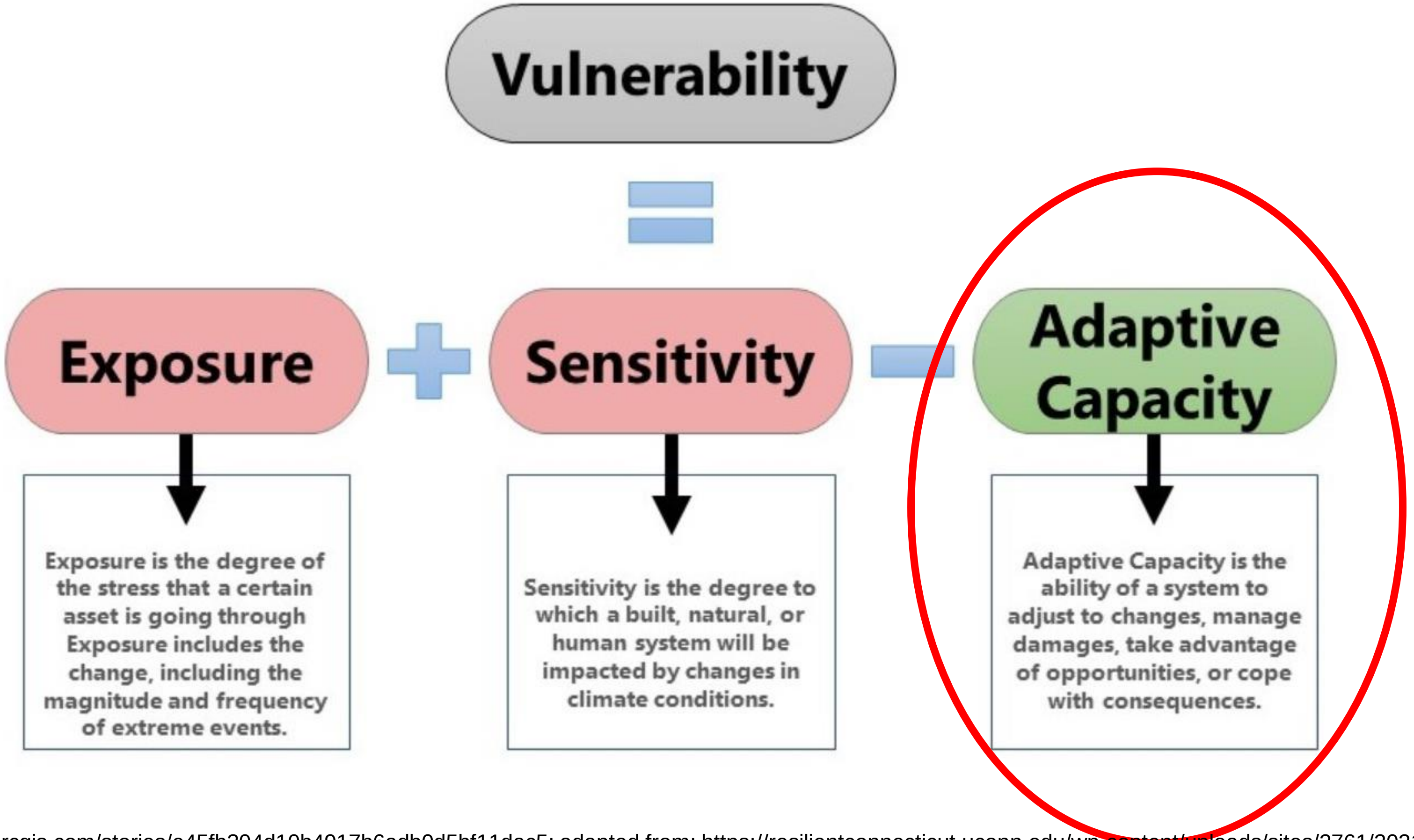
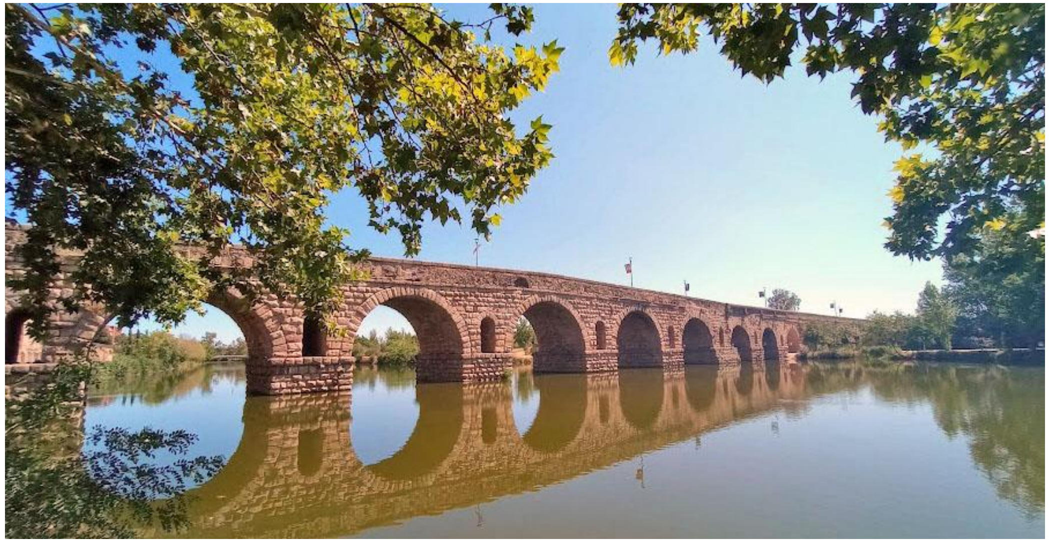


Image: https://storymaps.arcgis.com/stories/e45fb304d10b4917b6adb0d5bf11dac5; adapted from: https://resilientconnecticut.uconn.edu/wp-content/uploads/sites/2761/2021/10/CCVI-Fact-Sheet-2.pdf

Assessing Infrastructure Vulnerability

Infrastructure Adaptive Capacity

- Adaptive Capacity: the ***ability*** of a system to adjust to changes, manage damages, take advantage of opportunities, or cope with consequences

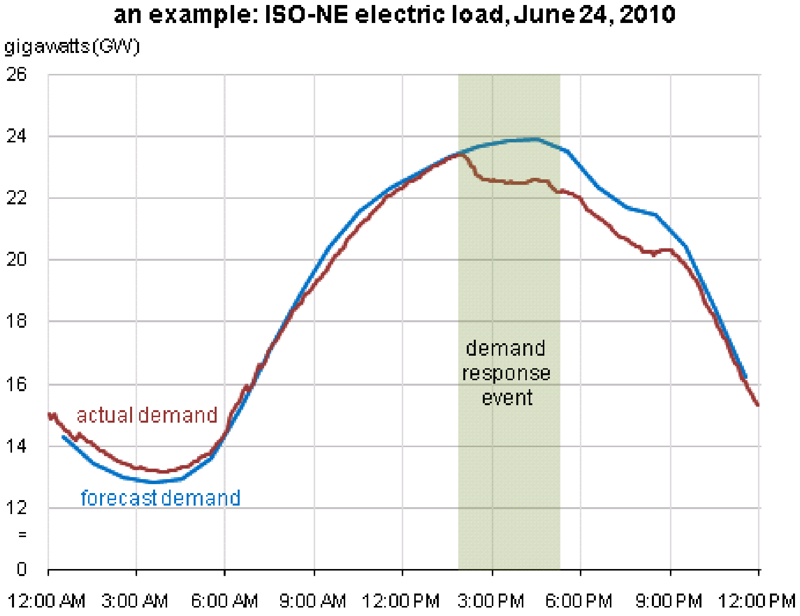


Images: https://en.wikipedia.org/wiki/Ponte_Milvio; https://en.wikipedia.org/wiki/Puente_Romano

Assessing Infrastructure Vulnerability

Infrastructure Adaptive Capacity

- Adaptive Capacity: the ***ability*** of a system to adjust to changes, manage damages, take advantage of opportunities, or cope with consequences
- This is not exclusively an engineering challenge/solution; concerns operations, emergency response, others solutions



Images: Unsplash; https://www.eia.gov/todayinenergy/detail.php?id=130

Assessing Infrastructure Vulnerability

Thinking About Vulnerability and Risk through the Lens of Resiliency

RESILIENCE

The ability to **prepare** for and **adapt** to changing conditions and **withstand** and **recover** rapidly from disruptions.

Source: The White House, PPD-21

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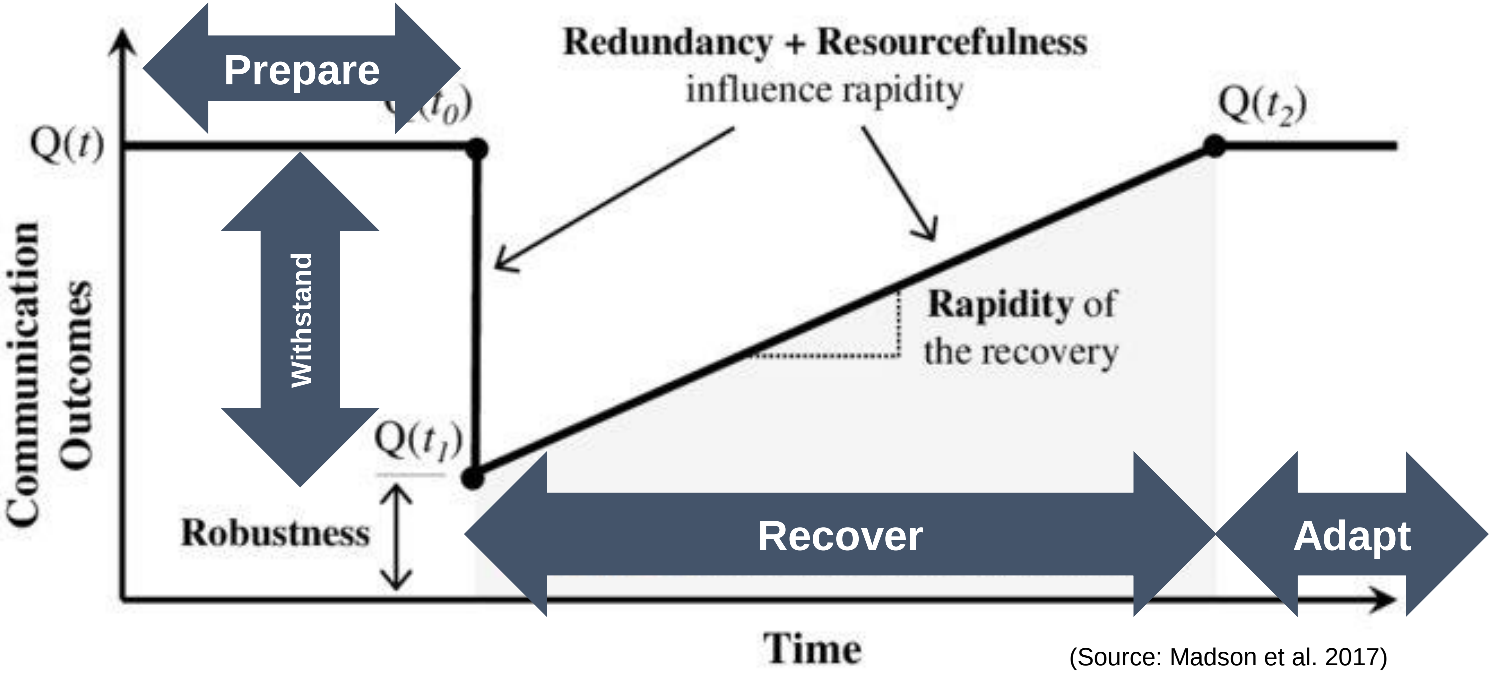
Assessing Infrastructure Vulnerability

Thinking About Vulnerability and Risk through the Lens of Resiliency

Resilience Elements

1. Prepare
2. Adapt
3. Withstand
4. Recover



(Source: Madson et al. 2017)

- Recall: Per ISO31000:2018, *risk evaluation* determining if/what actions
- Nichole Hanus will cover some of this in her talk later today

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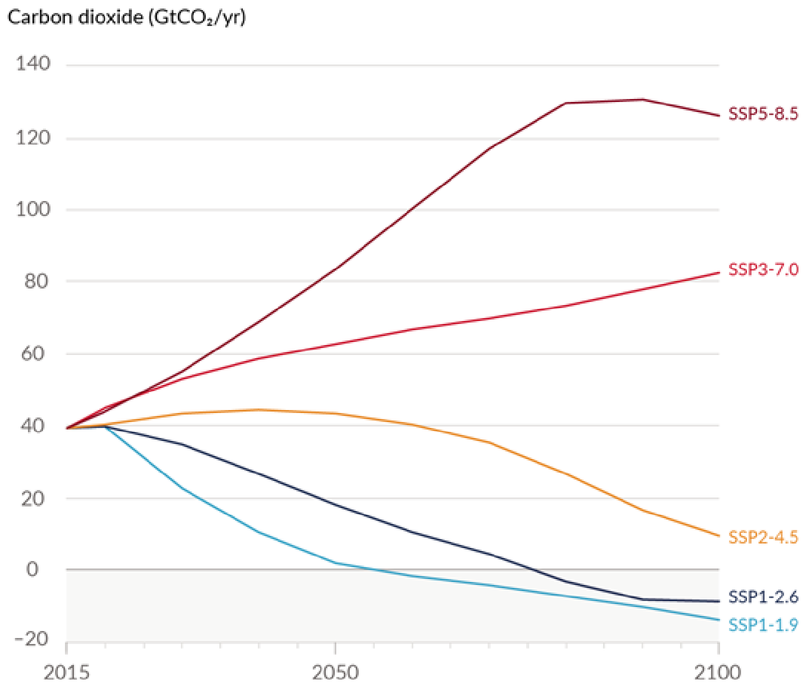
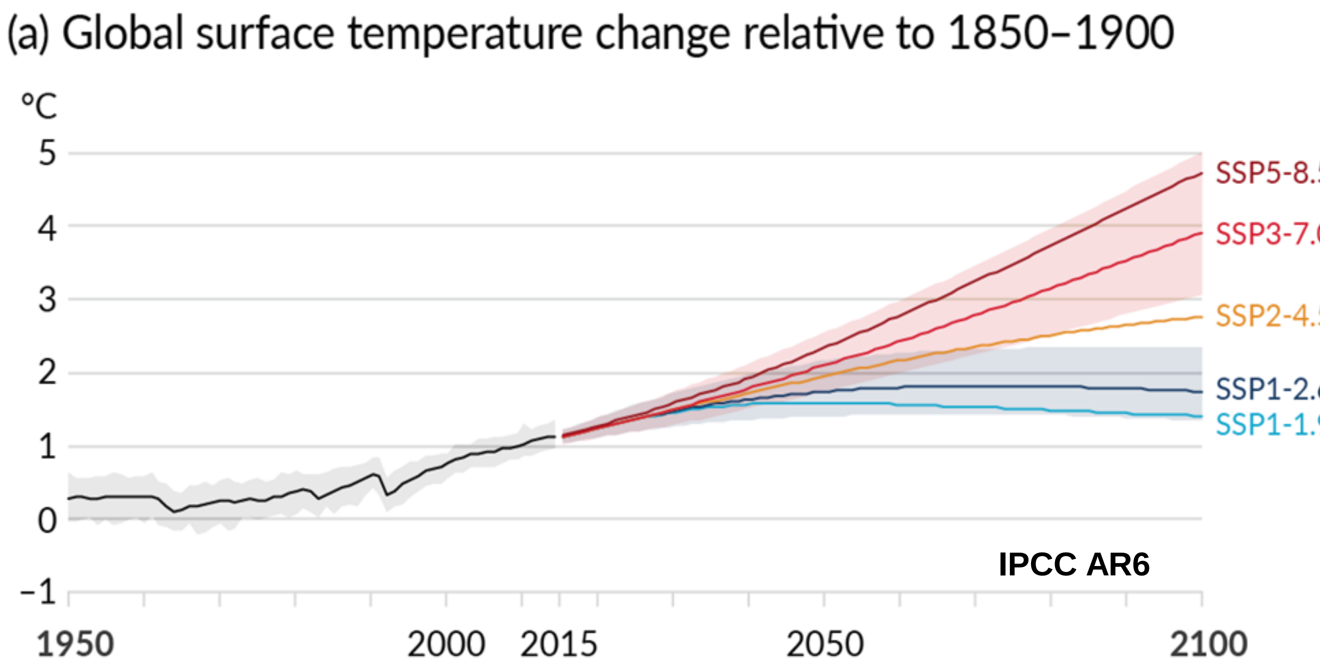
Climate Change Impacts

Climate Science & Modeling 101

Greenhouse Gas (GHG) Emission Scenarios

- Plausible future scenarios for atmospheric greenhouse gas concentrations, and the pathways to get there
    - Current Generation: Shared Socioeconomic Pathway (SSP)
    - Prior Generation: Representative Concentration Pathway (RCP)
- No probabilistic likelihood is assigned to any individual scenario



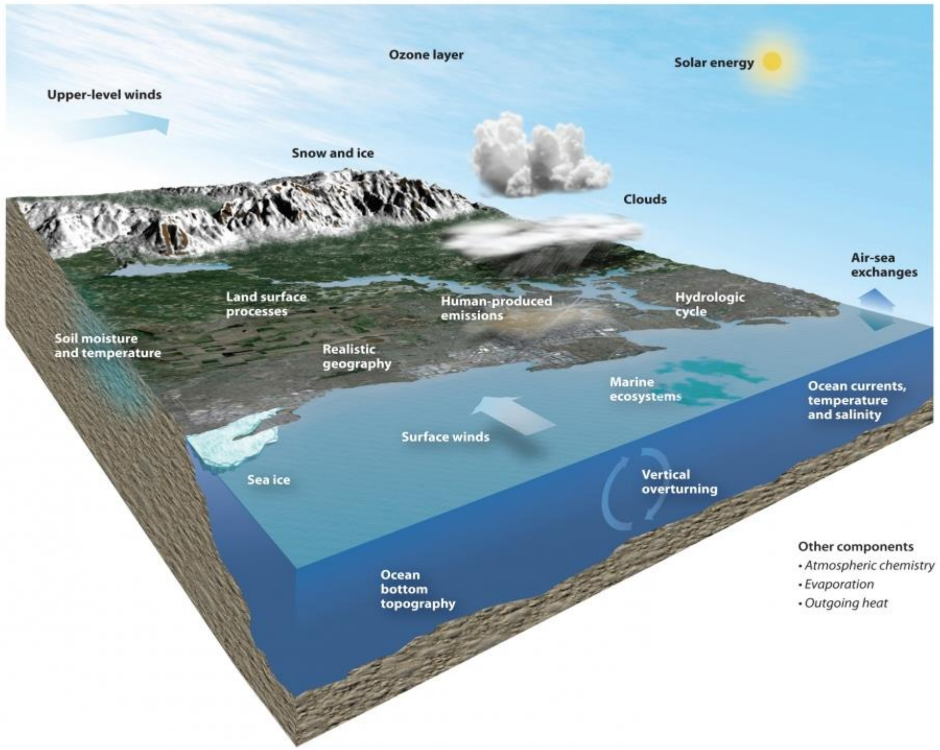


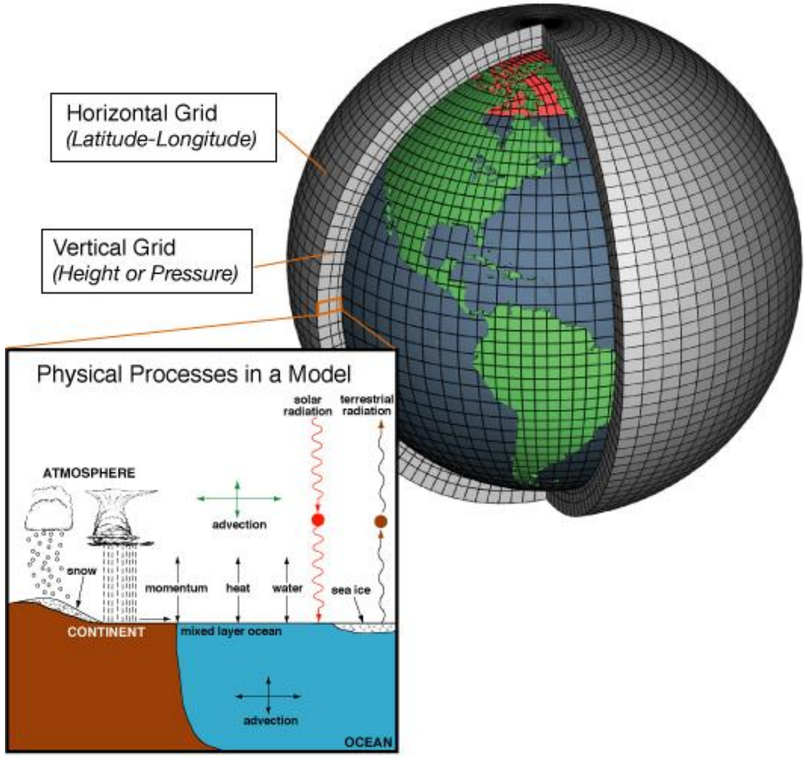
Images: https://www.ipcc.ch/report/ar6/wg1/figures/summary-for-policymakers

Climate Science & Modeling 101

Global Climate Models

Mathematical representations of the climate system based on physical laws and understanding of processes





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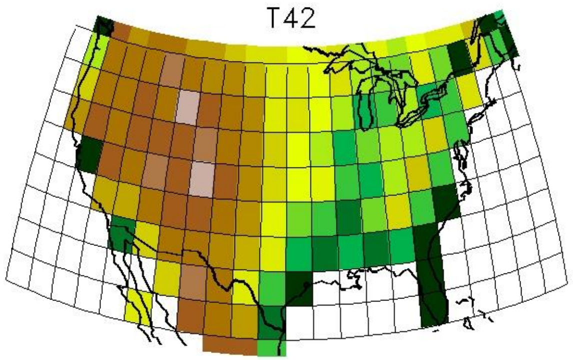
Images: https://scied.ucar.edu/image/community-earth-system-model; https://www.climate.gov/maps-data/climate-data-primer/predicting-climate/climate-models

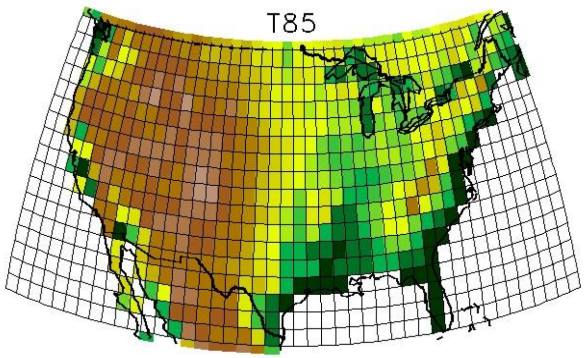
Climate Science & Modeling 101

Global Climate Models

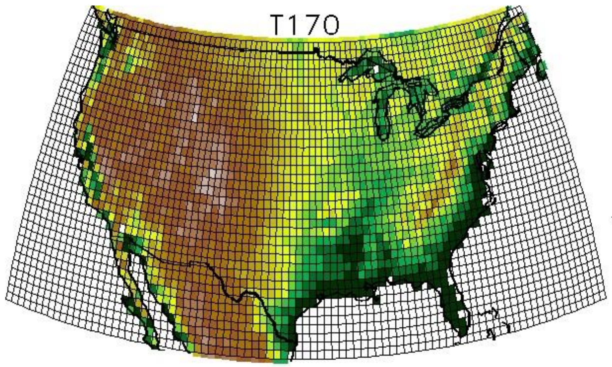
- As computing resources have improved over time, models have become increasingly complex and more detailed
- Smaller grid squares or “pixel sizes” enable more place-specific and detailed projections of locally relevant climate



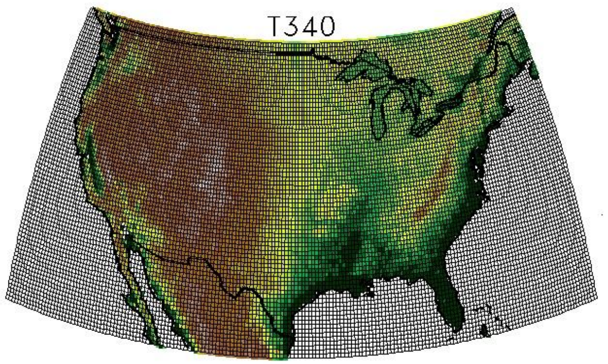
Mid-1990s 200~300 kms



2000s 100~150 kms



Current 50~100 kms



Future. 25~40 kms

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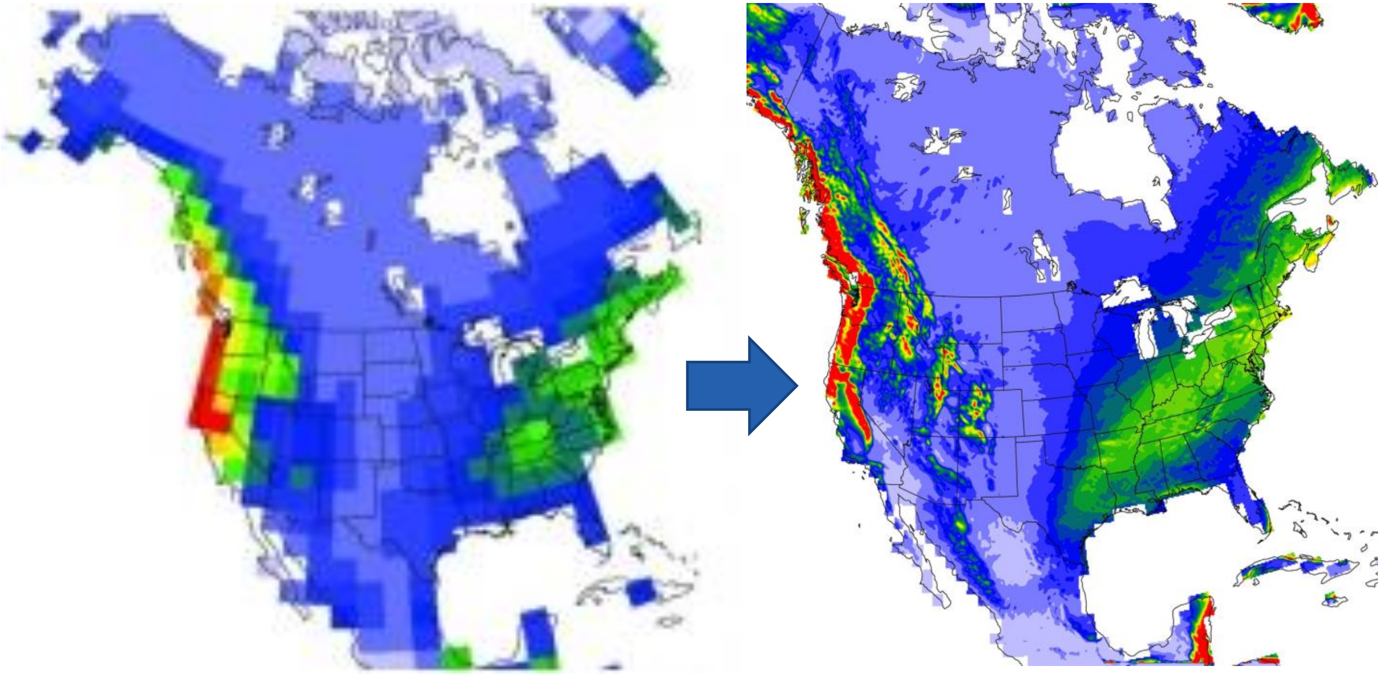
Image: https://eo.ucar.edu/staff/rrussell/climate/modeling/climate_model_resolution.html

Climate Science & Modeling 101

Downscaling Techniques to Increase Model Resolution

- **Statistical Downscaling**: A statistical relationship is developed between historical observed climate data and the output of a global climate model that has been run for the same historical period. That historically-based statistical relationship is then applied to forward-looking global climate model projections to develop higher-resolution future climate data. Essential for statistical downscaling is the availability of local weather data.

- **Dynamical Downscaling**: A higher resolution regional climate model (RCM) uses lower resolution climate models as boundary conditions and physical principles to reproduce local climate. Essential for dynamical downscaling is the availability of large computing resources.



Source: Copernicus.EU, Undated
Images: Argonne National Laboratory

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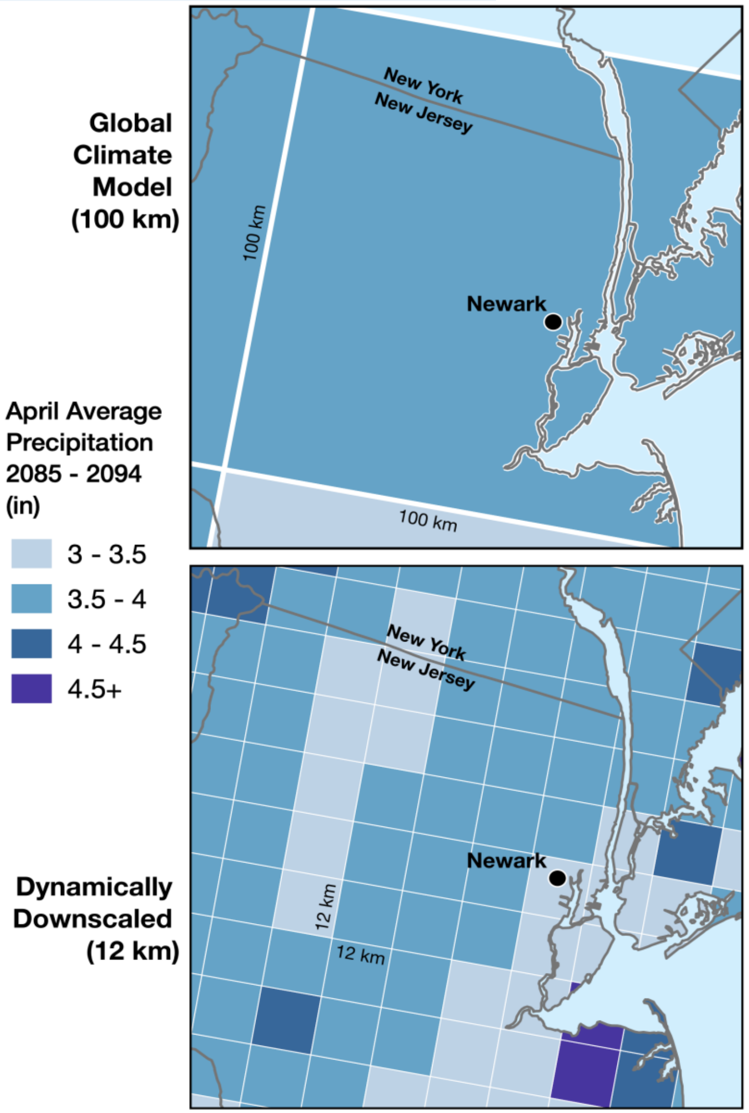
Climate Science & Modeling 101

Example: Dynamical downscaling at Argonne National Laboratory

- From coarse resolution (100-200km) to high resolution, community-level data (12km)
- Physics-based models that incorporate local geography & features (e.g., mountains, waterbodies)
- Downscaled data from three different global climate models
- Two GHG emission pathways: RCP8.5 (high emissions) + RCP4.5 (mid-century peak)
- Three timeframes: historical (1995-2004), mid-century (2045-2054), and end-of-century (2085-2094)
- Scientific transparency: widely published and peer reviewed modeling and outcomes



Images: Argonne National Laboratory

Climate Science & Modeling 101

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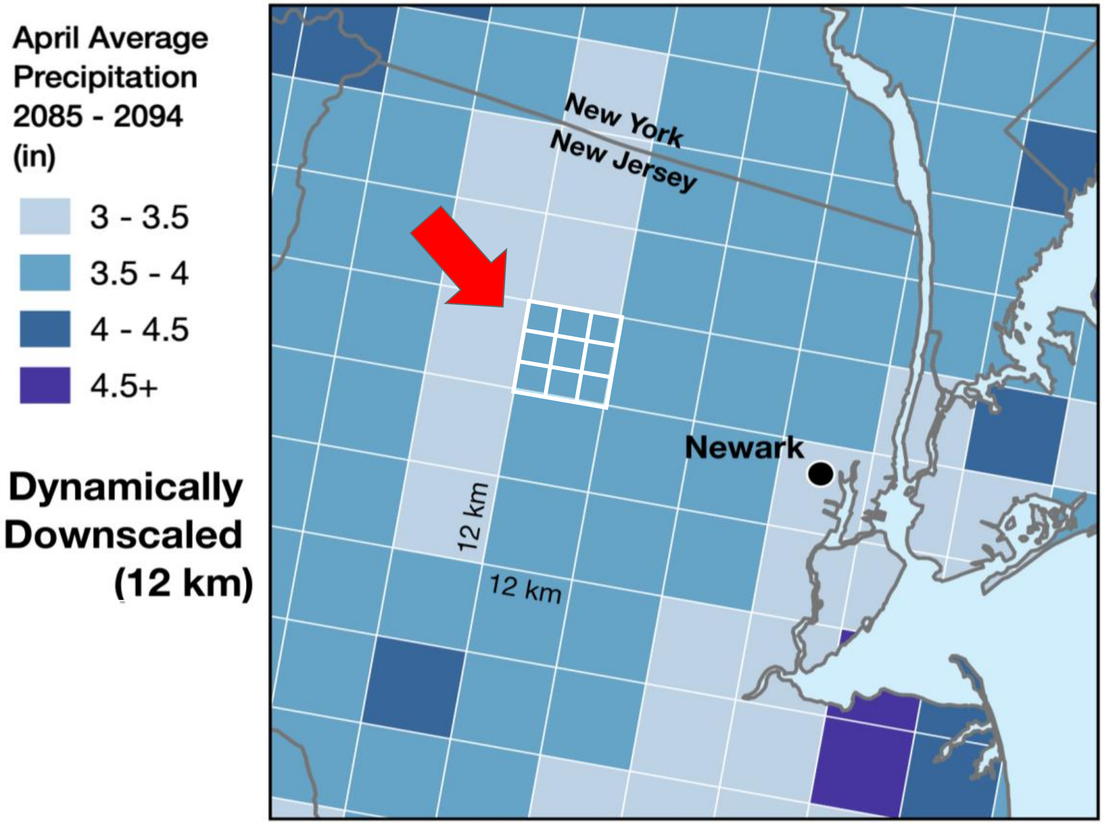
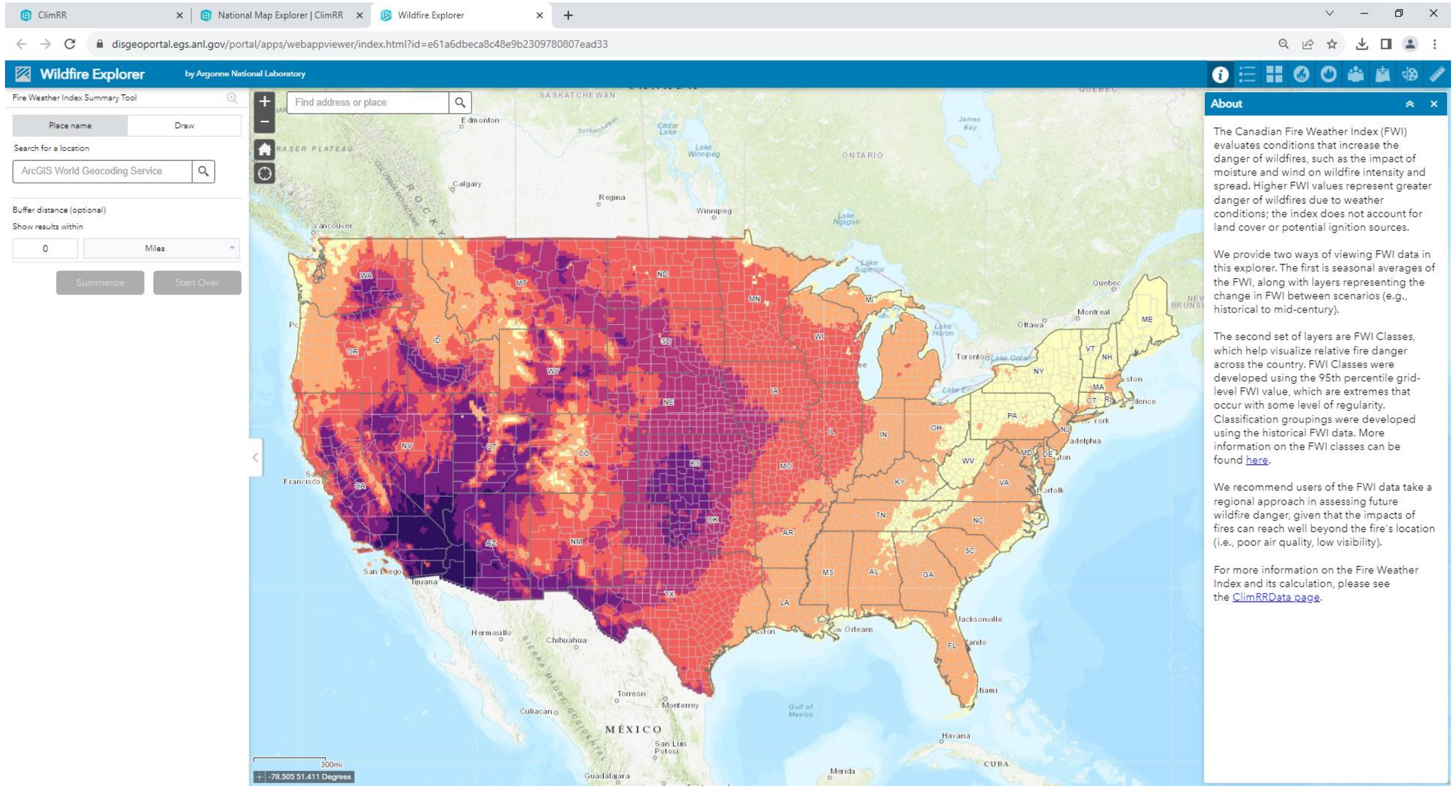
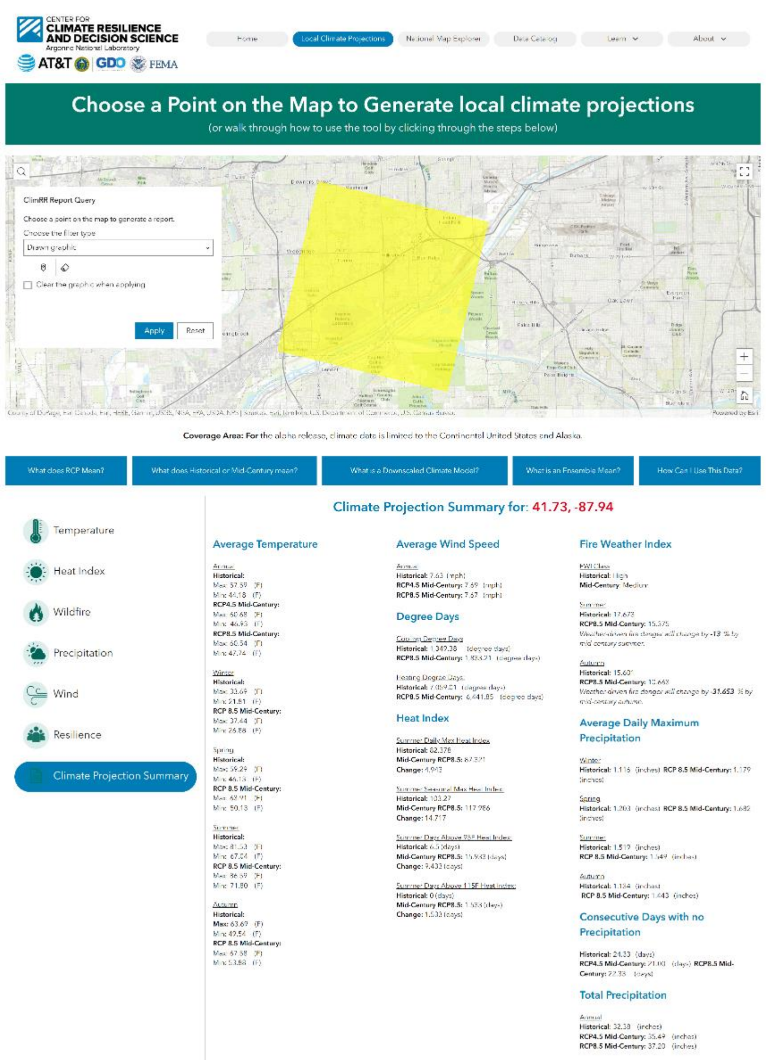


Images: Argonne National Laboratory

Climate Impact Data Resources

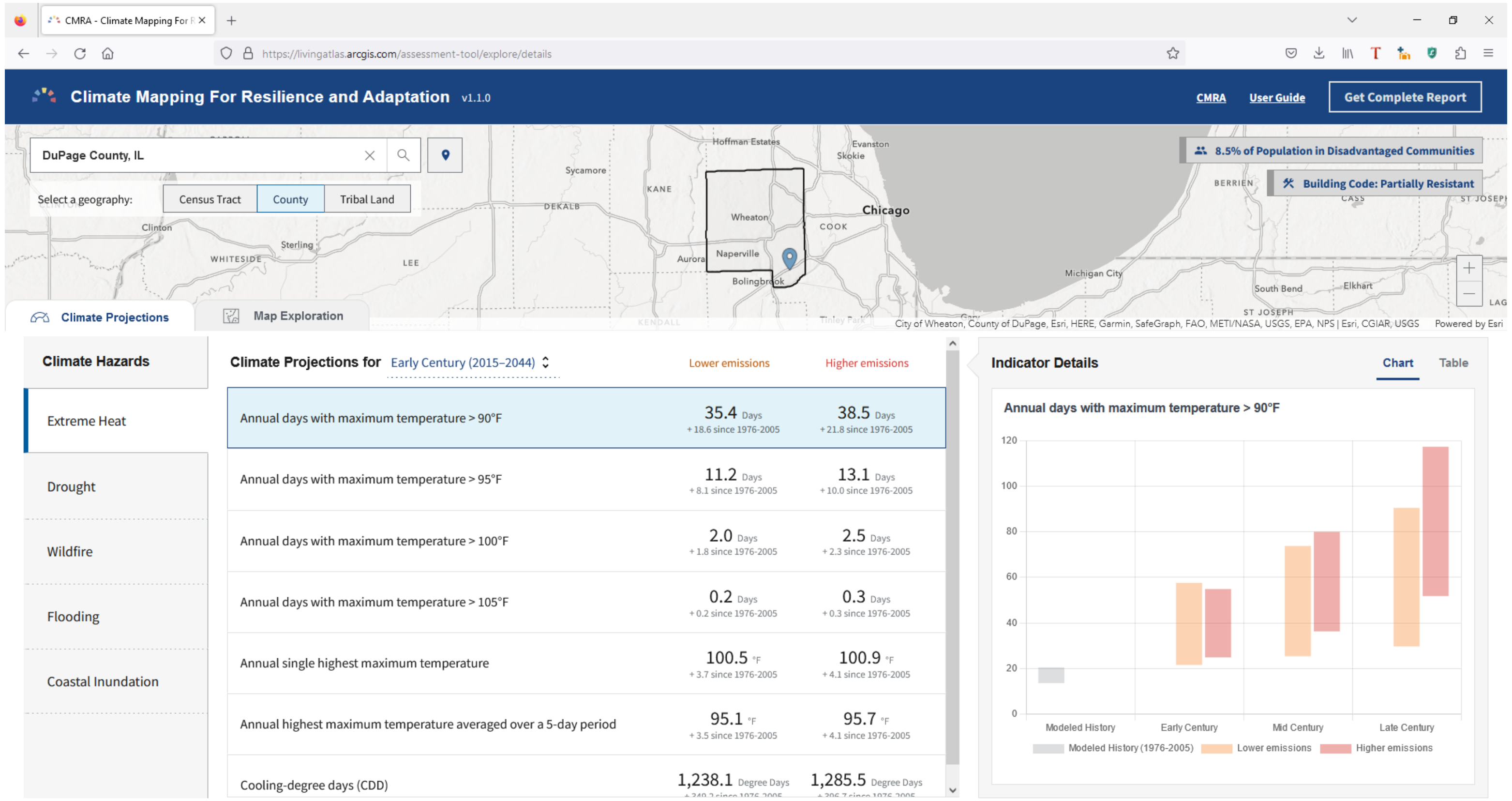
- Climate Risk and Resilience Portal (ClimRR) – Argonne National Laboratory, Federal Emergency Management Agency, DOE Grid Deployment Office, AT&T
- https://climrr.anl.gov





Climate Impact Data Resources

- Climate Mapping for Resilience and Adaptation (CMRA) Assessment Tool - NOAA, Esri
- https://livingatlas.arcgis.com/assessment-tool/home (find at https://resilience.climate.gov)



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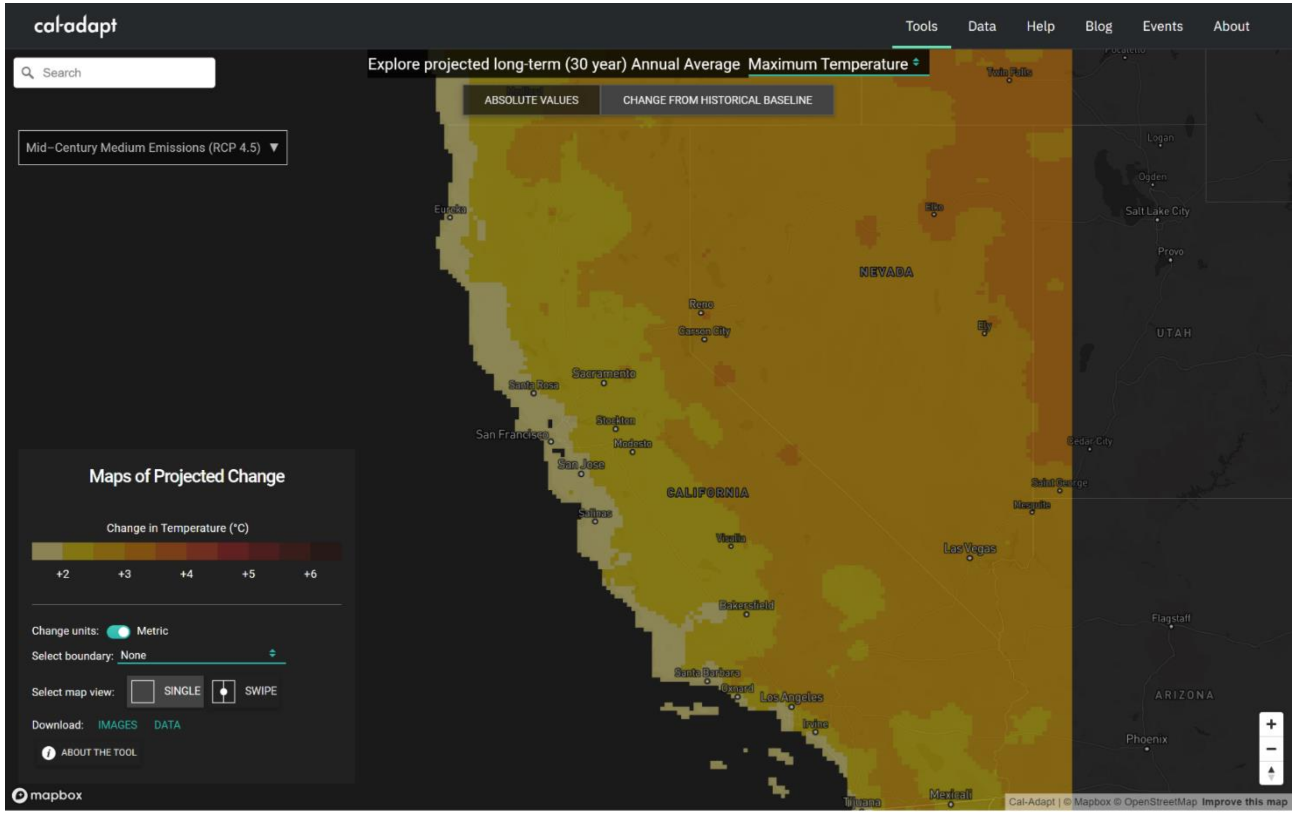
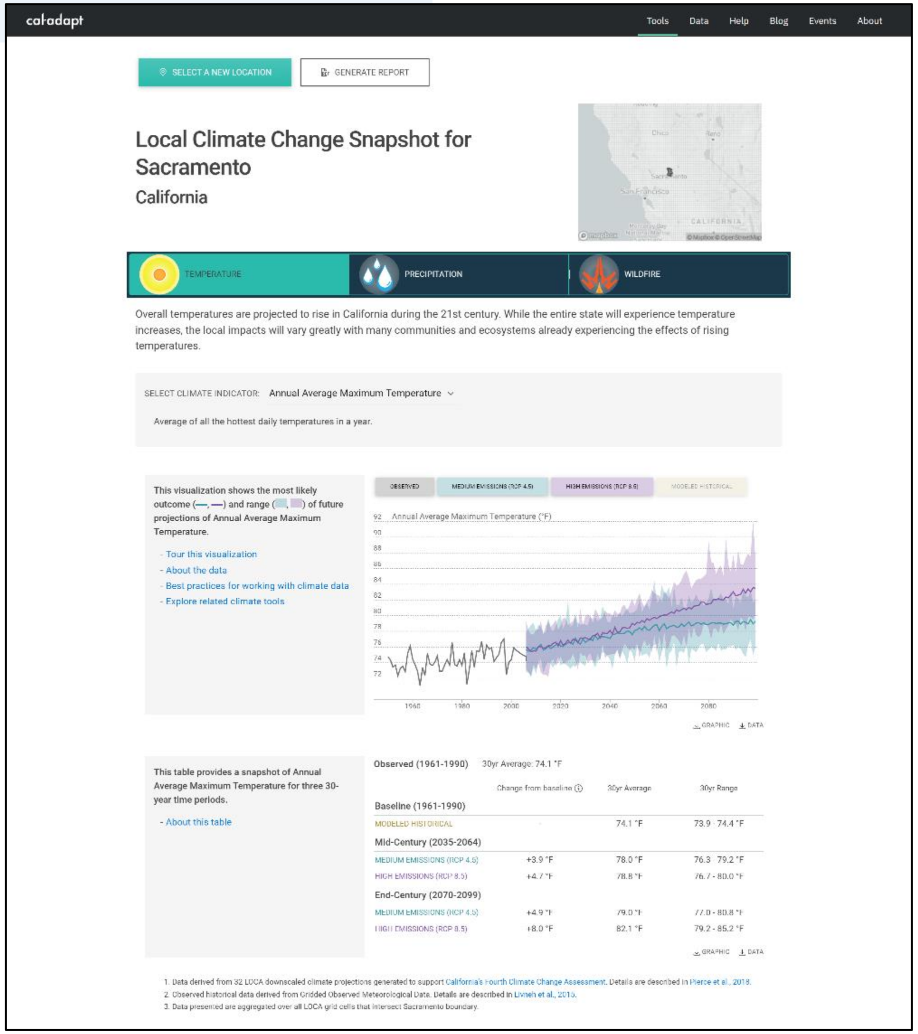
Climate Impact Data Resources

- Cal-Adapt – California Energy Commission, California Strategic Growth Council, UC-Berkeley
- https://cal-adapt.org





GRID DEPLOYMENT OFFICE

Risk-Based Climate Vulnerability Assessments

How is Climate Change Affecting the Electric Grid?

- Literature review of academic and industry studies
- https://www.osti.gov/biblio/1900595

Asset Type	Hazards	Effect	References[8]
Distribution Poles	Cold	Freeze expansion (concrete)	[21]
	Wind	Toppling, debris fall	[2]
	Flooding	Toppling, maintenance route closure	[2]
	Stream Flow	Earth destabilization, toppling	[4]
	Ice	Toppling, debris fall, freeze expansion	[21]
	Overgrowth	Debris fall, maintenance interference	[22]
DERs (SOLAR), Community Microgrid	Heat	Self-islanding, overloading, battery derating	[23]
	Cold	Self-islanding, overloading, photovoltaic (PV) icing	[23]
	Wind	Debris fall, unseating/destruction	[23]
	Flooding	Destruction, grounding	[23]
	Humidity	HVAC demand (depletion)	[15], [17], [18]
	Ice	PV and battery icing, maintenance prevention	[23]

Images: https://oklahoma.gov/oem/emergencies-and-disasters/2005/january-2005-winter-weather-event.html; https://www.energy.gov/eere/articles/let-it-snow-how-solar-panels-can-thrive-winter-weather

Risk-Based Climate Vulnerability Assessments

How is Climate Change Affecting the Electric Grid?

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Image: https://commons.wikimedia.org/wiki/File:Underwater_substation,_Cedar_Rapids,_June_12_2008.jpg

Asset Type	Hazards	Effect	References[5]
Transmission Lines	Heat	Sagging, ampacity derating	[7], [8]
	Humidity	Insulation derating, flashover	[2], [3]
	Wind	Cross-whipping, snapping, grounding contact	[7]
	Ice	Snapping, flashover faults	[9], [10]
	Flooding	Buried asset damage	[11]
	Overgrowth	Debris fall, arcing contact	[12]
Transmission Structures	Wind	Toppling	[2]
	Flooding	Maintenance route closure	[13]
	Ice	Toppling	[25], [10]
	Stream Flow	Earth destabilization (on embankments)	[4]
Transformers	Heat	Derating, loss of asset life, overloading	[14], [15]
	Humidity	Insulation derating, loss of asset life, heating, ventilation, and air-conditioning (HVAC) demand	[16], [15], [17], [18]
	Flooding	Destruction, faulting	[19]
	Cold	Overloading, HVAC demand	[15]
Switchgear	Cold	Freezing, gas pressure loss	[20]
	Ice	Freezing	[20]
Other Substation Assets	Humidity	Grounding impedance, HVAC demand	[2], [15], [17], [18]
	Heat	Overloading	[15]
	Flooding	Destruction, maintenance route closure	[2], [19]
Distribution Lines	Wind	Cross-whipping, snapping, grounding contact	[7]
	Heat	Sagging, ampacity derating, overloading	[6]
	Ice	Snapping, debris fall	[10]
	Overgrowth	Debris fall, arcing contact	[12]
	Flooding	Buried asset damage, maintenance route closure	[11]
	Humidity	Insulator derating, HVAC demand	[2], [15], [17], [18]

Risk-Based Climate Vulnerability Assessments

How is Climate Change Affecting the Electric Grid?

- Literature review of academic and industry studies
- https://www.osti.gov/biblio/1900595

Asset Type	Hazards	Effect	References[2]
Gas Lines	Cold	Supply pressure collapse	[1]
	Ice	Supply pressure collapse, fuel leak	[1]
	Flooding	Destruction	[2]
	Fire	Destruction, ignition	[3]
	Stream Flow	Earth destabilization (on banks), destruction at crossing	[4]
Generation	Cold	Water supply icing, equipment freeze	[24], [1]
	Heat	Cooling water shortage, cooling water inefficacy, ambient cooling impacts	[5]
	Ice	Structural damage, water supply icing	[24]
	Wind	Structural damage, hydroelectric overflow	[24], [6]
	Stream Flow	Water supply overflow	[24]
	Flooding	structural damage, maintenance route closure	[25]

- A California Energy Commission study found that capacity of natural gas combined-cycle power plants decreases by 0.3-0.5 percent for each 1C increase above a reference temperature of 15C (59F)
- Power transformer average power output decreases 0.7% to 1% per 1C increase in air temperature, above a reference temperature (usually 20C, or 68F)

(Source: Allen-Dumas et al. 2019)

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Image: https://en.wikipedia.org/wiki/List_of_natural_gas_power_stations_in_the_United_States#/media/File:Chehalis_Power_Plant,_September_2020.jpg

Wrapping Up

Questions to Ask

Questions to set that set the stage for understanding how utilities are assessing climate impacts and risks

- Scope, context, criteria
  - What GHG emission/concentration scenarios form basis of the assessment? RCP/SSP8.5? RCP/SSP4.5?
  - What is your assessment timeframe? Mid-century? End-of-century?
  - What models and data will you use? A single model? A multiple model ensemble?
  - How can the state ensure consistency across multiple utilities' assessments?
- Risk Identification
  - What are the climate impacts of greatest concern and why? (This wil be different by region/location)
  - What aspects of these impacts are of greatest concern? Averages? Extremes? Highs/lows? How does emission scenario affect this?
  - Does the assessment examine chronic (reliability) problems as well as catastrophic (resiliency) problems?

Image: https://www.iso.org/obp/ui/#iso:std:iso:31000:ed-2:v1:en

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Questions to Ask

- Risk Analysis
  - How are risks different according to various climate impacts and asset/equipment/facility types?
  - What are critical planning/operational thresholds?
  - Are there gaps in climate data/information that prevent certain risk analyses? Are there work-around solutions?
- Risk Evaluation
  - How will you determine risk levels and compare/prioritize?
  - What metrics and criteria will you use to assess risk?
    - Disruption time?
    - Economic impacts? Capital, customer, etc.?
  - How will you identify and prioritize risk treatments?
  - How will you reconcile/align climate impact risks with other risks and opportunities? Transition risk? Asset management? Decarbonization?

Image: https://www.iso.org/obp/ui/#iso:std:iso:31000:ed-2:v1:en

Contact

https://www.energy.gov/gdo/grid-deployment-office

Tom Wall, Ph.D. twall@anl.gov

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Example Utility Vulnerability Assessment

Duke Energy Climate Change Vulnerability Study

Cynthia Klein
Director
Strategic Initiatives
Duke Energy

Neil Weisenfeld
Senior Energy Resilience Expert
ICF

3/21/2024

Today's presenters + agenda

Cynthia Klein
Director – Strategic Initiatives
Duke Energy

Neil Weisenfeld
Senior Energy Resilience Expert
ICF

Agenda

- Climate risk and resilience study overview.
- Vulnerability assessment approach
- Climate adaptation framework.
- Next steps in Duke Energy's resilience journey.

Climate risk and resilience study overview

Duke Energy system included in the study

North Carolina operating companies:

- Duke Energy Progress
- Duke Energy Carolinas

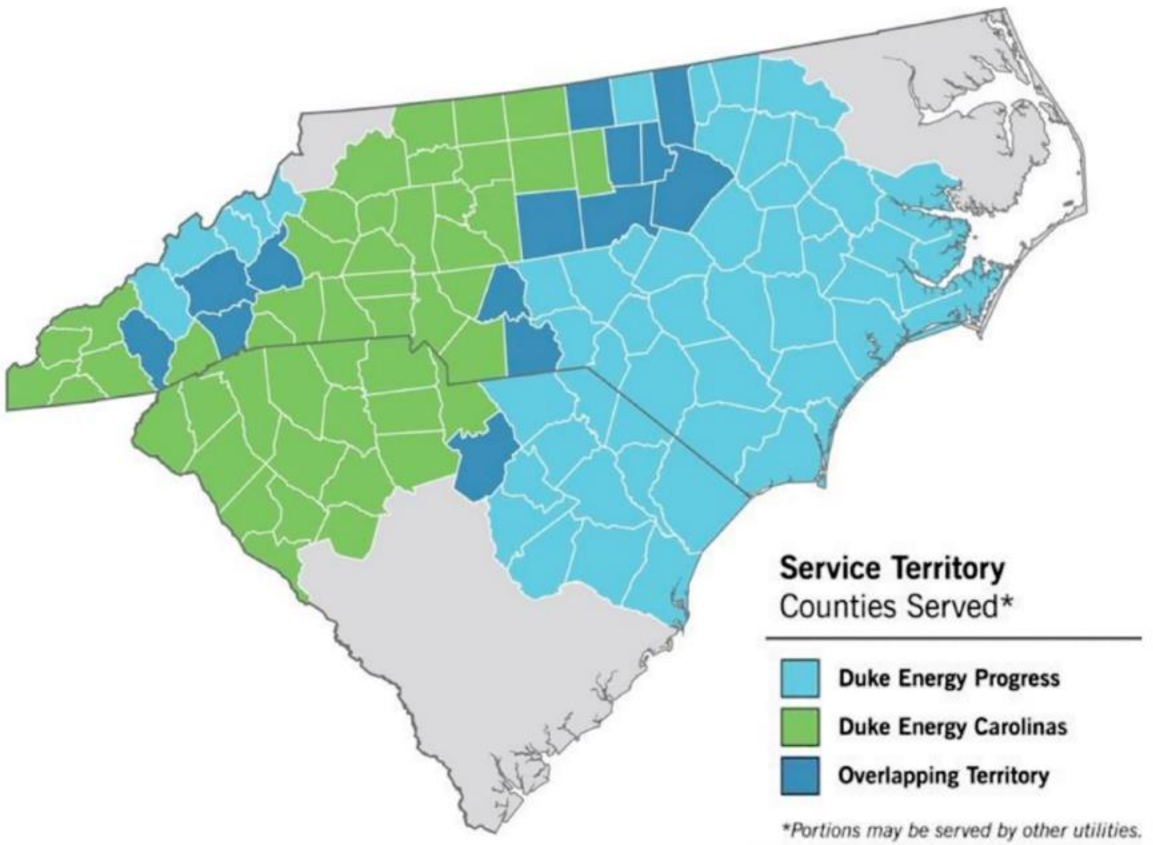
Duke Energy Progress

- 32,000 square miles
- 1.6 million customer accounts

Duke Energy Carolinas

- 24,000 square miles
- 2.7 million customer accounts

.



Objectives

- Develop a robust set of utility-relevant climate change projections.
- Understand the range of potential impacts (i.e., vulnerabilities) of climate change on Duke Energy's transmission and distribution system.
- Develop a flexible adaptation framework to help Duke Energy build resilience.
- Provide meaningful opportunities for stakeholder input.

Adaptation

Actions to increase resilience to physical impacts of climate change (e.g., new storm barriers)

Mitigation

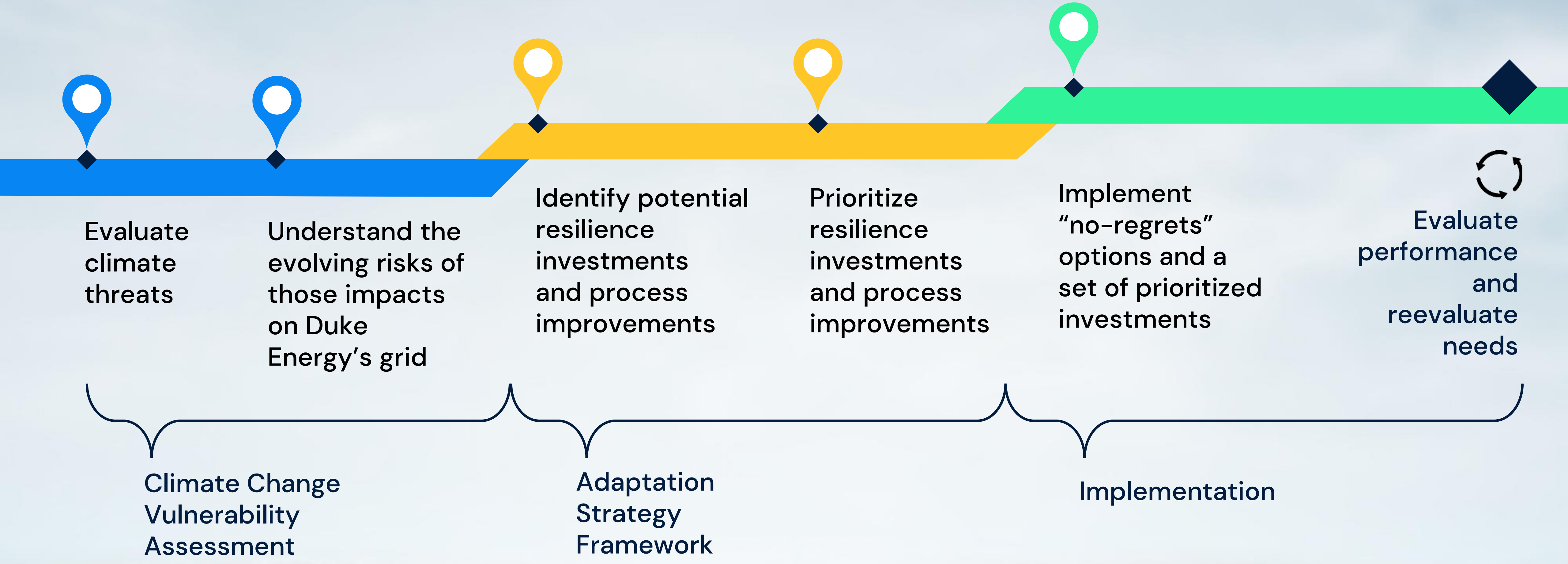
Actions to reduce greenhouse gas emissions (e.g., clean energy investments)

TWG participants

TWG members represent a wide range of communities, industries, scientists, and advocates across North and South Carolina

- Advanced Energy
- Carolina Industrial Group for Fair Utility Rates
- City of Asheville
- Clemson University
- Dominion
- Duke University
- Durham County
- Electric Power Research Institute
- ElectriCities of NC
- Gerdau
- Google
- Institute for Policy Integrity, NYU Law School
- Interfaith Power & Light, NC
- Lockhart Power Company
- NC Clean Energy Technology Center
- NC Department of Environmental Quality
- NC Department of Environment and Natural Resources
- NC Department of Justice
- NC Electric Membership Corporation
- NC Institute for Climate Studies
- NC Justice Center
- NC Sustainable Energy Association
- NC Utilities Commission Public Staff
- North Carolina State University
- Research Triangle Cleantech Cluster
- SC Department of Natural Resources
- SC Office of Regulatory Staff
- SC Office of Resilience
- Sierra Club
- Smart Electric Power Alliance
- Southern Alliance for Clean Energy
- Southern Environmental Law Center
- Strata Clean Energy
- Town of Chapel Hill
- UNCC EPIC Center
- Vote Solar
- Walmart

Duke Energy’s climate resilience journey



Vulnerability Assessment Approach

Vulnerability Assessment Methodology

The vulnerability assessment methodological framework produces an understanding of the **nature, extent, and priority of the vulnerabilities** that Duke Energy may face due to climate change.

For each major asset group (i.e., transmission, substations, distribution) and climate hazard combination, the vulnerability rating is summarized as low, medium, or high.

Vulnerability assessment is conducted based on the current state of assets and processes and does not consider future adaptations or mitigations.

Exposure
The degree to which assets, operations, or systems could face climate hazards, based on their physical locations and projected hazards

+

Potential impact
The potential for negative outcomes in the event of climate hazard exposure.

Sensitivity
The degree to which assets, operations, or systems could be affected by exposures.

Consequence
Estimated magnitude of negative outcomes associated with impacts. Incorporates criticality and adaptive capacity.

↓

Vulnerability | Interim Report 2022
The potential of assets, operations or customers to be affected by projected hazards, and the significance of the potential consequences.

Vulnerability of discrete assets

↓

Summary vulnerability of assets & ops categories

↓

Adaptation framework
Advancement of plans and processes for adapting and building resilience in vulnerability areas identified as high priority.

Climate science tailored to Duke's T&D system

Custom variables to evaluate potential impacts.

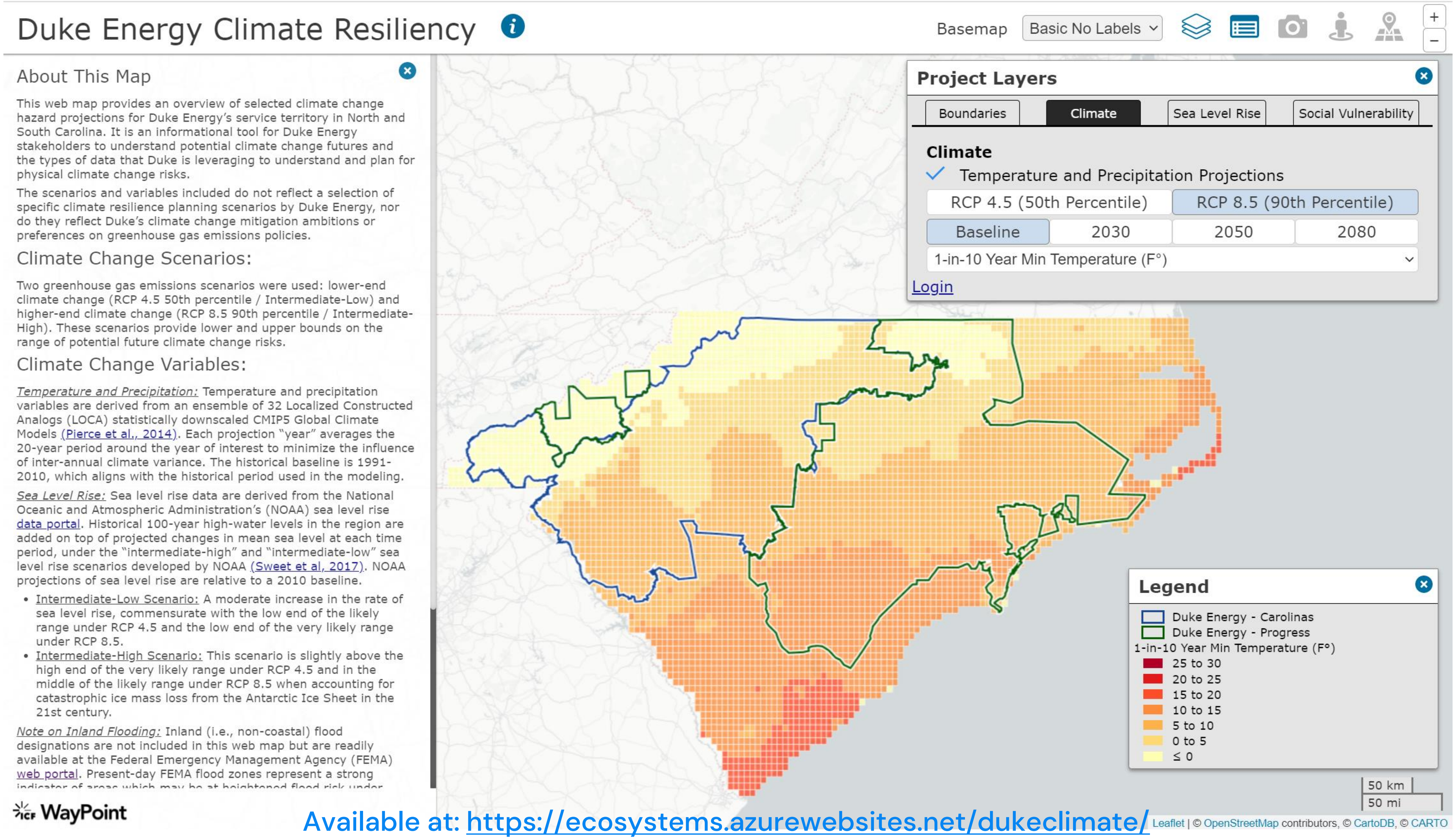
Best available climate datasets

- Global Climate Model projections downscaled to the Carolinas.
- NOAA sea level rise projections and coastal datasets.
- Multiple greenhouse gas concentration scenarios.
- Decadal projections through late-century.
- Synergy with the 2020 North Carolina Climate Science Report.

Key climate hazards:

- High temperature and extreme heat
- Sea level rise and coastal flooding
- Wind
- Extreme cold and winter storms
- Precipitation
- Wildfire

Duke's service area projections are publicly available on the web

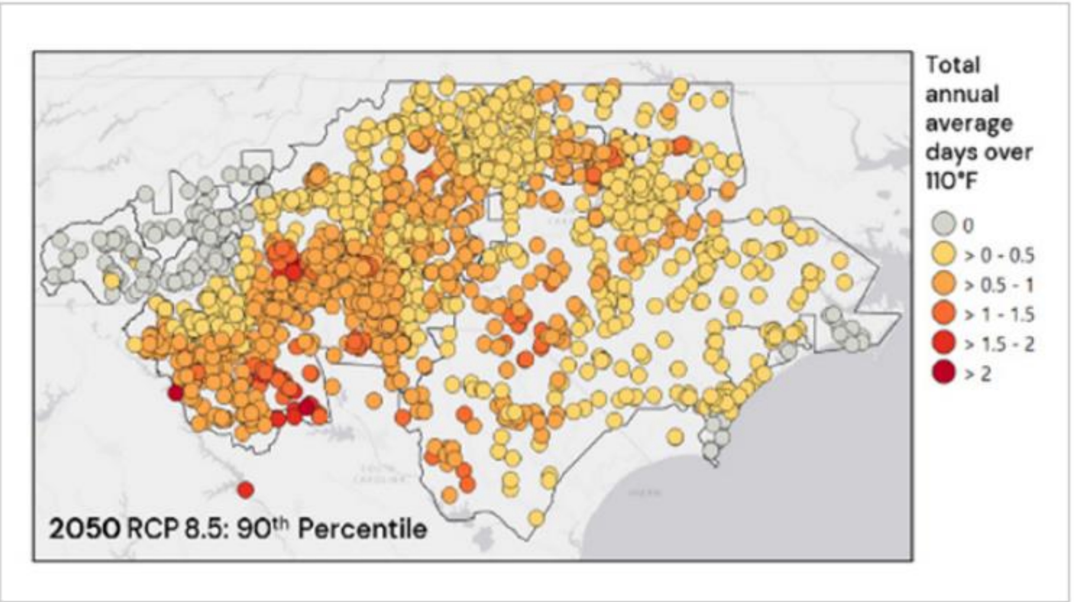


Available at: https://ecosystems.azurewebsites.net/dukeclimate/

The exposure analysis provides details on asset specific exposure to climate hazards

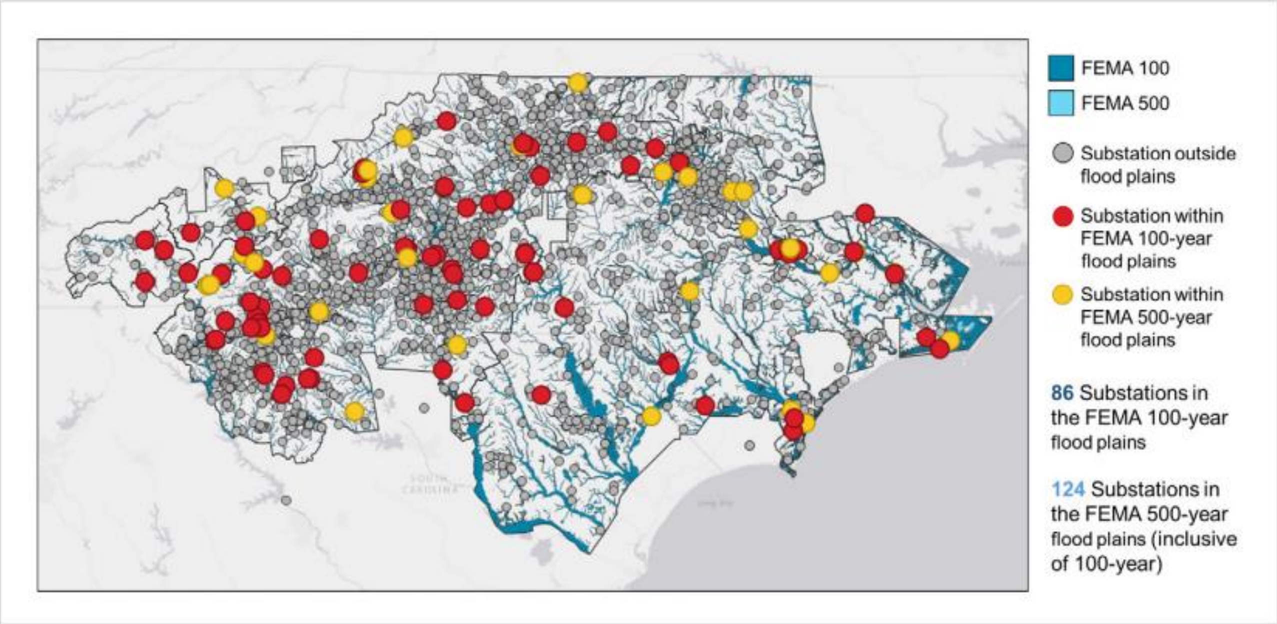
Extreme heat and substations

Substations by number of average annual days with daily temperatures exceeding 110°F in 2050.



Flooding and substations

Locations of substations within the 100- and 500-year FEMA flood plains.



Source: Duke Energy Climate Risk and Resilience Study, Interim Report, 2022.

Vulnerability assessment findings for assets (RCP 4.5)

Climate Hazard	Transmission	Substations	Distribution	Observations
High Temperature and Extreme Heat	Low	Med.	Low	Higher temperatures may reduce system capacity on the hottest days of the year, but unlikely that temperatures will result in exceptional levels of accelerated aging or load shedding.
Extreme Cold and Ice	Low	Low	Low	Winters are anticipated to warm, but severe winter weather and cold temperatures will still occasionally occur.
Coastal Flooding	Med.	Med.	Low	Flood risk driven by increasing intensity of hurricanes and the potential for coastal flooding.
Precipitation and Inland Flooding	Low	Med.	Low	Increases in annual average maximum five-day precipitation may impact substations in existing flood plains.
Wind	Med.	Low	Med.	Increases in hurricane storm intensity may impact transmission and distribution assets.
Wildfire	Low	Low	Low	Projections indicate a more moderate increase in wildfire risk and are subject to uncertainty because of wildfire control measures which may reduce risk.

Vulnerability assessment findings for processes

Process Area	Vuln. Score	Observations
Asset Management	High	Accelerated equipment aging; the need to adjust design criteria to address climate risks, need for better understanding of asset condition and the potential impact of climate on failure rates.
Load Forecasting	Medium	Incorporate temperature projections into load forecasting process
Capacity Planning	Medium	Incorporate local variations in temperature in determining equipment ratings.
Reliability Planning	Medium	Advance reliability planning tools and processes to improve the ability to model the impact of climate change on service reliability,
Emergency Response	Low	Emergency response processes are robust, flexible and scalable but must remain so to adapt to changing climate.
Workforce Safety	Low	More frequent periods of adverse weather will increasingly challenge safety and safety protocols need to adapt accordingly.
Vegetation Management	Low	Vegetation management practices are flexible and dynamic but will need to continue to adapt to stay ahead of climate risk.

Climate adaptation framework

Climate adaptation framework overview

Duke Energy's climate adaptation flexible framework is built on four primary pillars, aiming to optimize risk reduction and enhance future replication.

Monitor climate science

Use adaptation planning scenarios to inform planning and design. Update the scenarios as science evolves.

Maintain readiness

Continue to evolve T&D planning and operational practices to be ready for changing climate risks.

Incorporate new factors in T&D investments

Identify and prioritize selective T&D improvements, when and where appropriate, that will reduce climate risk for Duke's grid and customers.

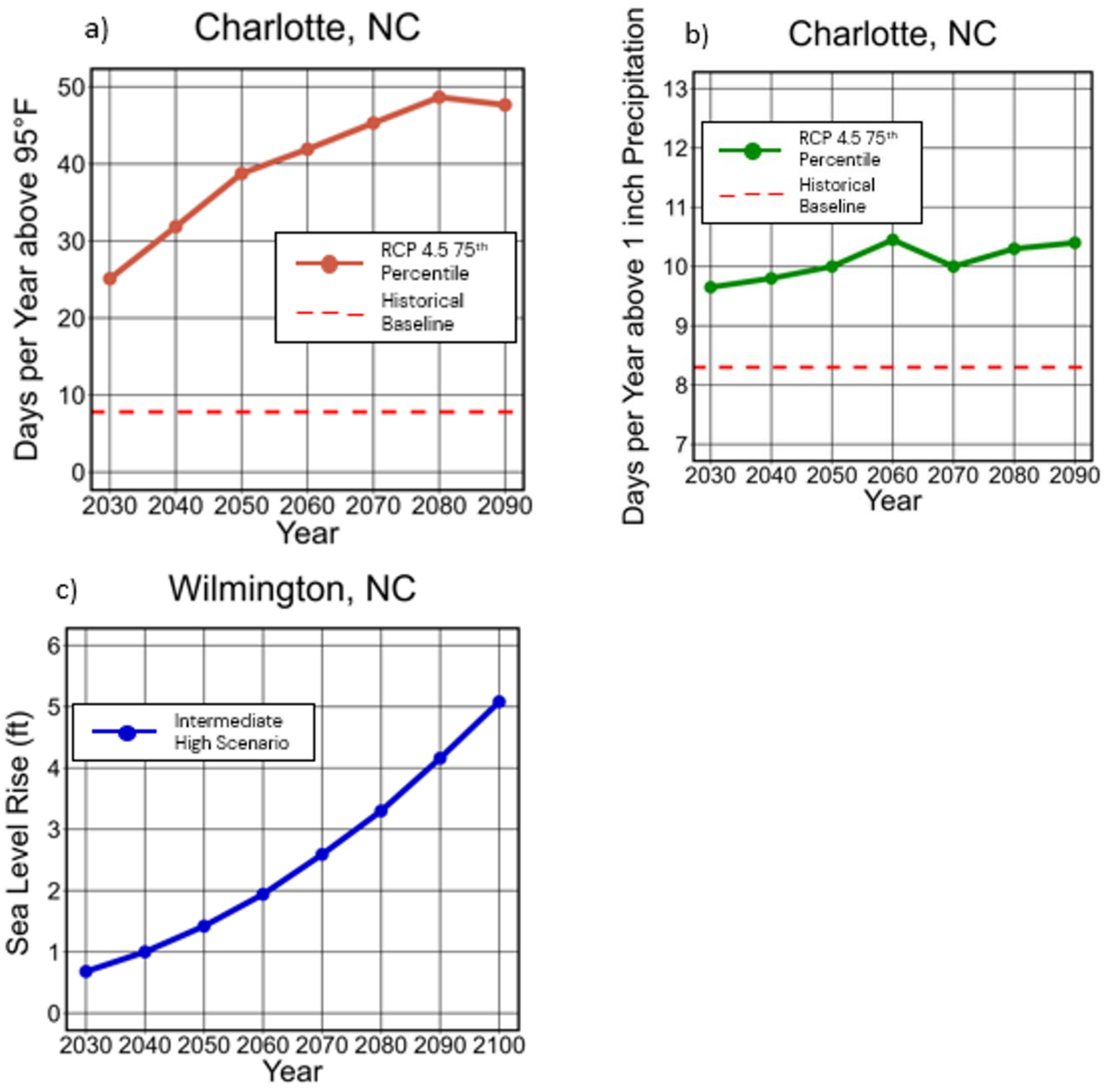
Partner with local communities

Continue to support community resilience planning efforts and incorporate community priorities in resilience planning.

Monitor climate science

What Duke has done to date

- One of the first utilities to have a carbon reduction goal.
- Published a climate report aligned to the Task Force on Climate-Related Financial Disclosures (TCFD) since 2018.
- Reviewed climate science to understand potential impacts.
- Selected a Climate Change Adaptation Planning Scenario.
  - 75th percentile of RCP 4.5 for temperature and precipitation.
  - Intermediate-High sea level rise projections.



Report recommendations on monitoring

- Continue to monitor and update Duke's understanding of climate risks and the Climate Change Adaptation Planning Scenario as climate science evolves.

- Explore the development of a Climate Change Design Guideline.

- Invest in standardizing Duke's data collection and internal solutions for weather and climate data.

Source: Duke Energy Multimedia Center

Maintain readiness

What Duke has done to date

- Emergency response, workforce safety, and vegetation management found to be flexible and robust to future climate change.
- Duke has been proactively investing in resilience and identifying and revising design and operations specifications to address emerging extreme weather risks.

Source: Duke Energy Multimedia Center

Report recommendations on readiness

- Proactively revise specifications to incorporate the Climate Change Adaptation Planning Scenarios.
- Quantify the impact of climate change on asset failure and replacement rates.
- Improve integration between data management systems to make use of the increasing amount of information from sensors.
- Continue the efforts to incorporate climate projections into the load forecasting process.

Source: Duke Energy Multimedia Center

Additional recommendations on readiness

- Incorporate climate change into the Capacity Planning Process.
- Consider incorporating more granular temperature assumptions when developing equipment ratings.
- Increase the level of SCADA temperature monitoring to improve visibility.
- Improve data related to joint-use poles.
- Explore reliability analysis tool options that can incorporate climate projections as well as the impact of new technologies.

Source: Duke Energy Multimedia Center

Incorporate new factors in T&D investments

What Duke has done to date

Duke Energy's grid investment plans include resilience investments:

- T&D hardening & resiliency.
- Targeted undergrounding.
- Hazard tree removal.
- Self-optimizing grid.
- Distribution automation.
- Voltage regulation/SCADA.

Source: Duke Energy Multimedia Center

Report recommendations on T&D investments

Develop formalized approaches to:

- Guide the selection of adaptation locations based on exposure, sensitivity, and consequence. Pilot approaches to consider social vulnerability.
- Determine the timing of executing adaptions based on factors such as the selected climate change adaptation planning scenario, level of risk, asset characteristics, and other investment plans.
- Identify specific adaptation options based on factors such as asset condition, future capital plans, alternatives to the adaptation, and costs and benefits.

Source: Duke Energy Multimedia Center

Partner with local communities

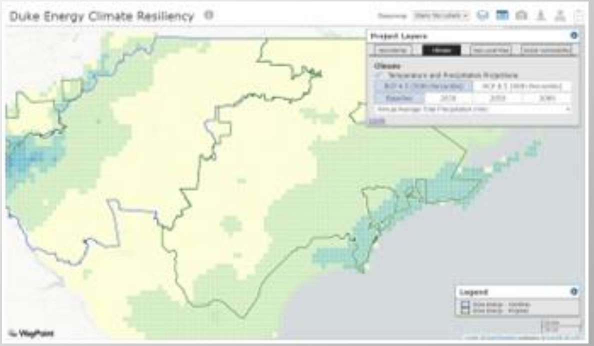
Partner with local communities

Duke is currently actively engaged with community partners in a broad array of resilience-supporting activities.

Real-time coordination during emergencies

Funding and grant support

Proactive planning and coordination



Future recommendations:

- Engage the community beyond the local government (between events).
- Continue improving coordination between Duke Energy and other utilities and first responders.

- Prioritize projects with communities where joint-adaptation actions may be most cost efficient.
- Continue to support academic research that will contribute to community resilience.

- Expand the detail of scenario-based tools.
- Curate additional resilience planning resources.
- Expand resilience planning guidance to local governments.

Next steps in Duke Energy's resilience journey

Next steps in Duke Energy's resilience journey

1. Set expectations and assign responsibility.
2. Continue implementation of process changes to maintain readiness.
3. Incorporate potential impacts of climate change into ongoing resilience planning efforts.
4. Approach the suite of resilience options holistically.
5. Determine funding approach.
6. Conduct regular engagement with stakeholders.
7. Establish climate resilience performance metrics.
8. Implement, monitor, revise.

What Should Grid Resilience Plans Include?

Planning Requirements, Emerging Best Practices, and Template

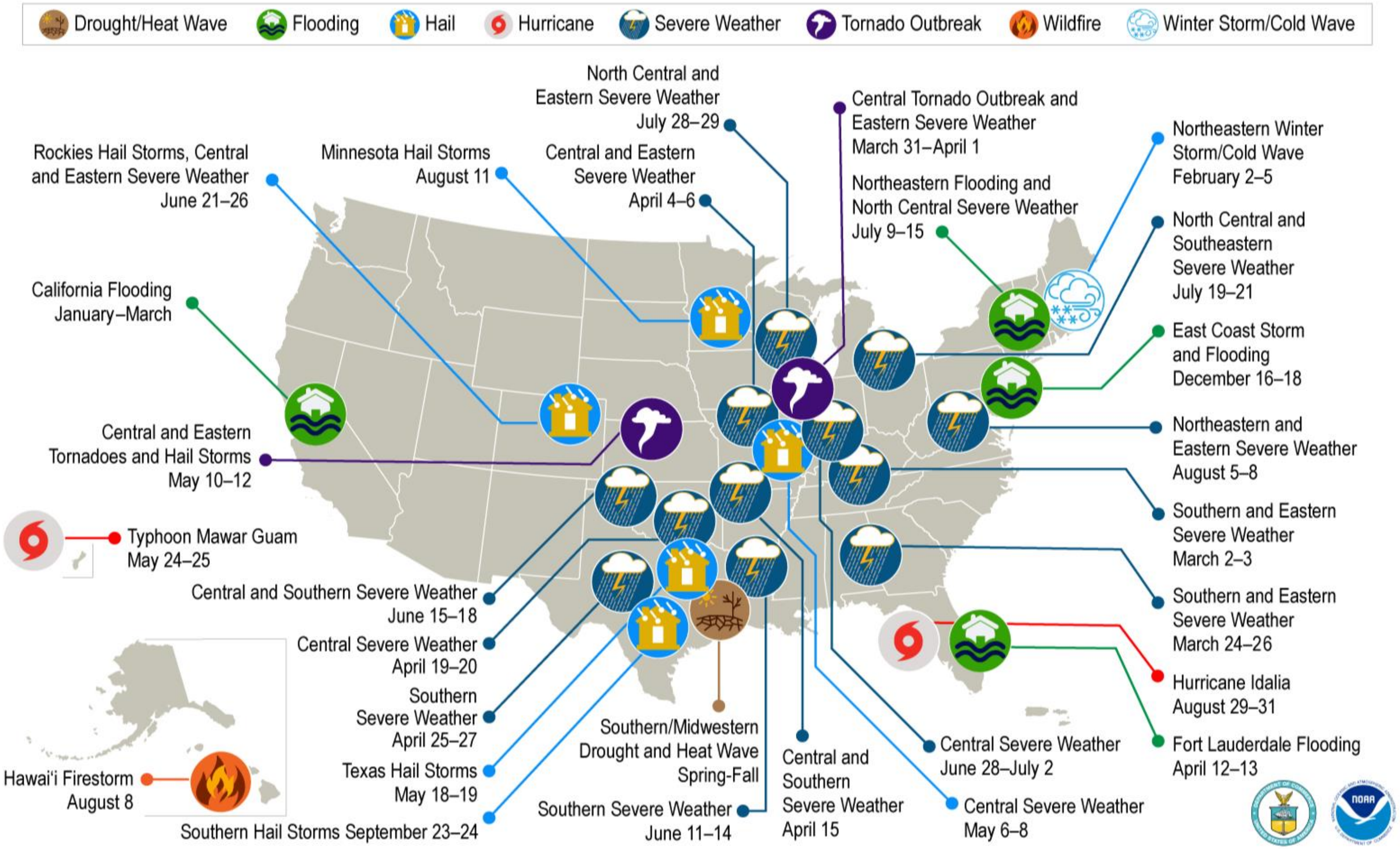
Presented by Josh Schellenberg, Affiliate, Berkeley Lab

Resilience Training for States
Nashville, Tennessee

March 21, 2024

2023 had more billion-dollar weather and climate disasters than any year on record (inflation-adjusted)

U.S. 2023 Billion-Dollar Weather and Climate Disasters



*This map denotes the approximate location for each of the **28 separate billion-dollar weather and climate disasters that impacted the United States in 2023.***

- **All 50 states** have been impacted by at least one of these billion-dollar disasters in the past 10 years
- Hawaii did not have any disasters of this magnitude for over 30 years until the August 2023 firestorm that destroyed the historic town of Lahaina on Maui Island
- 2023 was also the hottest year on record worldwide

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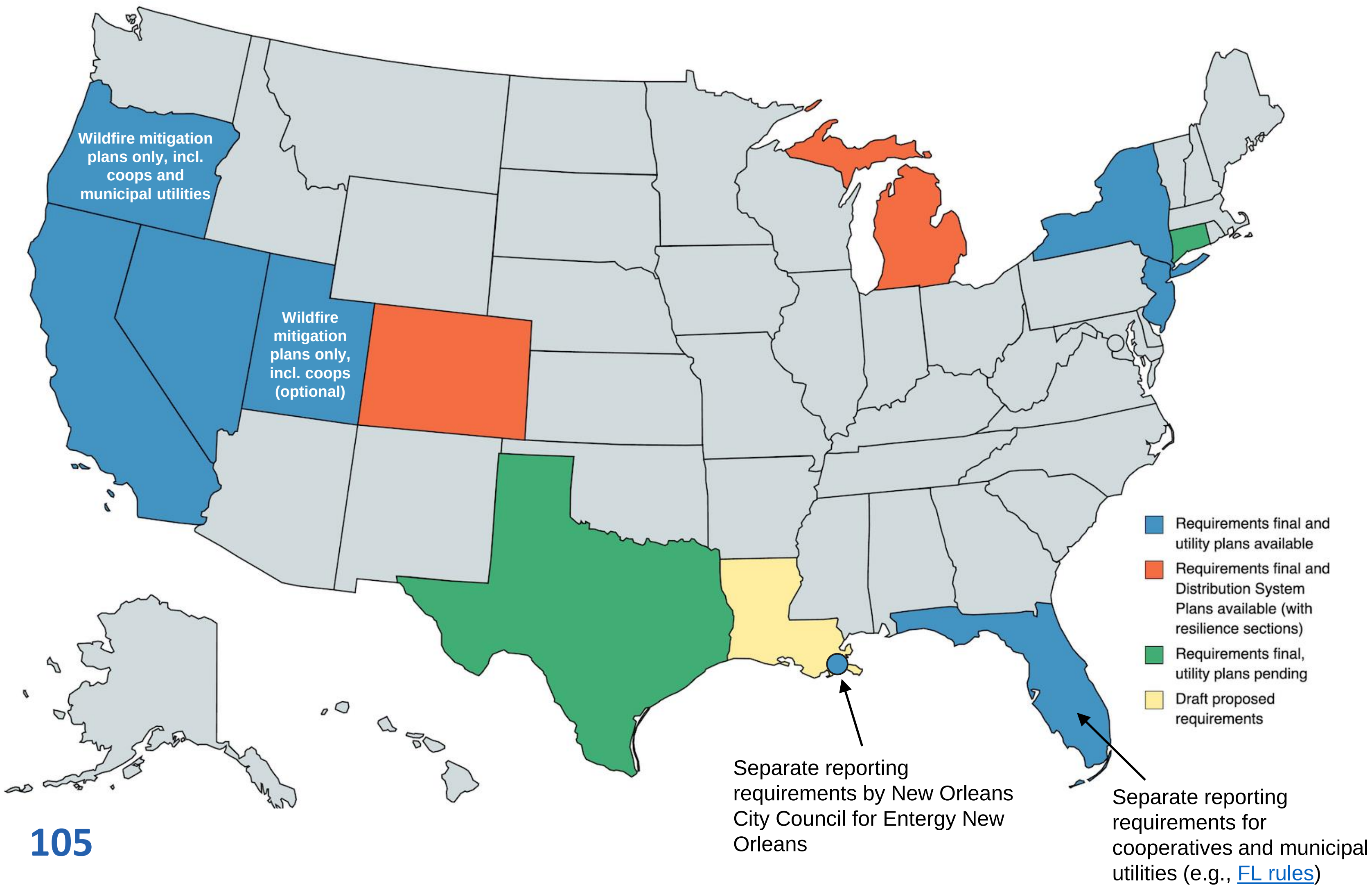
States are responding with resilience planning requirements for regulated utilities



- The four largest states – California, Texas, Florida and New York, which account for a third of the U.S. population – set resilience plan requirements, by law or rule, as well as eight other states.
- Existing requirements and utility plans have begun to point toward best practices, which serve as guidance to states that have not created resilience plan requirements and regulatory processes.

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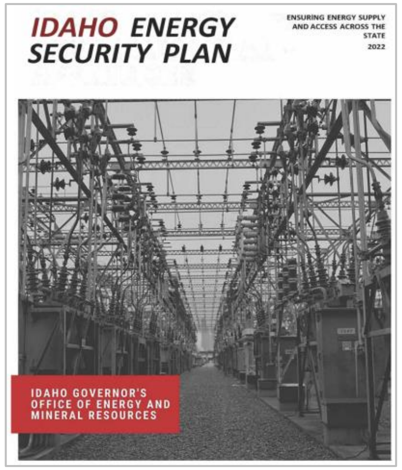
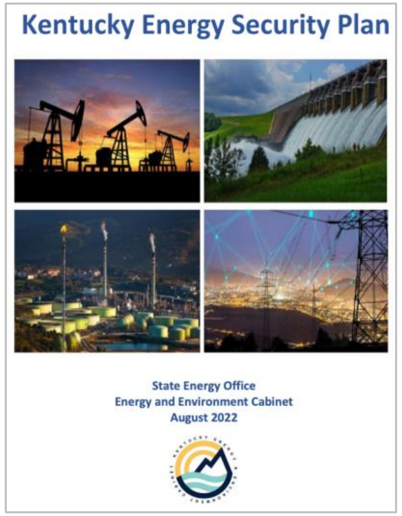
States are also developing Energy Security Plans

- Under IIJA, State Energy Security Plans must assess existing circumstances in the state and propose methods to strengthen its ability to:
    - Secure energy infrastructure against all physical and cybersecurity threats
    - Mitigate the risk of energy supply disruptions
    - Enhance the response to, and recovery from, energy disruptions
    - Ensure that the state has reliable, secure, and resilient energy infrastructure

- Specific resilience-related requirements include:
    - Addressing physical and cybersecurity threats and vulnerabilities
    - Providing a risk assessment of energy infrastructure and cross-sector interdependencies
    - Developing a risk mitigation approach to enhance reliability and end-use resilience

- The security plans are the **foundation of grid investment resilience planning** under the IIJA. They highlight resilience risks, discuss investment priorities for enhancing the grid, and provide insights into potential priority investments by utilities.
    - Utility resilience plans should align with methods, data sources and priorities in the state's Energy Security Plan





Source: NASEO and Berkeley Lab (2023). *State Energy Offices' Engagement in Electric Distribution Planning to Meet State Policy Goals*

Berkeley Lab plans to publish a resilience planning framework and standardized template for utility plans in early 2024

Resilience Plan Template

Section 1. Executive Summary

- Resilience plan objectives and motivation (e.g., legislation, PUC rulemaking, extreme weather events, increasing restoration costs, new funding, data sources and solutions, etc.)
- Definition of resilience and how it differs from reliability
- Types of measures considered as part of plan development to enhance the resilience of the utility's infrastructure and practices, including the following options:
    - Hardening electrical T&D facilities
    - Modernizing electrical T&D facilities
    - Undergrounding certain electrical distribution lines
    - Lightning mitigation measures
    - Flood mitigation measures
    - Information technology (IT)
    - Cybersecurity measures
    - Physical security measures
    - Vegetation management
    - Wildfire mitigation and response
    - Other eligible resilience measures
- Proposed resilience programs in plan
    - Name of each resilience program
    - Category of resilience measure (from list of measure types above)
    - Specific types of hazards mitigated by program, including high winds, lightning, flooding, freezes, earthquakes, cybersecurity threats, physical security threats and other hazards
- Summary of overall costs and benefits by resilience program, including:
    - Cost summary
    - Rate impacts
    - Expected benefit streams (such as reduced restoration costs, shorter outage duration, avoided outage events, lower unserved energy, avoided customer interruption costs and increased safety)
    - How the program prioritizes areas of lower expected performance

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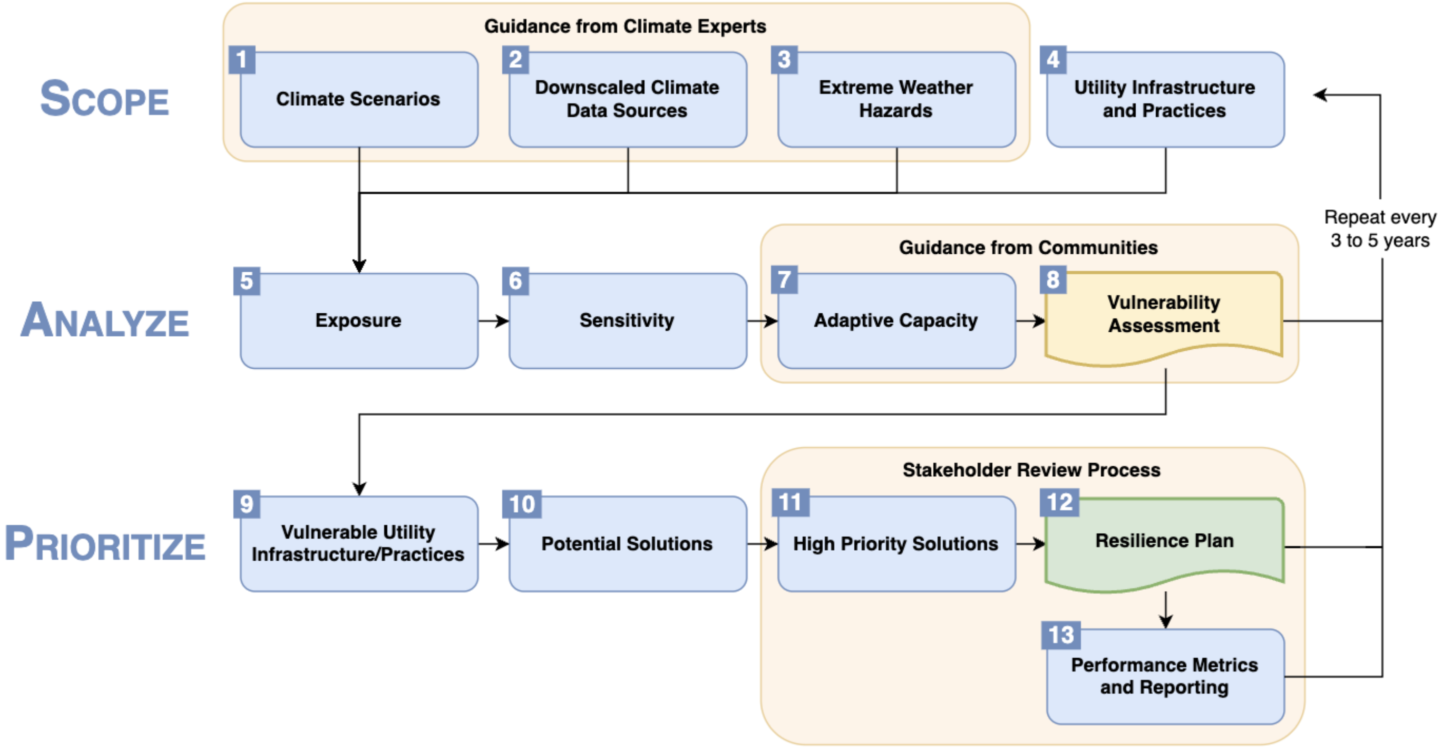
Resilience Planning Framework for Extreme Weather



Objectives:

- Facilitate development of plan requirements
- Assist with review of prepared plans
- Offer a standard format states can adapt (standardizing across utilities reduces burden of review)

Resilience Planning Requirements and Emerging Best Practices

Storms are impetus for requirements in Southern states, but proposed rules in LA and TX take an ”All-Hazards” approach

State	Plan Name	Hazards in Scope	Plan Frequency	Planning Horizon
Florida	Storm Protection Plan	**Extreme weather**	3 years	10 years
Louisiana (excluding NOLA)	Grid Resilience Plan (proposed final rule)	Any low-probability/high-consequence events, including *cyber/physical security threats*	5 years	10 years
New Orleans	System Resiliency and Storm Hardening Plan	**Extreme weather**	TBD	5 years
Texas*	T&D System Resiliency Plan	Any event involving extreme weather conditions, wildfires or *cyber/physical security threats* that poses a material risk to the safe and reliable operation of T&D systems	3 years (voluntary)	3 years (minimum)

* Per HB 2555 (2023) for Texas requirements

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Resilience planning requirements

Extreme weather is the primary focus in Northern states

State	Plan Name	Hazards in Scope	Plan Frequency	Planning Horizon
Connecticut	Resilience Plan	**Extreme weather**	4 years (part of GRC cycle)	10 years
Michigan	Distribution System Plan	**Extreme weather**	2 years	5 years
New Jersey	Infrastructure Investment Program	**Extreme weather** and *cybersecurity*	Voluntary	5 years
New York	Climate Change Vulnerability Study and Resilience Plan (required in legislation signed by governor)	Increase in **severe weather** expected from climate change, including stronger storms and more flooding	5 years	10 to 20 years

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Wildfire is the primary focus in Western states

State	Plan Name	Hazards in Scope	Plan Frequency	Planning Horizon
California	Climate Change Vulnerability Assessment	**Wildfires**, extreme heat, extreme storms, drought, subsidence, sea level rise and other climate change hazards	4 years (part of general rate case)	10 to 50 years
California*	Wildfire Mitigation Plan (required in Senate Bill 901)	**Wildfires**	Annual	3 years
Colorado	Distribution System Plan	Natural disasters and *cyber/physical security threats*	2 years	10 years
Nevada	Natural Disaster Protection Plan	**Wildfires** are primary focus, but state requirements cover other natural disasters	3 years	3 years**
Oregon	Wildfire Mitigation Plan	**Wildfires**	Annual	3 years**
Utah	Wildland Fire Protection Plan (required in House Bill 66)	**Wildfires**	3 years	3 years**

* This linked reference is for the original CPUC decision on 2019 Wildfire Mitigation Plans (WMP), submitted pursuant to Senate Bill 901. A new state agency under the governor called the Office of Energy Infrastructure Safety (OEIS) was then formed to oversee WMPs for regulated utilities. Since 2021, OEIS has issued several revised guidelines and other new requirements for the WMPs.

** These state requirements do not specify a planning horizon, but utilities have filed 3-year plans in practice

Emerging best practices for resilience plan requirements

1. **Hazards in Scope:** If policymakers prefer an All-Hazards approach, requirements should specify that utilities provide a summary of all hazards analyzed and the resulting vulnerability assessment
   - Utility resilience plans to date have not focused on cyber/physical security threats, even if those hazards are included as an option in the requirements (Colorado and New Jersey)
   - Texas' resilience planning law and proposed Louisiana requirements include cyber and physical security measures as options to include in a resilience plan

2. **Planning Horizon and Frequency:** Given the long-term nature of most resilience investments, requirements should specify a planning horizon of at least 10 years, with more detail provided in the first 3 to 5 years and updates every 3 to 5 years
   - Wildfire Mitigation Plans have a shorter planning horizon (3 years) and are updated more frequently (1 to 3 years), most likely due to the urgency of the wildfire threat in Western states in recent years

Emerging best practices for resilience plan requirements (continued)

3. **Measures in Scope:** Consider most viable resilience measures, *including changes to planning/operational practices*, and specify that utilities analyze those measures
   - Undergrounding (in California, New York, Michigan and Texas requirements)
   - Vegetation management (in most plan requirements)
   - De-energization events, including protocols and emergency communications (in Wildfire Mitigation Plans)
   - Lineworker staffing and storm severity forecasting (in Connecticut requirements)
   - Measures that mitigate gas-electric dependencies during winter storms (in Louisiana requirements)

4. **Vulnerability Assessment:** Require a matrix that summarizes all hazards relative to assets and practices analyzed with a clearly defined vulnerability rating that applies to each asset-hazard and practice-hazard pair
   - Emerging best practice from utility vulnerability assessment and plans (examples provided in next section of this presentation)
   - Resilience solutions are then identified and prioritized for each asset/practice-hazard pair that the assessment identifies as highly vulnerable

Emerging best practices for resilience plan requirements (continued)

5. **Performance Reporting:** Require quarterly to annual reporting of specific, impact-oriented metrics (relative to key benchmarks if applicable)
   - “Metrics should focus on the success of mitigation at lowering the risk of catastrophic wildfires and not simply program targets such as the number of trees removed or wires replaced” (in California requirements)
   - Utilities file forecasted reliability metrics and benchmarks, with and without major storm events, and map planned system investments against metrics to better understand expected impacts (in Michigan requirements)
   - Major storm data on outages, blocked roads, critical facility impacts and life-threatening emergency response events by storm intensity and level of resilience investment (in Connecticut requirements)

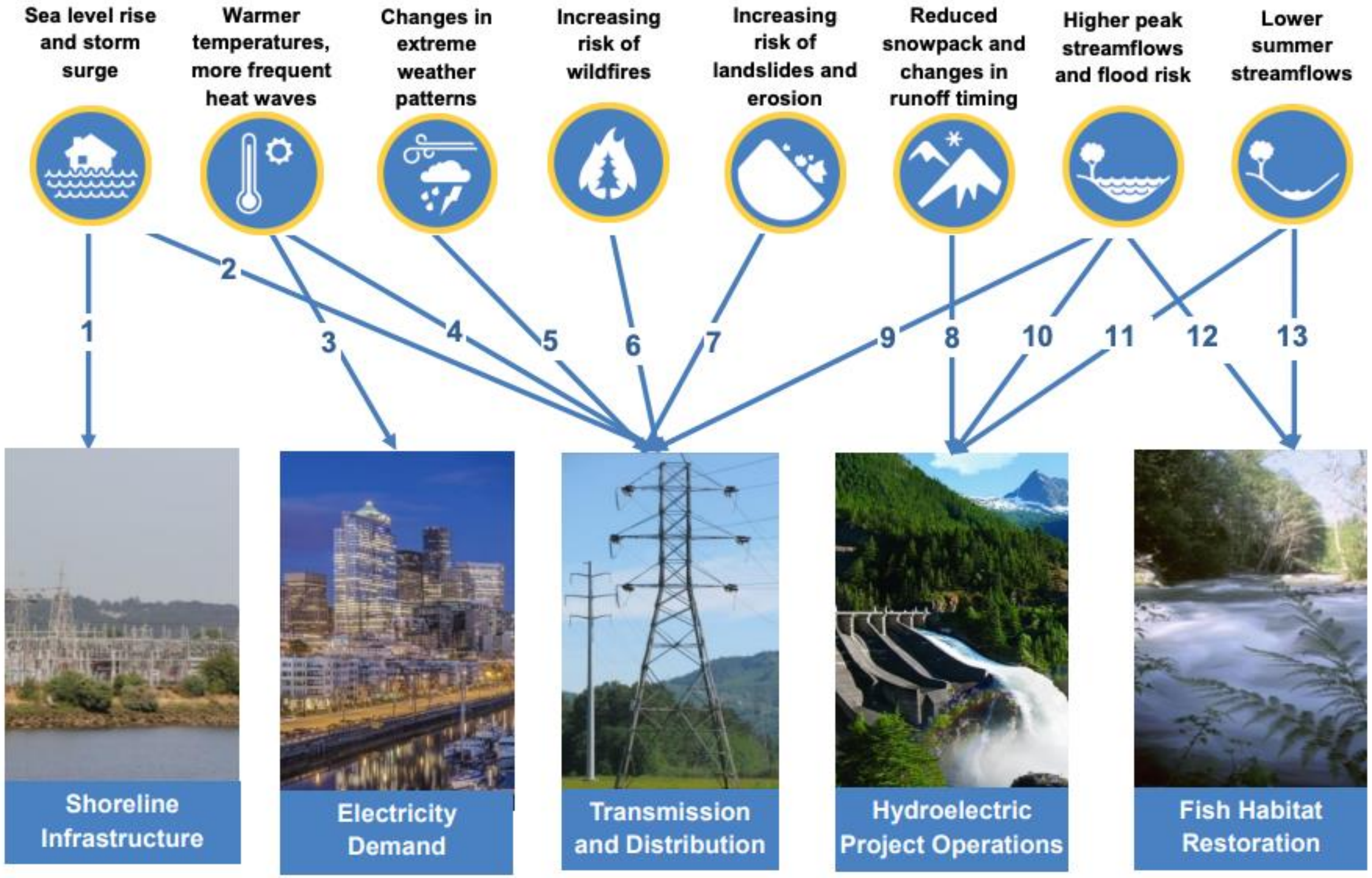
6. **Funding Support:** Include requirement to seek funding support (if applicable for a given measure), particularly IIJA, and report progress
   - Connecticut and Louisiana requirements include almost identical language: “Every effort must be made, both now and in the future, to identify non-ratepayer funds to offset the costs associated with implementing [resilience plans] required herein. Specifically, it is incumbent on each [utility] to continuously review the [plans] for alignment with and potential leveraging of existing and future federal or state funding opportunities, particularly those included in the Federal Infrastructure Investment and Jobs Act (IIJA).”
   - Connecticut requirements include detailed quarterly funding status updates

Emerging best practices for resilience plan requirements (continued)

7. **Climate Scenarios and Data:** For extreme weather hazards, specify climate scenarios for vulnerability assessment and provide source for downscaled climate data based on expert input
    - In California and New York, State Energy Offices worked with climate experts at leading universities in their states to develop extreme weather forecasts for a variety of climate hazards, downscaled for their state
    - This is a critical step to ensure consistency of data sources and scenarios for utilities, including municipal utilities and rural electric cooperatives
    - With the general warming trend and increasing frequency and severity of extreme weather events, long histories of weather data may lead to misguided resilience investment decisions

Example Utility Plans and Best Practices

Seattle City Light Climate Change Vulnerability Assessment and Adaptation Plan (2015)



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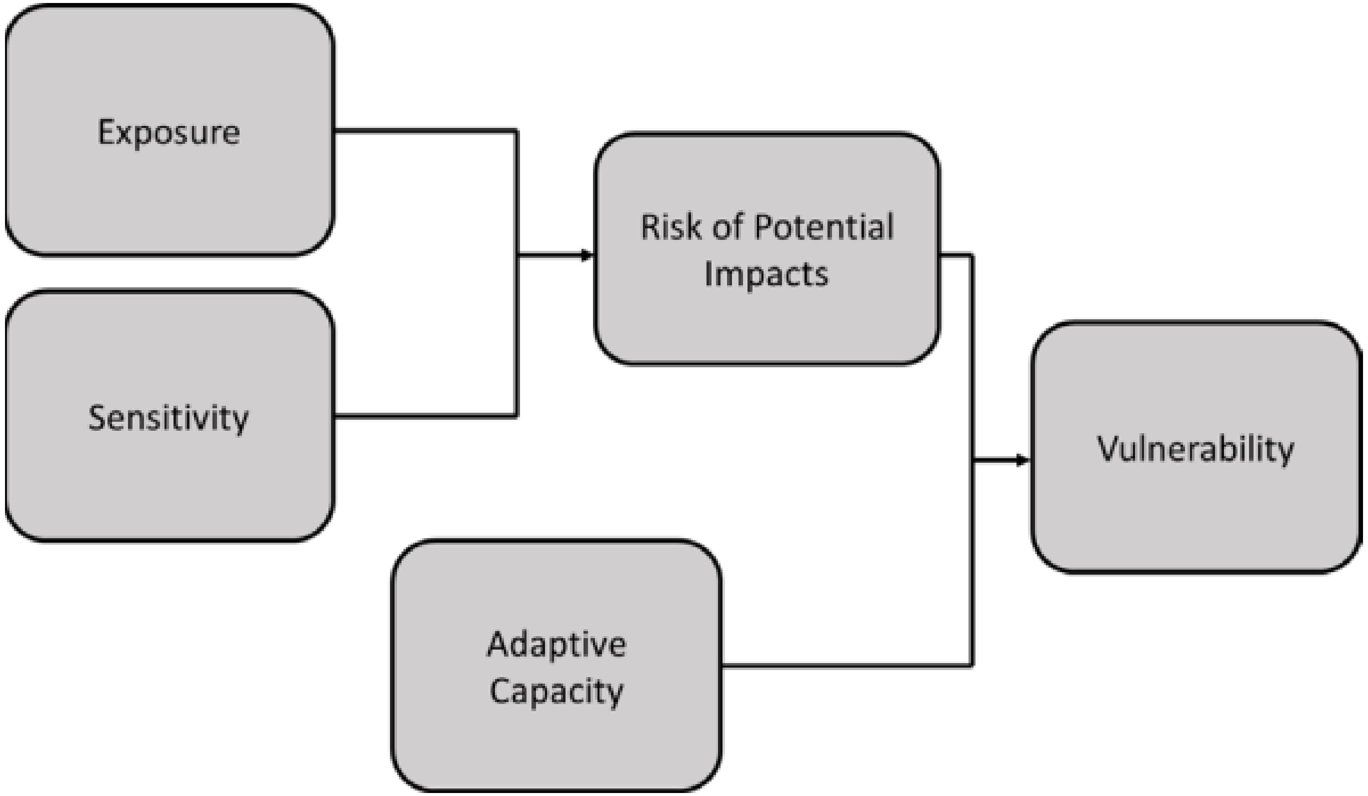
California Department of Water Resources Climate Change Vulnerability Assessment (2019)



Con Edison Climate Change Vulnerability Study (2023) – Summary of Vulnerabilities

	Temperature and Temperature Variable (TV)	Flooding	Wind and Ice
Area and Unit Substations	Primary	Primary	Low
Transmission Substations	Primary	Primary	Low
Overhead Transmission	Primary	Low	Secondary
Overhead Distribution	Secondary	Low	Primary
Underground Transmission	Secondary	Secondary	Low
Underground Distribution	Primary	Secondary	Low
Key Company Facilities	Secondary	Secondary	Low

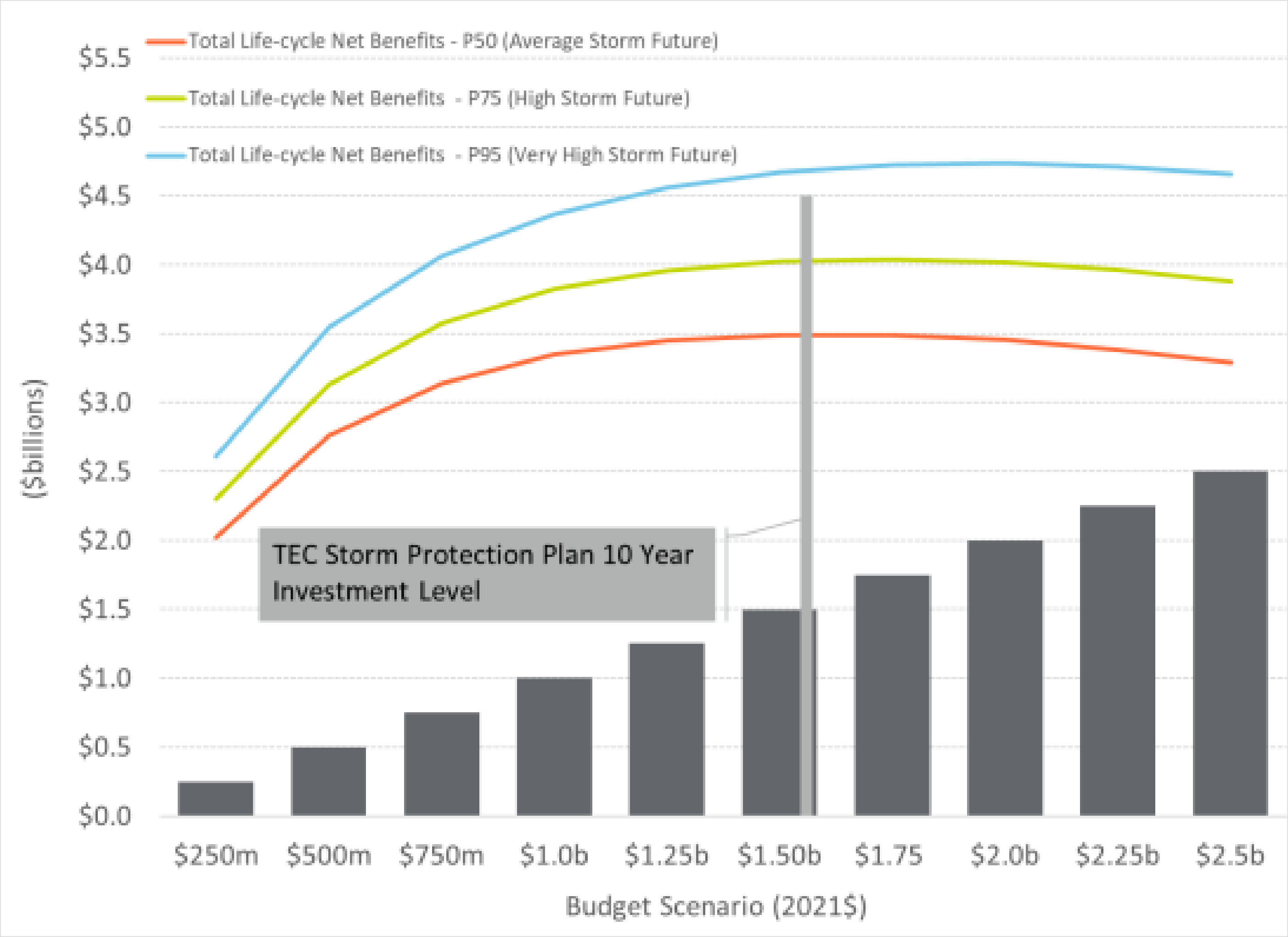
Duke Energy Climate Risk and Resilience Study (2022)

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

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

"Risks to Duke Energy's asset management include accelerated equipment aging; a potential need to adjust design criteria to address the risk of changing precipitation, flooding and heat patterns; an incomplete understanding of the pole fleet's weather readiness; and limited insight into failure data and impact of climate on failure rates."

Tampa Electric Storm Protection Plan (2022)



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Draft Resilience Plan Template

Overview of Draft Resilience Plan Template

- Section 1. Executive Summary
  - Resilience plan objectives and motivation
  - Definitions of key terms
  - Measures considered in plan development
  - Proposed resilience programs
  - Summary of overall costs and benefits by resilience program
  - Summary of metrics the utility will use to evaluate the plan’s performance
  - Describe how the utility's resilience plan aligns with the State's Energy Security Plan
  - Status of state and federal resilience funding support
  - How the overall resilience plan is in the public interest
- Section 2. Vulnerability Assessment and Prioritization Approach
  - Description of service area
  - History of extreme weather events in service territory
  - Summary of approach for forecasting frequency and severity of extreme weather events
  - Practices and infrastructure prioritized for enhancement, including a matrix that summarizes all hazards relative to assets and practices, analyzed with a clearly defined vulnerability rating
  - Summary of third-party review/engagement

Overview of Draft Resilience Plan Template (continued)

- Section 3. Description of each proposed resilience program
  - Time period (actual or estimated start and completion dates)
  - Expected improvement to utility's existing infrastructure and practices
  - Estimate of the resulting benefits
  - How resilience program impacts prevention of, response to, and recovery from major outage events
  - Program performance metrics
  - Cost estimate including capital and operating and maintenance expenses
  - Comparison of costs and benefits for the proposed resilience program
  - Description of criteria used to select and prioritize the proposed program

Overview of Draft Resilience Plan Template (continued)

- Section 4. Projected rate impacts
  - Estimated number and costs of projects under each program
  - Relevant cost drivers for each program
  - Estimated annual revenue requirements for each year of the plan (see example table below)
  - Estimated rate impacts for each year of the plan
  - For each of the first three years of the plan, estimated rate impacts by customer class (see tables below)
  - Description of implementation alternatives that the utility considered to mitigate the resulting rate impact

EXAMPLE TABLES

Year	Resilience Plan Annual Revenue Requirement ($ millions)
2024	
2025	
2026	
2027	
2028	
2029	
…	

Customer Class	Resilience Plan Estimated 3-year Rate Impacts		
	2024	2025	2026
Residential ($/kWh)			
Commercial ($/kW or $/kWh)			
Industrial ($/kW or $/kWh)			

Guide for Applying Resilience Plan Template

- Policymakers can adapt the template to their state's needs based on:
  - State objectives
  - Definitions for key terms
  - Hazards, assets and practices in scope for a given utility service territory
  - Availability of downscaled climate data for specific hazards
  - Most viable resilience measures, including changes to planning and operational practices
  - Specific, impact-oriented performance metrics and benchmarks
  - Equity considerations and third-party review and engagement processes
  - Alignment with other applicable plans for state energy security, transmission and distribution systems, emergency response, etc.

Next steps

- **Berkeley Lab:** Complete draft report, including resilience planning framework and standardized plan template based on emerging best practices, and request external review
- **Public Utility Commissions:** Consider framework and template for utility resilience plans — in close alignment with integrated distribution system plans — to:
  - Facilitate development of plan requirements
  - Facilitate Commission review of filed plans
  - Reduce the burden of review by using a standard format across regulated utilities
- **State Energy Offices:** Consider working with climate experts at leading universities in your state to develop extreme weather forecasts for a variety of climate hazards, downscaled for your state
  - Critical step to ensure consistency of data sources and scenarios for all types of utilities in your state, including municipal utilities, rural electric cooperatives, and investor-owned utilities

Questions to ask

- Should the regulated utilities in my state develop resilience plans that follow a standardized format, frequency and planning horizon?
- What hazards and resilience measures should be in scope for the plans?
- How can we align resilience plan development with other processes such as integrated distribution planning and State Energy Security Plans?
- How can we support the development of similar resilience plans for municipal utilities and co-operatives?
- How can we ensure consistency of climate scenarios and data sources across the state for these planning processes?

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Engaging Stakeholders and Building Equity in Resilience Planning

Dimensions of Equity

- *Structural/Recognitional*
- Restorative
- *Procedural*
- Distributional

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State Energy Officials

THE SPECTRUM OF COMMUNITY ENGAGEMENT TO OWNERSHIP

▸▸▸▸▸▸ INCREASED EFFICIENCY IN DECISION-MAKING AND SOLUTIONS IMPLEMENTATION ▸▸▸▸▸▸ EQUITY

STANCE TOWARDS COMMUNITY	0 IGNORE	1 INFORM	2 CONSULT	3 INVOLVE	4 COLLABORATE	5 DEFER TO
IMPACT	**Marginalization**	**Preparation or Placation**	**Limited Voice or Tokenization**	**Voice**	**Delegated Power**	**Community Ownership**
COMMUNITY ENGAGEMENT GOALS	Deny access to decision-making processes	Provide the community with relevant information	Gather input from the community	Ensure community needs and assets are integrated into process & inform planning	Ensure community capacity to play a leadership role in decision-making and the implementation of decisions.	Foster democratic participation and equity through community-driven decision-making; Bridge divide between community & governance
MESSAGE TO COMMUNITY	***Your voice, needs & interests do not matter***	***We will keep you informed***	***We care what you think***	***You are making us think, (and therefore act) differently about the issue***	***Your leadership and expertise are critical to how we address the issue***	***It's time to unlock collective power and capacity for transformative solutions***
ACTIVITIES	Closed door meeting Misinformation Systematic Disenfranchisement Voter suppression	Fact sheets Open Houses Presentations Billboards Videos	Public Comment Focus Groups Community Forums Surveys	Community organizing & advocacy Interactive workshops Polling Community forums Open Planning Forums with Citizen Polling	MOU's with Community-based organizations Citizen advisory committees Collaborative Data Analysis Co-Design and Co-Implementation of Solutions Collaborative Decision-Making	Community-driven planning and governance Consensus building Participatory action research Participatory budgeting Cooperative models
RESOURCE ALLOCATION RATIOS	**100%** Systems Admin	**70-90%** Systems Admin **10-30%** Promotions and Publicity	**60-80%** Systems Admin **20-40%** Consultation Activities	**50-60%** Systems Admin **40-50%** Community Involvement	**20-50%** Systems Admin **50-70%** Community Partners	**80-100%** Community partners and community-driven processes ideally generate new value and resources that can be invested in solutions

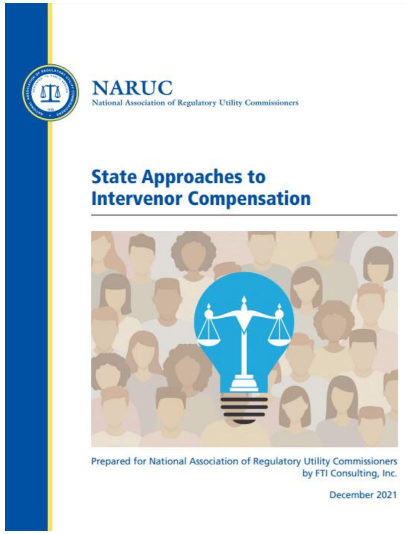
NARUC Energy Equity Resources

N-Groups Regional Equity Roundtables

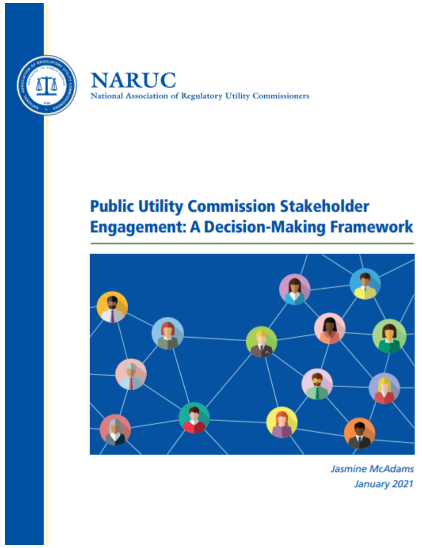
Midwest, June 2023
Western, Sept 2023
Northeast, Dec 2023
Mid-Atlantic, April 2024
Central, April 2024
Southeast, June 2024

https://www.naruc.org/core-sectors/energy-resources-and-the-environment/stakeholder-engagement/

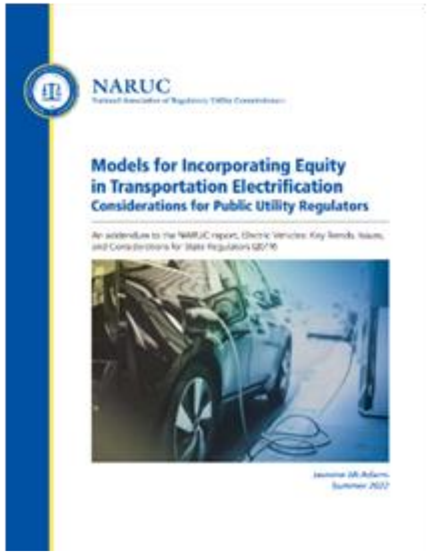
State Approaches to Intervenor Compensation



Public Utility Commission Stakeholder Engagement: A Decision-Making Framework



Equity in Transportation Electrification



Energy Justice Series

Metrics

Affordability and Arrearages

Participation in Decision Making

NASEO Energy Equity Resources

NASEO Energy Equity Committee

N-Groups Regional Equity Roundtables

Midwest, June 2023
Western, Sept 2023
Northeast, Dec 2023
Mid-Atlantic, April 2024
Central, April 2024
Southeast, June 2024

NASEO Energy Equity Publications

Advancing Equity in Grid Planning and Operations

A growing number of states are taking action on energy equity and justice. But there are **limited examples of equity and justice incorporated into electricity planning and operations processes**. This project will help states make and accelerate progress by:

- Developing and regularly update a comprehensive **repository and database**
- **Assembling and convening a working group** of PUCs, SEOs, community, and utility perspectives to identify and prioritize emerging equity issues,
- **Researching emerging electricity equity and justice topics** related to grid planning and operations
- Providing **direct technical assistance and training for states**
- Discussing and disseminate equity efforts through an **in-person summit with DOE and the national labs**

For more information and resources see**:** https://emp.lbl.gov/projects/equity-in-grid-planning-and-operations

Contact: Natalie Mims Frick, nfrick@lbl.gov

Select Resources

Websites:

- Equity in Grid Planning and Operations
- Energy Equity (LBNL)
- Energy Equity at PNNL

Forthcoming Resources:

- U.S. Department of Energy-National Lab Equity Summit: Grid Planning and Operations: Workshop Report (March 2024)
- Distributional Equity Analysis for Energy Efficiency and Other Distributed Energy Resources: A Practical Guide (March 2024)
- Engagement Guide for the Distribution Equity Analysis (May 2024)

Active Projects:

- Equity in Grid Planning and Operations
- Distributional Equity Analysis
- Energy Storage for Social Equity

Presentations:

- Advancing Energy Equity in Grid Planning
- Considerations for Planning for Resilience and Equity
- Incorporating Equity Objectives into Transmission Planning

Publications and Reports

- Advancing the state of energy equity metrics
- Advancing energy equity considerations in distribution system planning
- Advancing Equity in Utility Regulation
- Analysis of Energy Justice and Equity Impacts from Replacing Peaker Plants with Energy Storage
- Assessing the energy equity benefits of energy storage solutions
- Assessing the Current State of U.S. Energy Equity Regulation and Legislation
- Business model for coal plant decommissioning
- Communities in transition: Exploring best practices and decision support tools to provide equitable outcomes.
- Distribution System Planning: Goals & Objectives
- Grid Modernization: Metrics Analysis – Affordability
- Review of Energy Equity Metrics

Strategies for Valuing and Prioritizing Resilience Investments and Measuring Progress

Presented by Pete Larsen, Berkeley Lab

Resilience Training for States
Nashville, Tennessee

March 21, 2024

Goals for today

Information Sharing

- Metrics in practice to facilitate project valuation and prioritization
- Valuation frameworks and measuring progress
- Examples of valuing and prioritizing a resilience strategy
- Links to references and a glossary

Method

- Presentation
- Discussion
- Interactive polls

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Availability of information

- **Regulatory processes lead to publicly-available information** that can be useful for (1) evaluating projects that have societal benefits and (2) measuring performance after the project has been installed
- For this reason, there tends to be more information in the public domain for regulated utilities and less so for other utilities

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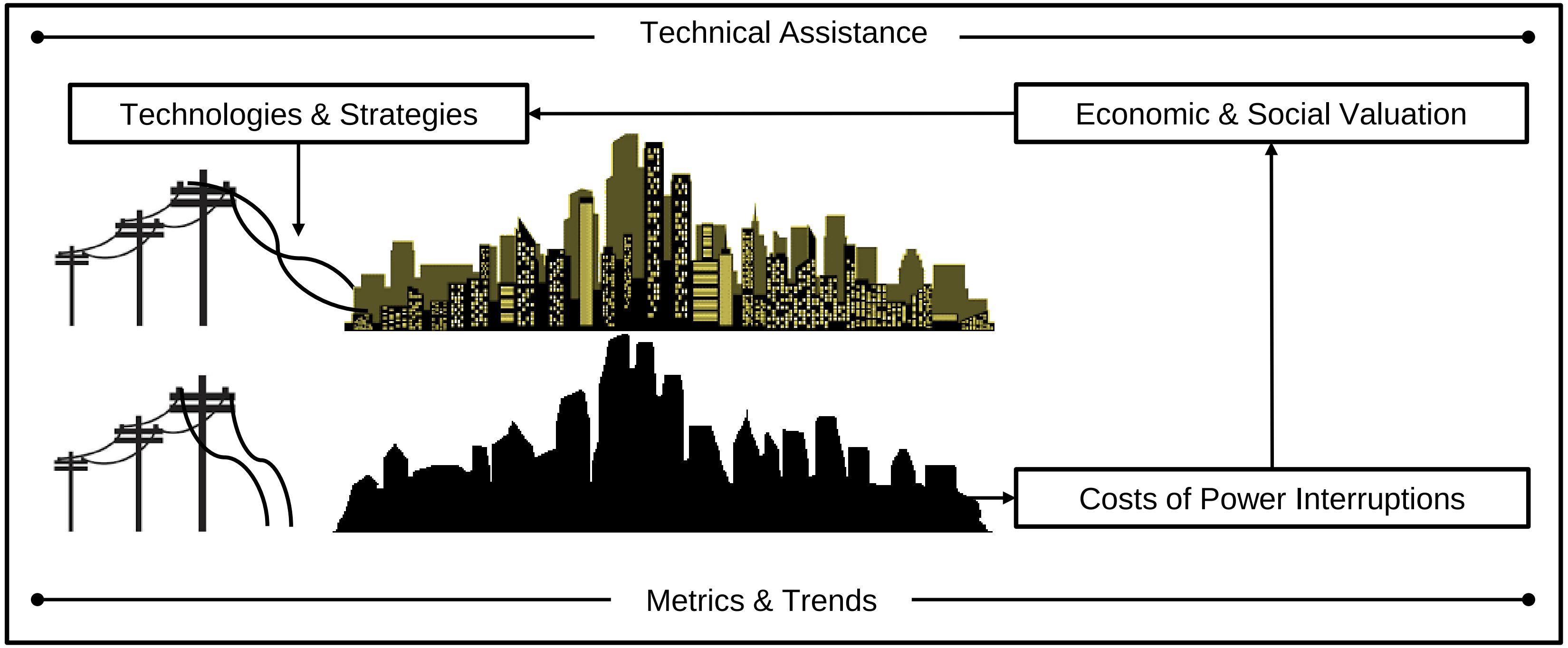
Metrics in Practice for Valuing and Prioritizing Resilience Projects

Metrics within context of project valuation and prioritization

Berkeley Lab's Portfolio of Resilience Activities



- **Metrics are important because they allow key stakeholders to assess the performance of systems before <u>or</u> after an investment**

- Some metrics (e.g., costs of power interruptions) are critical inputs into the value proposition for new projects

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Selected metrics in practice

State	Metric	Comments
California	IEEE 1366 reliability metrics, with and without major event days (MEDs)	• Circuit level and company-wide SAIDI • Circuit level and company-wide SAIFI • Circuit level and company-wide CAIDI • Circuit level and company-wide MAIFI (see glossary) • Top 1% of worst performing circuits (defined by circuit-level SAIDI and SAIFI excluding MEDs)
	Community Resilience Metric (CRM) (*mostly used for resilience planning)*	• A set of scores measuring the sensitivity and corresponding adaptive capacity of a particular community to potential loss of utility service • Prioritizes the timing/order of adaptations based on socioeconomic indicators that approximate a community's resilience to power outages
	Risk-reduction and Risk-spend Spend Efficiency (*mostly used for resilience planning)*	• Estimation of the cost-effectiveness of initiatives based on risk-reduction benefits (calculated by probability and associated consequences) and costs for a specific solution
	Resiliency scorecard *(mostly used for resilience planning)*	• Scoring resiliency configuration characteristics including those that support state policy goals (e.g., mitigation measure characteristics (duration of backup, load capacity, fuel availability, emission levels))

Sources: CPUC (2016), CPUC (2021), SCE (2021), SCE (2023), SDGE (2023)

Selected metrics in practice (2)

State	Metric	Description
Nevada	IEEE 1366 reliability metrics	• SAIDI, SAIFI, CAIFI
	Resilience metrics *(proposed)*	• Quantity of distributed resources available to respond to resilience events • Compliance with Natural Disaster Protection Plan (NDPP) mandates • Time to recover from service disruptions due to resiliency events • Amount of load voluntarily reduced under emergency conditions
Washington	IEEE 1366 reliability metrics (*Circuit-level and system-wide*)	• SAIDI, SAIFI (with and without MED) • Customers Experiencing Multiple Sustained and Monetary Interruptions (CEMSMI; number of customers experiencing more than a certain number of interruptions a year, including both momentary and sustained outages)
	Reliability metrics (*Circuit-level and system-wide*)	• CEMI-3 (customers experiencing more than three outages of 1 minute or more per year) • Average outage duration • Number of outage events per year • Total customer outage hours • Average number of affected customers per outage event • Circuit performance indicator (CPI) to identify areas of greatest concern and worst performing circuits

Sources: NV Energy (2020), PUCN (2020), Watts et al. (2020), Pacific Corp (2021), AVISTA (2022)

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Selected metrics in practice (3)

State	**Metric**	**Description**
Idaho	IEEE 1366 reliability metrics	• SAIDI, SAIFI with and without MEDs, significant events • SAIDI and SAIFI by underlying causes • CEMSMI
	Reliability metrics	• Number of incidents by underlying causes • Worst performing circuits based on CPI • Reliability performance indicator (RPI)
Oregon	IEEE 1366 reliability metrics (*Circuit-level and system-wide*)	• SAIDI, SAIFI, CAIDI • MAIFI$_e$ (Momentary Average Interruption Frequency Index event, total number of momentary interruption events divided by the customer base for the relevant period)
	Reliability metrics	• Under-performing circuits (identified by CPI) • Customer minutes lost for incident (with of without MEDs) by cause and region • Customers in incident sustained (with or without MEDs)
	Resilience metrics *(mostly used for resilience planning purposes (benefit calculations))*	• Reduction in Near-Term Asset Risk (NTR) values (reduced annual risk value) • Reduction in Near-term Customers Minutes Interrupted • Reduction in expected outage durations and numbers

Sources: Rocky Mountain Power (2019), Portland General Electric Company (2022), ISEA (2023), Pacificorp (2023),

Selected metrics in practice (1)

State	Metric	Comments
Florida	IEEE 1366 reliability metrics	• SAIDI • SAIFI • CAIDI • MAIFI (see glossary)
	L-Bar	• Average time it takes to restore power to all customers
	Customer-specific reliability metrics	• Customers experiencing multiple interruptions (customers experiencing more than X outages of 1 minute or more per year) • Customers experiencing multiple momentaries • Customer momentary events (customers affected by a momentary event)
	Customer interruption cost	• Florida Power and Light uses Berkeley Lab's ICE Calculator to estimate benefits of reducing SAIDI/SAIFI

Sources: Florida PSC (2013), FPL (2004), Florida PSC (2021)

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Interactive poll #1

What new metrics might be needed in your region to evaluate proposed or past investments in resilience?

Kahoot!

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Valuation Frameworks and Measuring Progress

Selected economic and social valuation methods

Method	Units	Examples	Comments
Least-cost, best-fit	$ divided by a non-monetary value	X dollars invested in grid to avoid Y number of fatalities X dollars invested in grid to reduce SAIDI by Y minutes	• Presumes that an investment is needed and helps prioritize options to achieve objectives • Does not require monetization of any or all benefits of project
Cost-benefit analysis	$ divided by $	X dollars invested in grid leads to Y dollars in societal benefits	• Does not presume that an investment is needed • Allows for an apples-to-apples comparison of options • Can be extremely challenging to put a dollar value on some benefits

Source: Woolf et al. (2021)

Examples of information needed for valuing a strategy

Cost	Benefits: Non-monetized	Benefits: Monetized	Other
• Capital/installation • Annual operations and maintenance	• Avoided pollution • Avoided health/safety risk • Avoided damage to utility infrastructure • Reduction in frequency and/or duration of power interruptions • Avoided impacts to national security	• Avoided morbidity and mortality costs • Avoided capital and O&M costs to utility • Avoided interruption costs to customers • Avoided "spillover" effects to regional economy • Avoided aesthetic costs (if applicable)	• Real discount rate (or weighted average cost of capital) • Lifespan of strategy • Local, state, and federal incentives and rebates • Frequency and duration of power interruptions before and after investment • Detailed information about customers impacted

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Forward- and backward-looking analyses

- Valuation activities can be conducted “ex ante” or “ex post”

Ex ante: “Based on forecasts rather than actual results”

Ex ante analysis is often used to identify a **proposed investment** and, in some cases, rank it among alternatives

- Undergrounding circuit 1234 has *expected* net benefits of $1M over its lifespan

Ex post: “Based on actual results rather than forecasts”

Ex post analysis is often used to measure progress or performance of an **investment that has already been made**

- Undergrounding circuit 1234 improved SAIDI and SAIFI by 21.2% and 19.4%, respectively.

Source: Oxford Dictionary (2023)

Interactive poll #2

What resilience valuation methods have you observed in your region?

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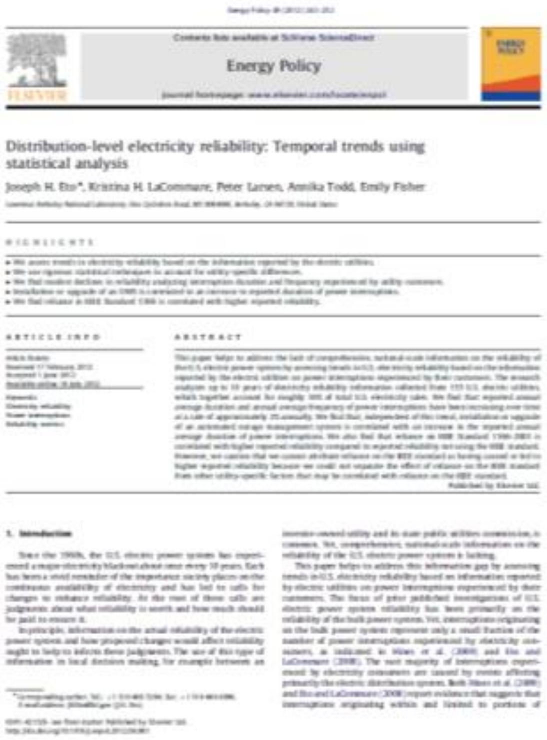
Examples of Valuing and Prioritizing Resilience Strategies

Example #1: Valuing a utility resilience strategy

- Berkeley Lab research into factors that impact long-term reliability of the U.S. power system led to research on the **value of undergrounding power lines**

- Increase in % share of transmission and distribution lines that are **underground has a statistically significant correlation with improved reliability/resilience** ([Larsen et al. 2020](#))



Components of valuation framework (1)

Despite the high costs attributed to power outages, there had been **little or no research to quantify both the benefits and costs of improving electric utility reliability/resilience**—especially within the context of decisions to underground T&D lines

- Study perspective:
  - Regulator who cares about maximizing private benefits
- Key stakeholders with standing:
  - Investor-owned utilities (IOUs), ratepayers, and all residents within service territory
- Policy alternatives:
  (1) Status quo (i.e., maintain existing underground and overhead line share)
  (2) Underground all T&D lines (i.e., underground when existing overhead lines reach end of useful lifespan)
- Why Texas?
  -Texas IOU service territories were selected due to (1) previous study evaluating costs and (some) benefits of undergrounding; (2) ready access to useful assumptions; and (3) public utility commission showing interest in undergrounding major portions of electrical grid

Source: [Larsen (2016)]

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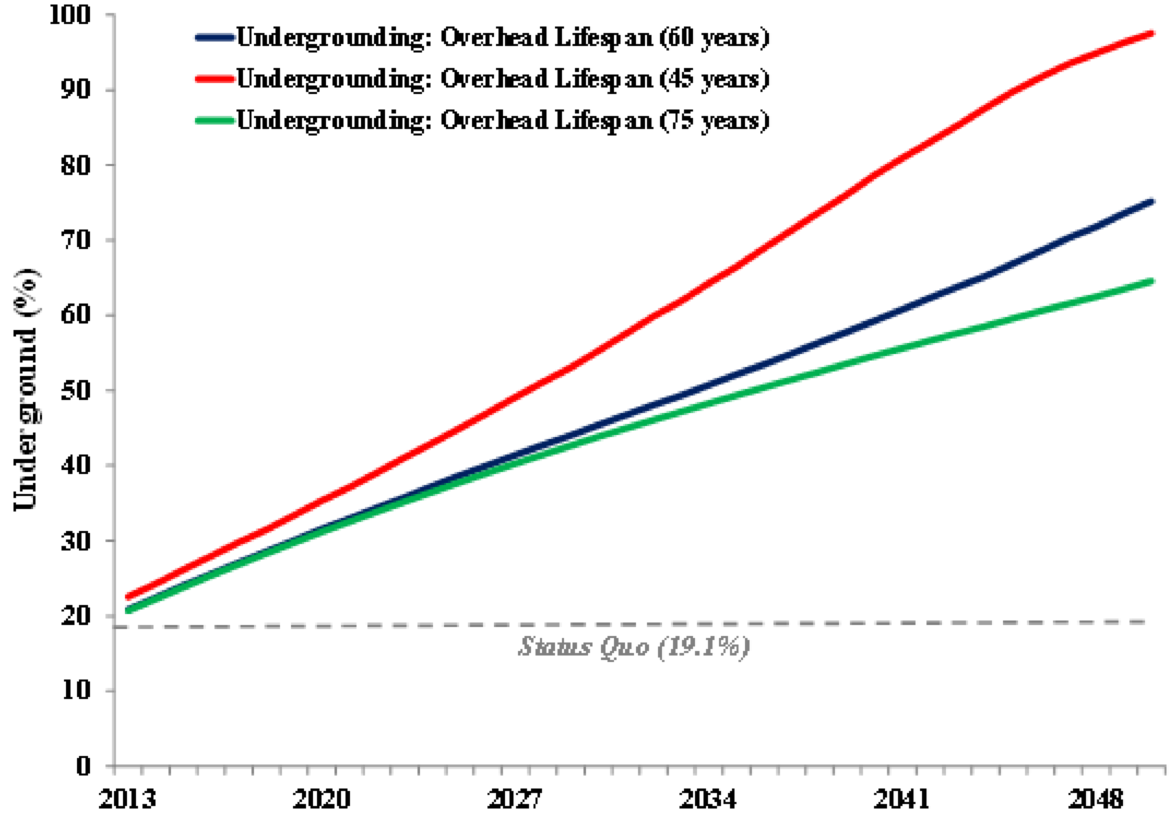
Components of valuation framework (2)

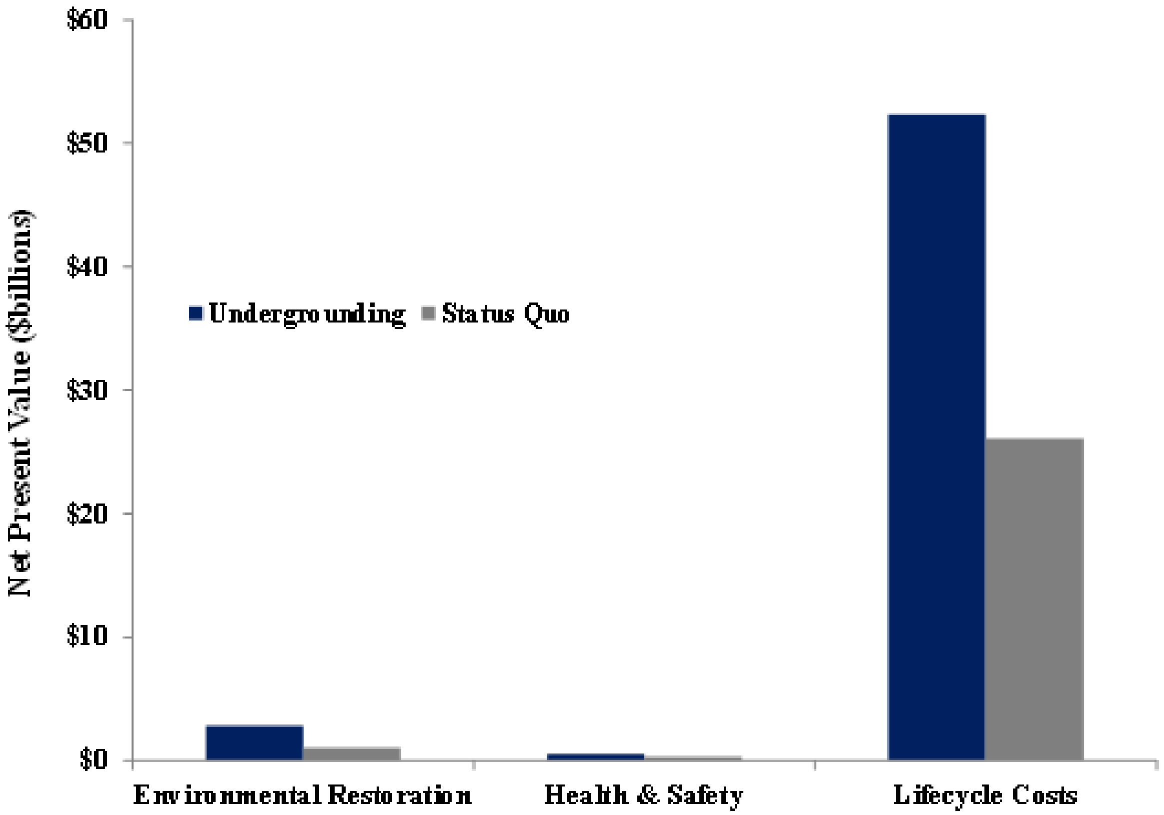
Key Stakeholders	Undergrounding Mandate	
	Selected Costs	**Selected Benefits**
IOUs	• Increased worker fatalities and accidents*	
Utility ratepayers	• Higher installation cost of underground lines***** • Additional administrative, siting, and permitting costs associated with undergrounding* • Increased ecosystem restoration/right-of-way costs**	• Lower operations and maintenance costs for undergrounding*
All residents within service area		• Avoided societal costs due to less frequent power outages*** • Avoided aesthetic costs**

* Denotes degree of impact on overall results

Can you spot the metrics included in this valuation framework?

Estimated costs





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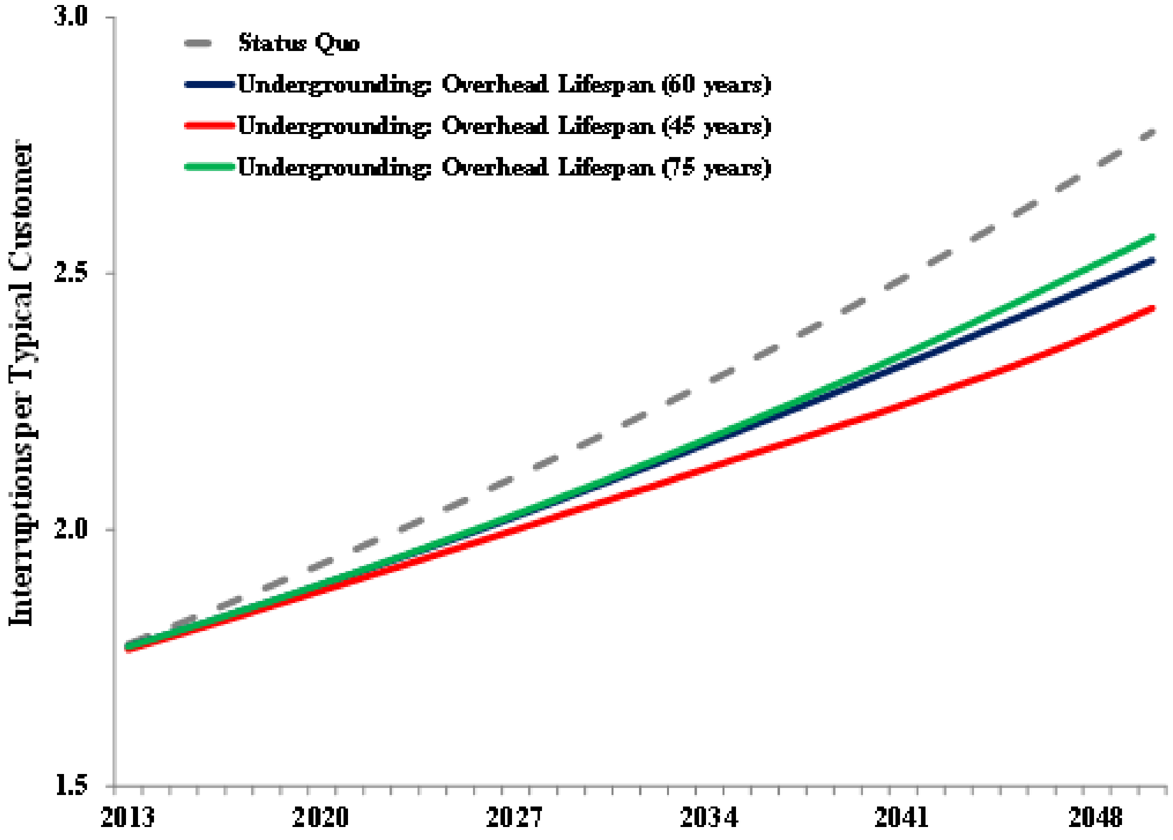
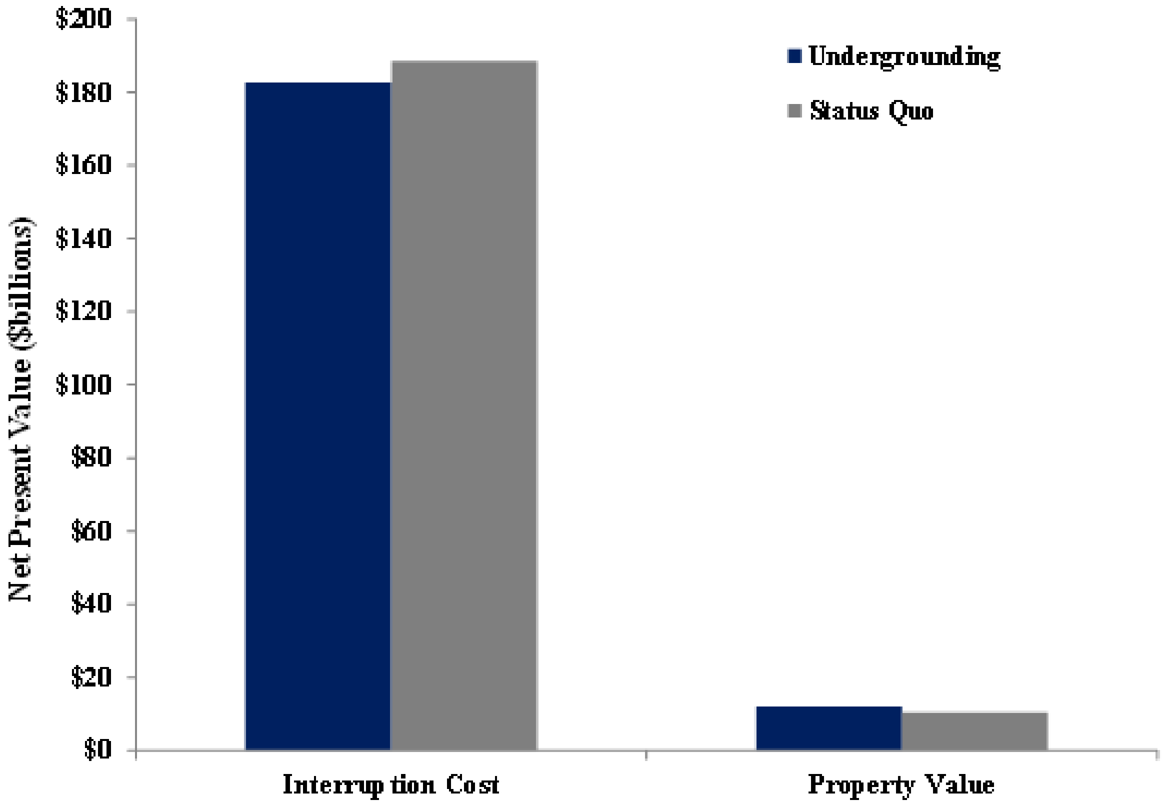
Estimated benefits (1)





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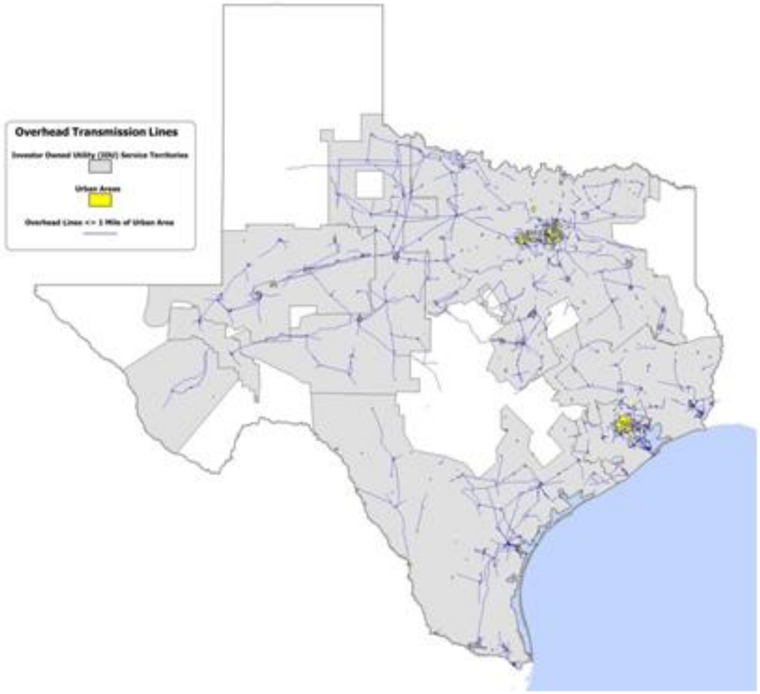
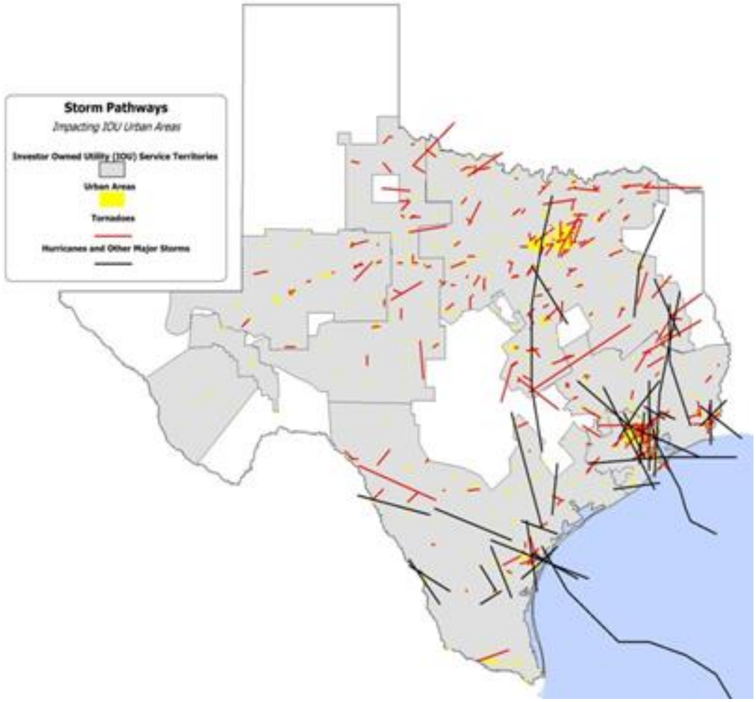
Estimated benefits (2)

The initial valuation indicated that **broadly mandating undergrounding when overhead T&D lines have reached the end of their useful life is not cost-effective for Texas IOUs.**





What are the minimum conditions necessary for a targeted undergrounding initiative to have positive net benefits?

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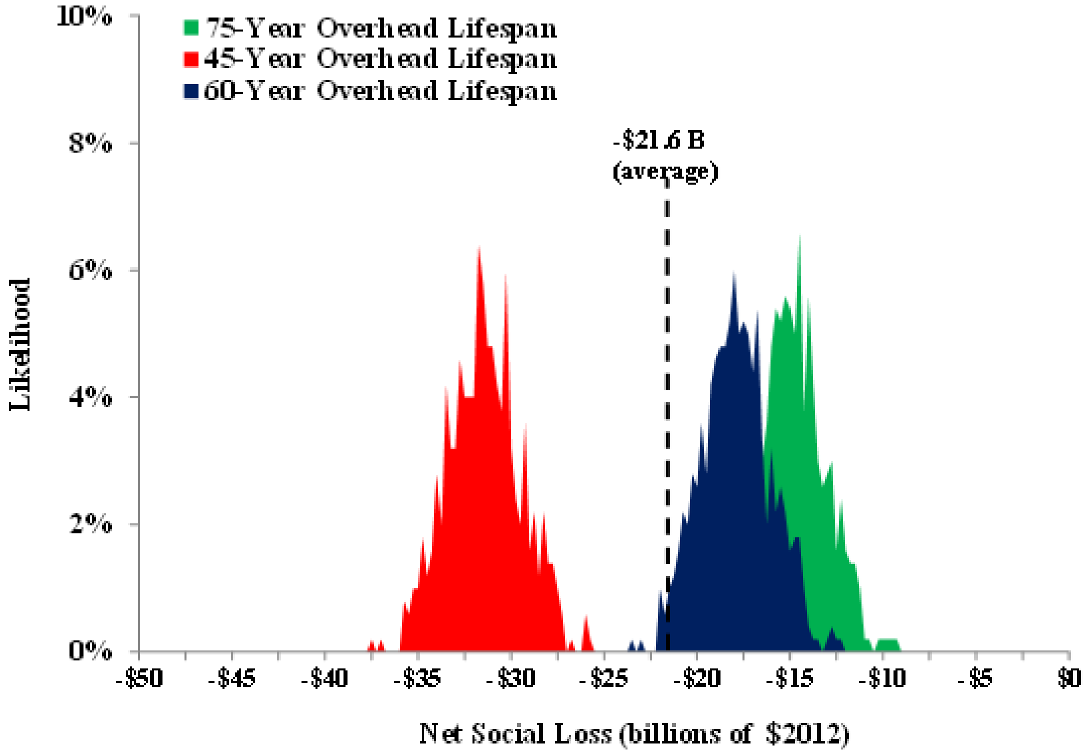
Valuation results

Impact Category	Undergrounding	Status Quo	Net Cost ($billions)
Environmental restoration	$2.8	$1.0	$1.8
Health & safety	$0.56	$0.31	$0.2
Lifecycle costs	$52.3	$26.1	$26.3
Total net costs (Undergrounding)			$28.3
Impact Category	**Undergrounding**	**Status Quo**	**Net Benefit ($billions)**
Interruption cost	$182.7	$188.4	$5.8
Avoided aesthetic costs	$12.1	$10.6	$1.5
Total net benefits (Undergrounding)			$7.3
Net Social Benefit (Undergrounding)			
Net social benefit (billions of $2012)			-$21.0
Benefit-cost ratio			0.3



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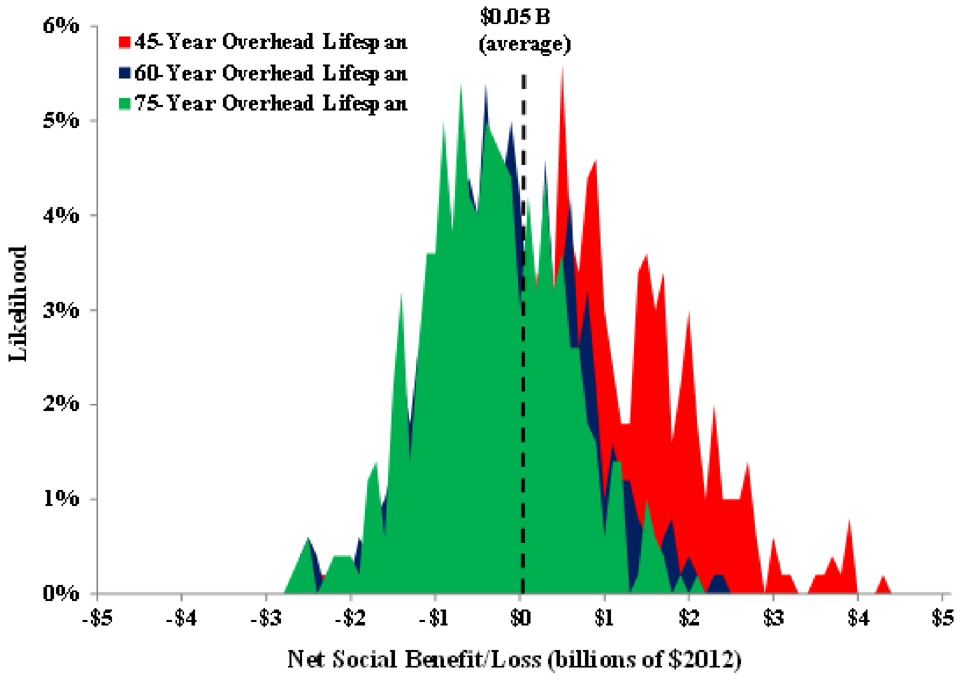
Possibility of net benefits

Texas policymakers should consider requiring that all T&D lines be undergrounded in places where:

- **there are a large number of customers per line mile** (e.g., greater than 40 customers per T&D line mile)
- **there is an expected vulnerability to frequent and intense storms**
- **there is the potential for economies of scale for installing underground T&D lines** (e.g., installation costs decrease each year)
- **overhead line rights-of-way are larger than underground line rights-of-way (i.e., less environmental footprint)**



"Electric utility providers should evaluate strategic, targeted undergrounding of distribution lines in limited, appropriate circumstances based on the exposure to the threat of severe winter events."
Source: ORC (2021)

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Example #2: Valuing a customer resilience strategy

- **Residential rooftop and storage systems (PVESS) can mitigate long duration interruptions** by providing backup power during power outages. This can reduce the economic and social impacts of power outages—a key resilience benefit.

- The benefit-cost ratio (BCRs) of PVESS varies by region, depending on the cost of PVESS, the value of lost load (VOLL), and the likelihood of long duration interruptions.

Key Research Questions

- What is the regional distribution of the ability of residential PVESS to mitigate resilience events (long duration interruptions lasting longer than 1 day)?
- Assuming regionally-differentiated PVESS costs and VOLL, what is the benefit-cost of storage investments on existing PV systems?
- How does this benefit-cost change considering Inflation Reduction Act (IRA) support?

Source: Baik et al. (2023)

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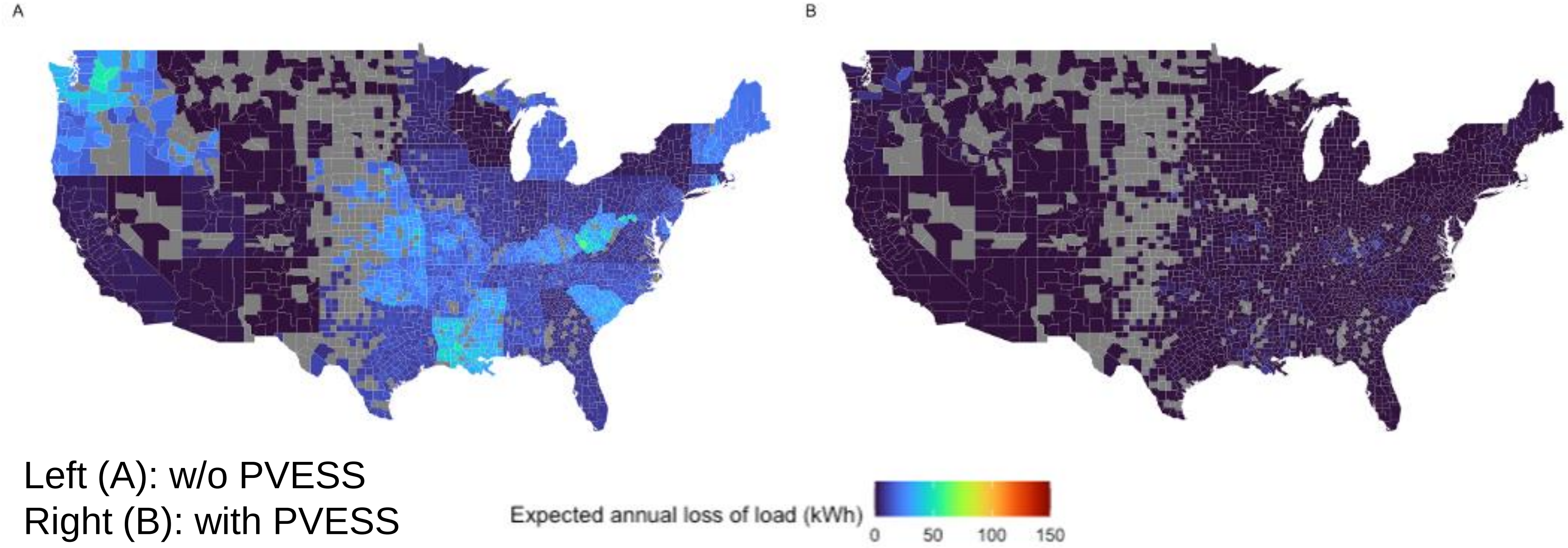
PVESS mitigates customer interruptions

- States with a high frequency of resilience events (e.g., Louisiana, West Virginia) showed significant load loss without PVESS, while regions less impacted had lower loss
- **PVESS introduction mitigates or eliminates load loss across regions** (96% interruptions mitigated)



Left (A): w/o PVESS
Right (B): with PVESS

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Calculating the benefit-cost ratio

- **Benefits of storage investments in regions were assessed using load served, event frequency, duration, and state-level VOLL estimates**

- Benefit-cost ratio was computed by comparing benefits with annualized region-specific storage costs

$$BCR_{FIPS} = \frac{\sum_1^m \sum_1^d (VOLL_{FIPS} \times \text{Expected number of resilience events}_{m,d} \times \text{Load served by } PVESS_{m,d})}{\text{Annualized cost of the PVESS system}_{FIPS}}$$

$$\begin{aligned} \text{where } d &= \text{resilience event duration interval (ranging from 1 day to 10 days)},\\ m &= \text{month},\\ VOLL_{FIPS} &= \text{VOLL estimate assigned to each FIPS region belonging to each state} \end{aligned}$$

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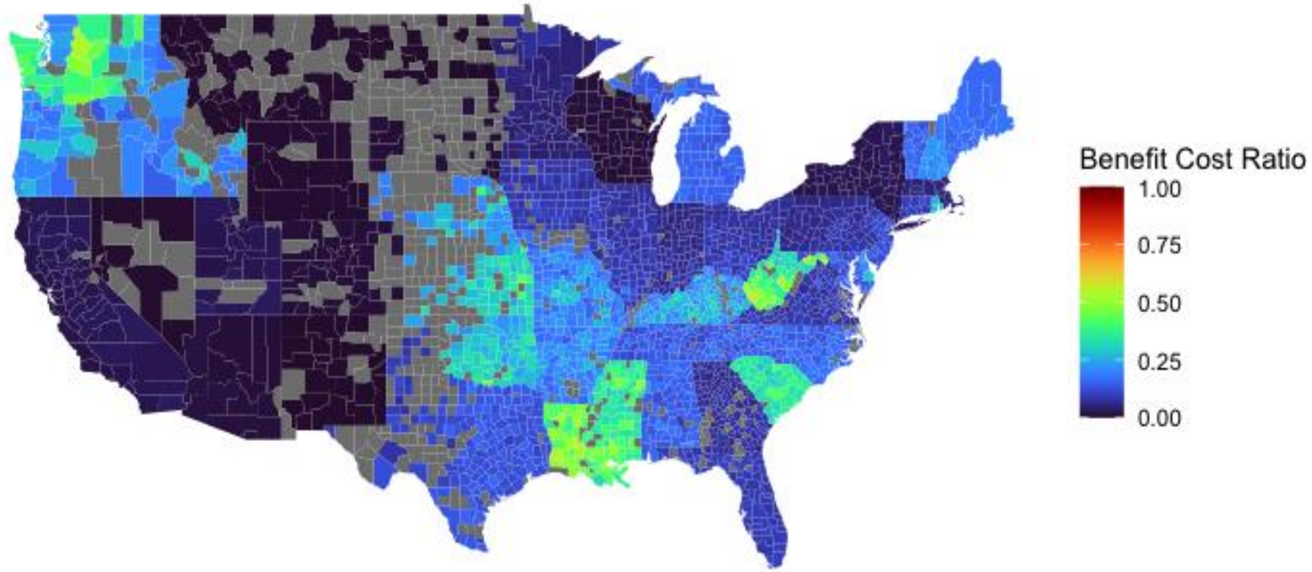
Distribution of benefit-cost ratios

- Resilience benefits from PVESS averaged 20% of total costs, ranging from 0% to 83% depending on load served, event frequency, duration, and state-level VOLL estimates
- However, **resilience was the only benefit considered in this research effort**
- **Other benefit streams are often included as part of the decision to install PVESS**



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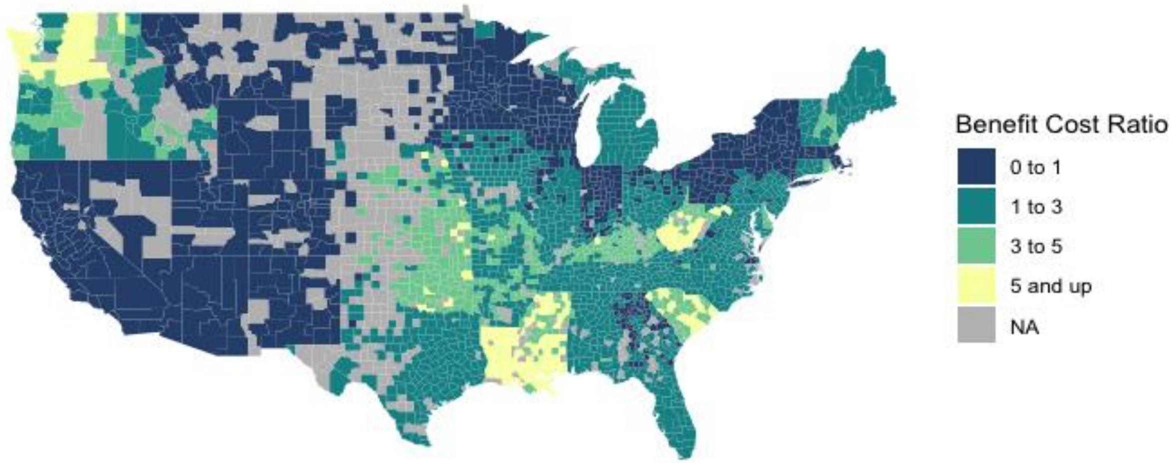
Importance of scenario/sensitivity analyses

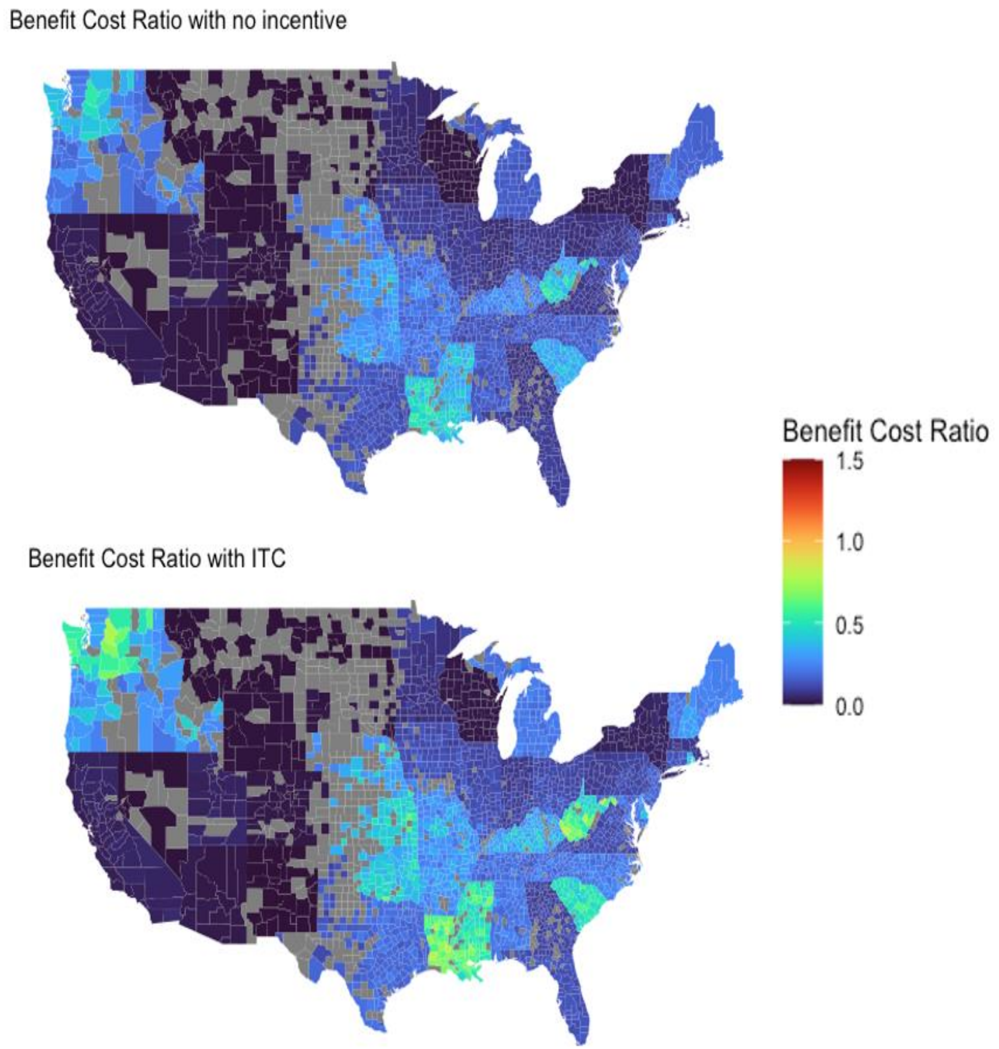
- Scenario and sensitivity-based analyses communicate the range of possible outcomes given uncertainties
- Four scenarios were analyzed individually and collectively: two **storage cost** scenarios, a **high VOLL scenario**, and a **higher event frequency** scenario
- Individual scenarios achieve BCR > 1.0 in some states
- We also evaluated the **combined impact** of storage cost reduction, a high VOLL, and increased frequency of resilience events



- **Customers experiencing above-average long-duration event frequencies and higher VOLL are likely to observe resilience benefits greater than the cost of installing PVESS**

Impact of federal incentives

- **Incentives from the investment tax credit (ITC) were considered**
- Applying a 30% ITC reduction to storage acquisition costs improved BCRs by 50% compared to no incentives
- Notably, some regions (e.g., West Virginia, Louisiana) show higher BCRs, yet BCRs are still below 1
- If only considering the resilience benefit, the **ITC only incentivizes PVESS adoption for customers with high VOLL and higher frequency of long duration events**



Interactive poll #3

What challenges do you foresee when reviewing a utility's valuation and justification of a resilience investment?

Kahoot!

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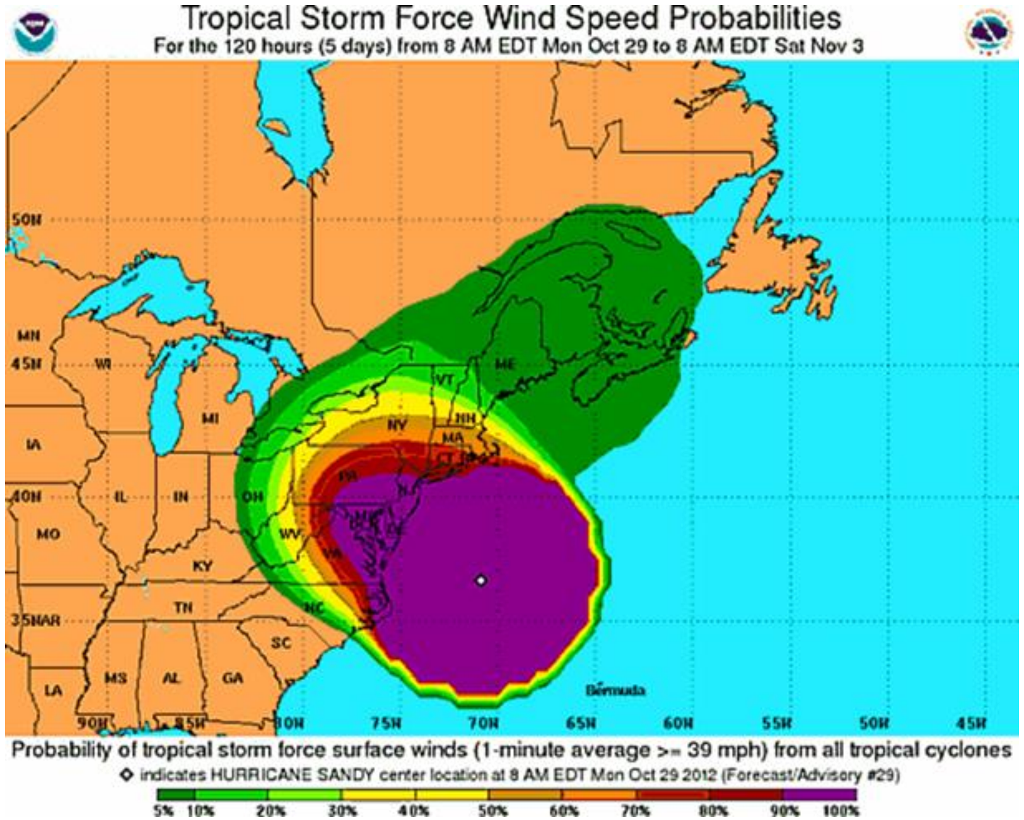
Example #3: Prioritizing a resilience strategy

- The U.S. Department of Energy Grid Deployment Office is sponsoring the development of “Resilience Spotlights” that feature examples of how organizations value and prioritize a specific project among a portfolio of proposed projects.

- The first spotlight focuses on activities in New York City in the immediate aftermath of Super Storm Sandy.

- Resilience spotlights will be accessible at the [DOE-GDO website.](#)



Super Storm Sandy

- 20% of the city’s land area was flooded, **exceeding FEMA’s “100-year” floodplain** boundaries
- Loss of power to **> 2 million** Con Ed customers
- Full restoration took **~14 days**
- **Major equipment failure:** Con Ed’s East 13th Street Substation flooded and failed due to record levels of storm surge.

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Regulatory processes

- January 2013 (three months after storm): Con Ed proposed a **portfolio** of storm hardening projects in a general rate case filing.

- Many stakeholders in rate case had **opposing views**:
  - Hardening plan was too ambitious and expensive
  - Utility should develop a bigger “comprehensive and longer-term approach”

- **Key point of dispute:** What criterion should Con Ed use to evaluate hardening against flooding risks?

- Summer 2013: NYPSC ordered formation of a **Storm Hardening and Resiliency Collaborative** to work in parallel to rate case proceedings and consider:
  - Design standard
  - Approach to risk assessment and cost-benefit analysis

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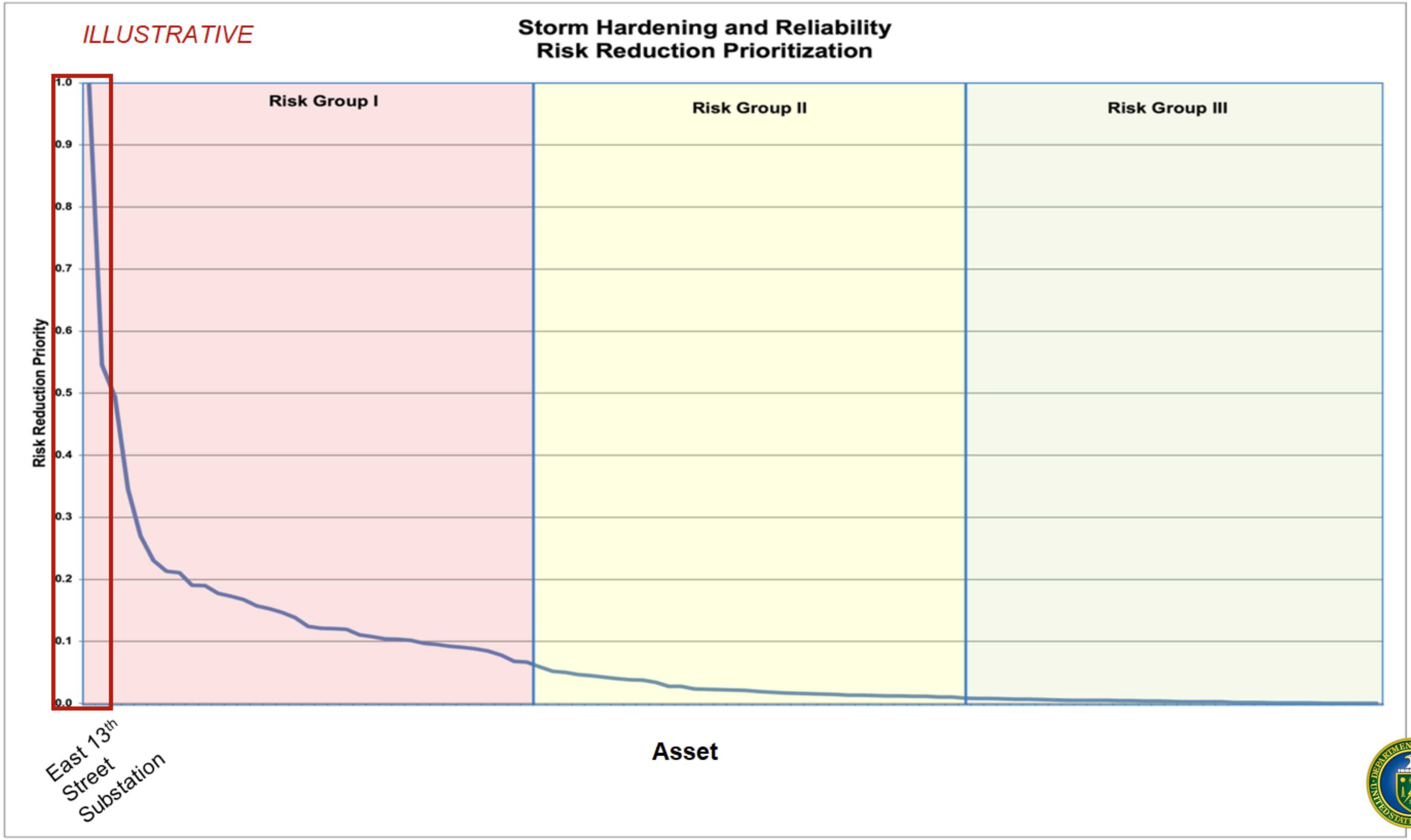
Project prioritization and valuation (1)

- The Collaborative developed a procedure for ranking the storm hardening projects that considered the following:

Probability: estimate likelihoods of significant storms and damage to infrastructure
Consequence: characterize physical and economic impacts of damage
Priority: run potential projects through models to rank them

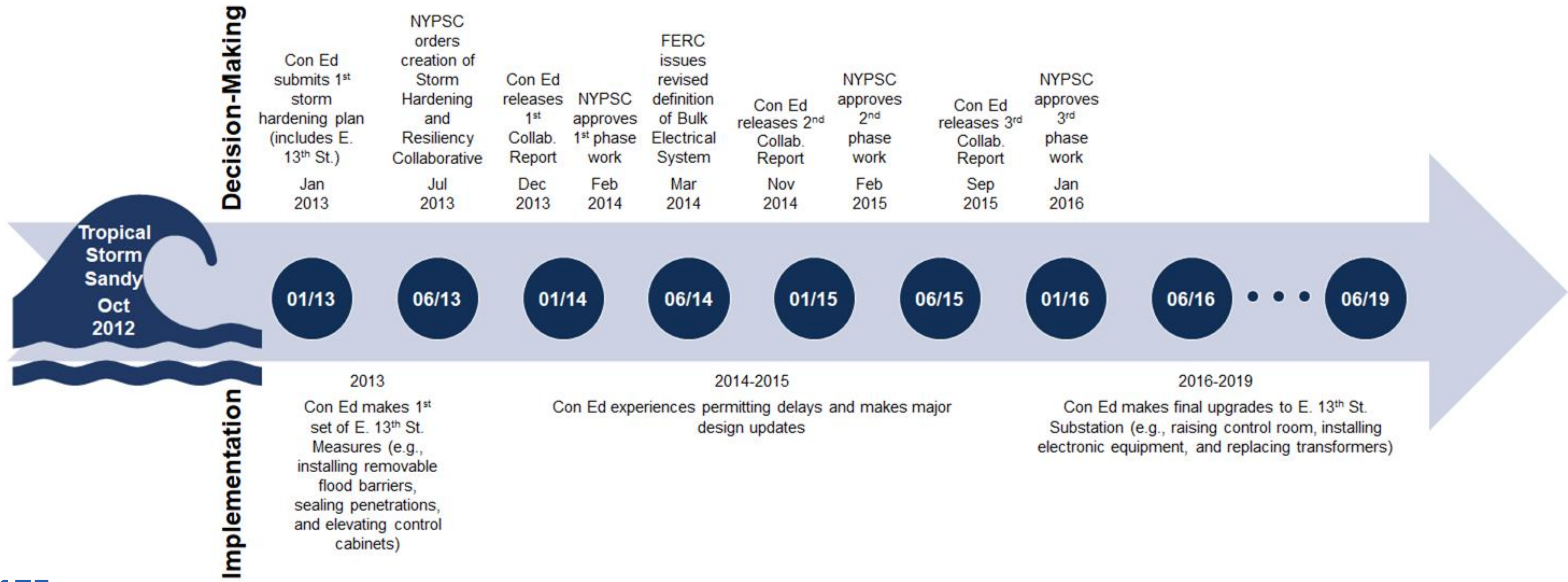
Models	Key Inputs
Risk Assessment and Prioritization Model	• Location-based flood probabilities provided by proprietary New York City inundation models • Wind damage probabilities derived from historical wind gust frequency distributions • Costs of storm hardening measures • Estimated power interruption durations with and without hardening measures
Cost-Benefit Model	• Costs of storm hardening measures (from the Risk Assessment and Prioritization Model) • Estimated power interruption durations with and without hardening measures (from the Risk - Assessment and Prioritization Model) • Extrapolated avoided cost (i.e., value of lost load) estimates based on Lawrence Berkeley National Laboratory’s ICE Calculator

Project prioritization and valuation (2)



Source: [ConEd (2013)]

Response timeline

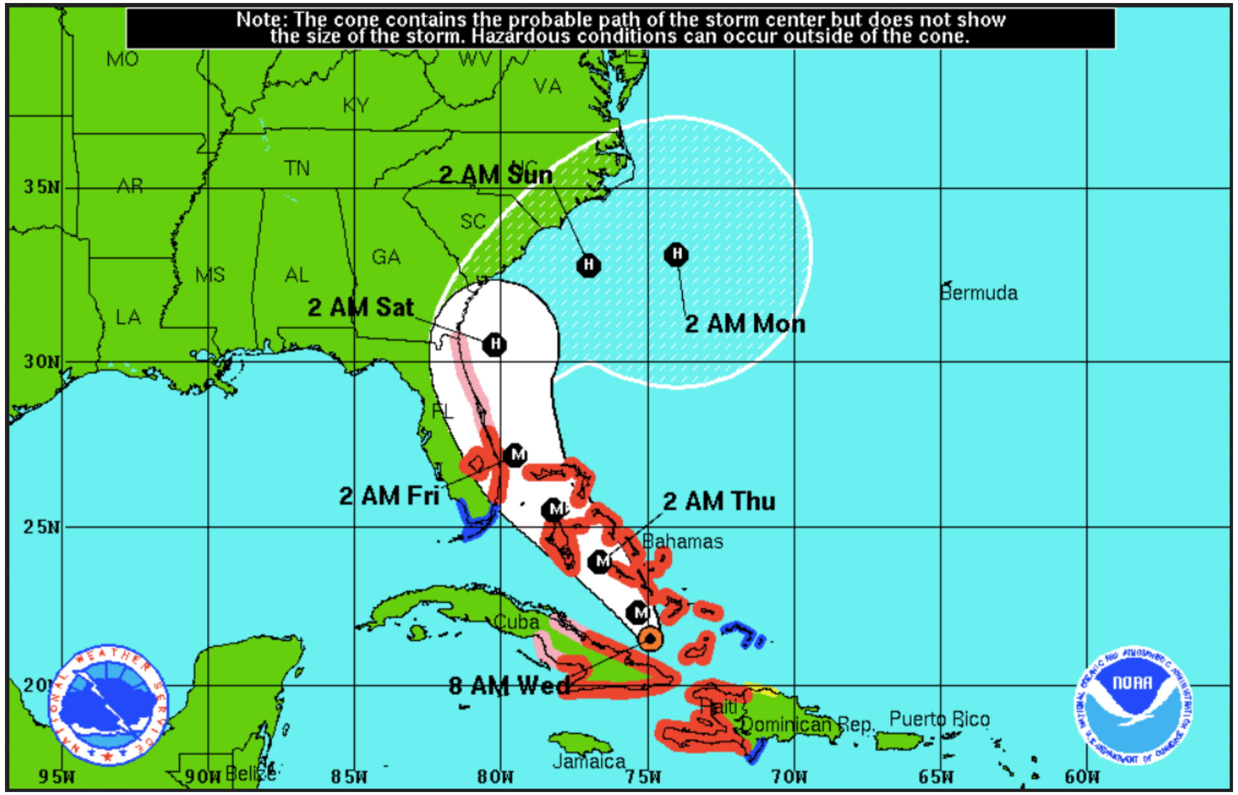


Example #4: Prioritizing a resilience strategy

- Regulations introduced in 2006-2007 **required that Duke and other Florida utilities begin systematically collecting data on the relative performance of underground and overhead lines** during extreme weather

- An especially severe hurricane season in 2016-2017 **demonstrated that underground lines were systematically less vulnerable** to disruption than overhead lines

- As a result, Duke Energy Florida (Duke) began a "Targeted Underground Program."



Regulatory and utility processes

- In 2019, Florida required that the state's electric energy utilities submit triennial "Storm Protection Plans" with **new requirements including cost and benefit estimation**, 10-year planning horizons, and more complete descriptions of proposed measures and implementation strategies.

- Duke began working closely with Guidehouse, Inc. to develop and implement a decision-support framework and software tool in their storm preparation planning.

Duke’s three-part analytic framework

Risk modeling

Probabilistic weather modeling of storm scenarios using Monte Carlo methods, combined with spatial modeling of Duke distribution infrastructure, to estimate conditional probabilities of asset failures and the reductions in these probabilities as a function of storm hardening measures

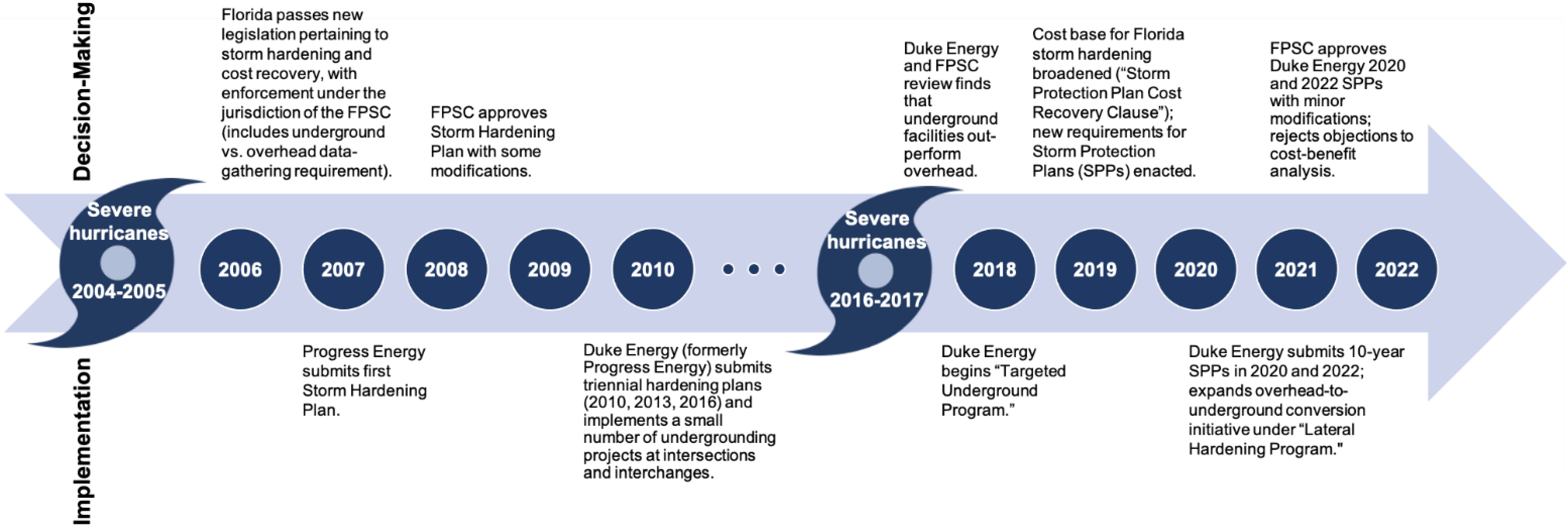
Benefit-cost modeling

Estimating Duke’s capital and operations and maintenance costs of storm hardening measures and prospective utility benefits in the form of reduced future costs from avoiding damage to infrastructure and storm restoration activities; quantifying customer benefits in terms of projected reduced outage times by customer class, and applying avoided customer costs from Berkeley Lab’s ICE Calculator, using the Calculator’s 16-hour avoided cost estimates as a simplifying assumption for outage times greater than 16 hours

Decision analysis and prioritization

Calculating benefit-cost ratios and using them to rank projects and create a preferred portfolio, then applying funding and timing constraints, taking account of practical implementation constraints based on the judgment of Duke staff including subject matter experts

Response timeline



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Lessons learned

- Many, but not all, utility reliability and resilience investments are developed, proposed, and adjudicated in the **context of a general rate case**. This process is not always well-suited to addressing **novel, complex technical problems**.

- The need to address **low-probability/high-consequence events** requires flexibility in regulatory processes.

- **Collaborative work groups** can enable utilities to improve resilience planning methods and practice.

- **Requiring utilities to measure past performance** of underground lines has helped build confidence and justify future investments in this strategy.

- **Cost-benefit analyses** used in NY and FL could inform similar valuation and prioritization activities in other parts of the country.

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Interactive poll #4

What is the most important criteria for prioritizing one resilience strategy over another?

Kahoot!

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Questions to ask

- Is the utility putting an economic value on reliability or resilience? If so, what tools or techniques are they using?
- Does the utility track the performance of past investments? Can you describe how this performance is tracked?
- What technology would the utility install if it could only install one type of technology to make the grid more resilient?
- What is the biggest challenge that the utility has faced when attempting to identify, prioritize, and justify a resilience project?

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https://www.energy.gov/gdo/grid-deployment-office

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Glossary of selected performance-based metrics

Metric	Description	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
CAIFI	Customer Average Interruption Frequency Index	Average number of interruptions per customer interrupted 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
MED	Major Event Day	Any day with a daily reliability metric that exceeds a statistically-defined threshold based on the previous five years of daily data (e.g., IEEE 1366 standard)

Source: CPUC (2021)

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BERKELEY LAB

Mitigation, Rapid Restoration Strategies, and Best Practices – with Case Studies

Presented by Josh Schellenberg, Berkeley Lab Affiliate
Slides by Nichole Hanus, Berkeley Lab

Resilience Training for States
Nashville, Tennessee

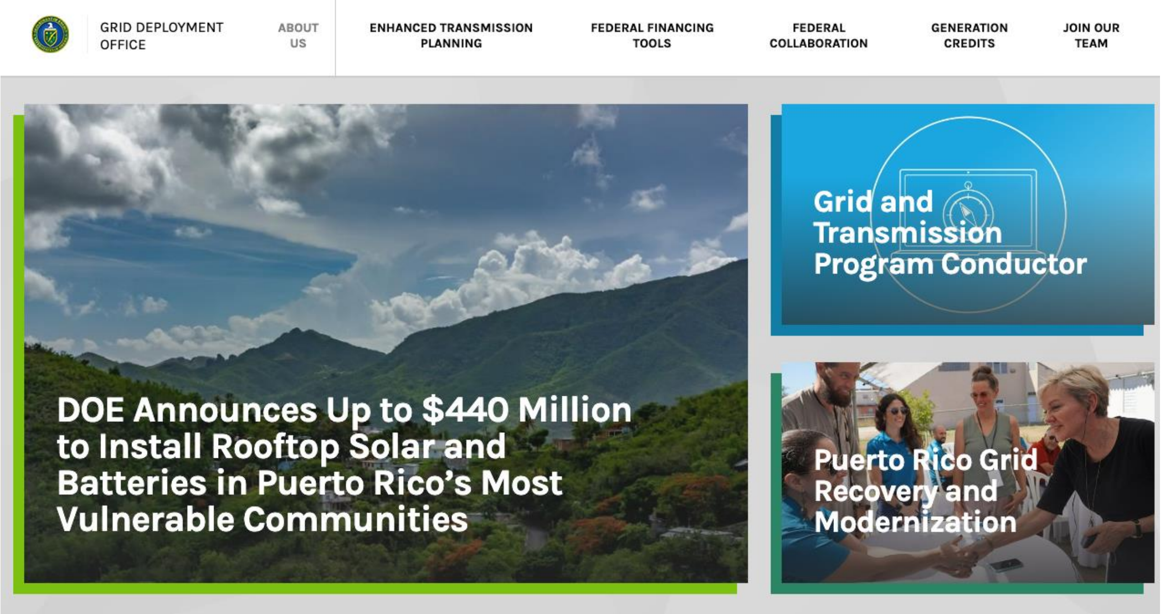
March 21, 2024

Today’s agenda

- Resources from the U.S. Department of Energy’s Grid Deployment Office
- Overview of identified grid resilience strategies
- Three case studies of mitigation strategies implemented in various U.S. jurisdictions

Resources from GDO

- ***The Grid Deployment Office (GDO)*** provides guidance to State Energy Offices, regulators, utilities, and other electricity investment decision-makers on ***grid resilience best practices***
- ***FORTHCOMING*** – Early 2024 Resources:
  - **3 Resilience Prioritization Case Studies**
    - NY Con Ed – East 13th St. Substation Hardening
    - FL Duke Energy – Undergrounding Lines
    - CA SDG&E – Borrego Springs Microgrid
  - **10 Resilience Strategy Fact Sheets**
    - Undergrounding
    - Pole Investments
    - Wires Investments
    - Vegetation Management
    - Monitoring and Controls
    - Adaptive Protection Technologies
    - Distributed Energy Resources (DERs)
    - Weatherization Technologies
    - Fire-resistant/prevention Technologies
    - Advanced Modeling Technologies
- GDO is developing the case studies and fact sheets to provide ***timely guidance*** on how to take advantage of funding available through the ***Infrastructure Investment and Jobs Act (IIJA)***



[1] Source: https://www.energy.gov/gdo/grid-deployment-office

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Overview of Resilience Strategies

General Pros/Cons/Costs of Resilience Strategies

Strategy	Description	Pros	Cons	Costs
Vegetation Management	Ground-to-sky clearing on a regular cycle, hazard-tree programs, targeted maintenance	Prevents initial outages and reduces restoration times against: • High winds • Severe rain • Ice	• Subject to utility rights-of-way to affected areas • May have aesthetic impacts, causing community resistance	Vegetation management is less costly than other measures (such as undergrounding) and can be quite cost-effective overall
Hardening	Undergrounding, substation and generation hardening, utility pole investments, and wires investments	This broad list of strategies improves performance against: • Extreme weather conditions • Flooding • Wildfire • Vehicle and animal interference	Disadvantages vary across these strategies, but generally include higher capital and maintenance costs than traditional infrastructure	Costs vary across strategies by a wide margin
Customer-focused Strategies	Distributed energy resources (e.g., storage, demand flexibility, microgrids) and making buildings more resilient	DERs can be flexibly harnessed to support the grid by: • Reducing peak demand and alleviating stress on the transmission and distribution systems • Providing voltage and frequency support • Cutting costs for both grid operators and energy • Increasing consumer resilience	• Larger-scale DERs are considerably more expensive than individual backup generators, which are already mature and widely adopted in the market • DERs that rely on variable energy sources are susceptible to weather conditions	Costs of DERs can be high and vary based on system size, location, configurations, and complexity
Redundancy and Back-up	Includes transmission-, distribution-, and customer-level strategies	Prevents initial outages and reduces restoration time across threats to utility-scale generation and distribution	Can be a time-intensive strategy requiring planning and coordination across multiple parties	Costs will depend on the existing redundancy and back-up in place at the generator or by individual customers
Grid Modernization Technologies	Advanced Distribution Management System (ADMS); Fault Location, Isolation, and Service Restoration (FLISR); Distributed Energy Resource Management System (DERMS)	Prevent outages and reduces system average restoration times against these hazards by automatically reconfiguring grid operations	Primary disadvantage is wide-scale investment for grid sensors, systems integration, and communication infrastructure, including advanced metering infrastructure	Wide range of costs, primarily due to differences in the scope of what is included in each utility plan or program

Vegetation Management

- **Tree pruning:** Cutting back tree growth to maintain clearances from utility transmission and distribution overhead lines
- **Tree removal:** Taking out damaged, unhealthy, or dead trees in proximity to utility lines
- **Vegetation control:** Removal of flammable brush and suppression of hazardous brush growth
- **Integrated vegetation management:** "promoting desirable, stable, low-growing plant communities that will resist invasion by tall-growing tree species through the use of appropriate, environmentally-sound, and cost-effective control methods" [2]

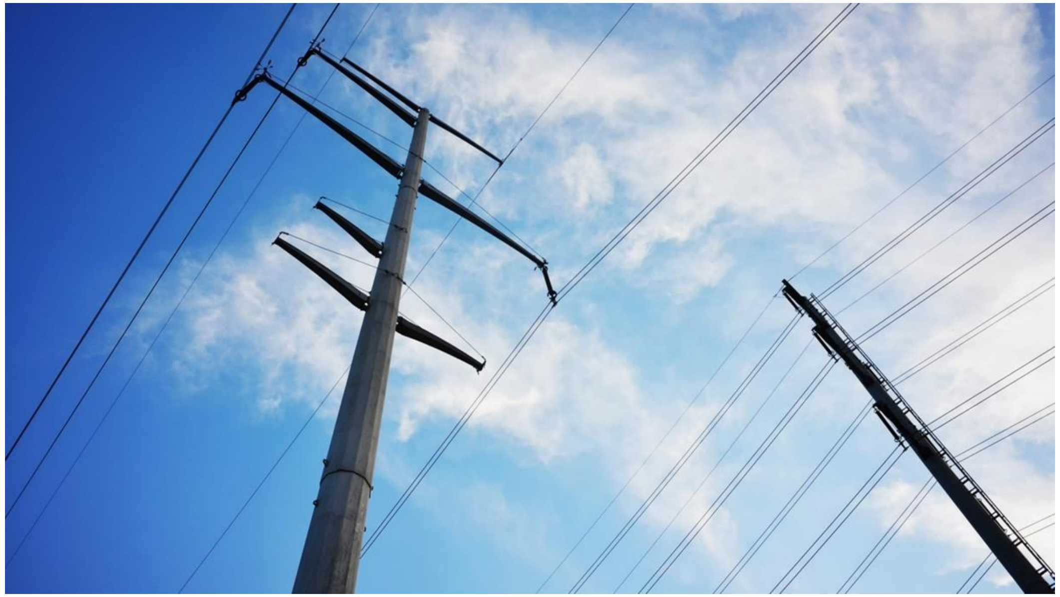
Cost Range: $3,000 – 12,000 / mile [3-7]

[8] Source: EPRI

Hardening

1. Undergrounding

2. Pole Investments



3. Wire Investments

[8] Source: EPRI

1. Undergrounding

Advantages:

- The key advantage of underground transmission and distribution lines is reduced vulnerability to disruption from extreme weather and wildfires
- Larsen (2016) found that a 10% increase in a system's underground line miles was correlated with a 14% reduction in annual interruption durations across the U.S. [9]

Disadvantages:

- Underground repairs generally take longer because of access difficulties
- Underground lines also have generally shorter lifetimes than overhead
- Depending on location, underground transmission and distribution lines may be at risk from flooding, including due to sea level rise

Cost Range:

- Transmission: $6M – 100M / Mile [10]
- Distribution: $0.2M – 6M / Mile [10-12]

[8] Source: EPRI

2. Utility Pole Investments

- Two general types of pole-related measures for improving transmission and distribution reliability and resiliency:
  - inspection and maintenance of installed wood poles
  - conversion of wood poles to non-wood material
- Inspection and maintenance:
  - decayed but can be serviced and remain in use
  - decayed to the point of requiring replacement

Disadvantages:

- Wood poles are easier to climb than non-wood poles and are less conductive than steel and ductile iron poles, which are safer for line-workers.
- Additionally, concrete and ductile iron poles are heavier than wood poles, making them difficult to transport.

Cost Range:

- Transmission: ~$37,000 / Mile (inspection and repair) [13, 14]
- Distribution: $500 – 10,000 / Pole (inspection and repair) [15, 16]

[17] Source: Wikipedia

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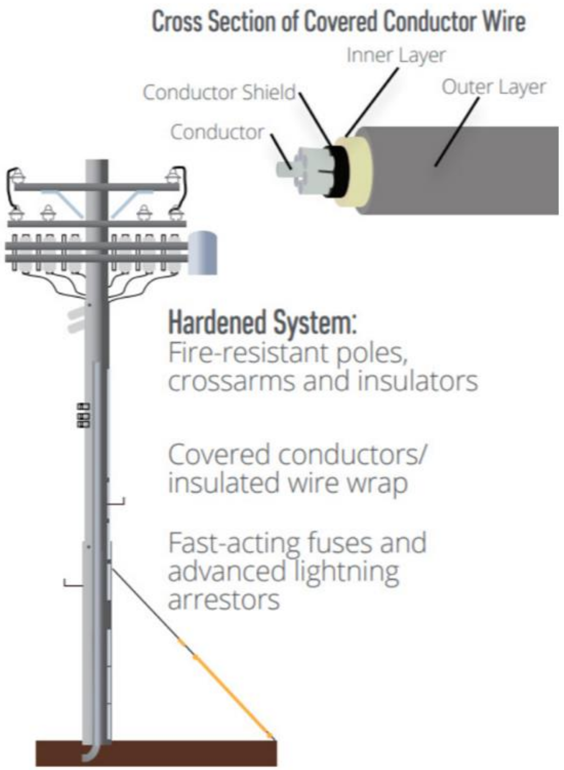
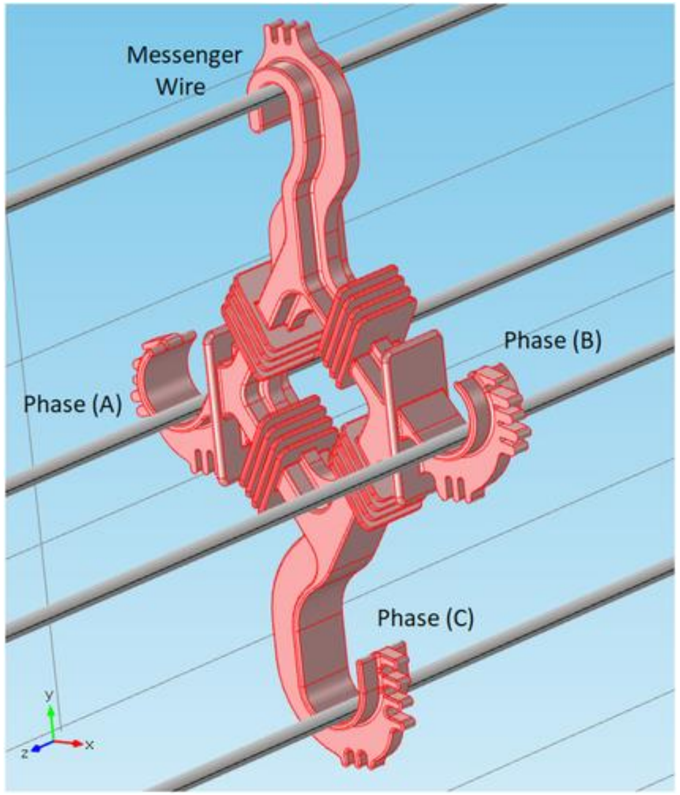
3. Utility Wire Investments

- Relocation/replacement or reconductoring of power lines with low-sag, advanced conductors, covered conductors, spacer cables, guy wires
  - **Covered Conductors:** Equipped with an external polymer sheath to prevent accidental contact with other conductors and grounded objects
  - **Spacer Cables**: Type of overhead power line construction that employs non-shielded, non-tensioned, insulated conductors arranged in a compact triangular configuration
- **Line Management and Inspections**: Infrared assessments, corona scanning, and high-definition imagery acquisition can detect defects and abnormalities that may not be visible during mandatory inspections
- **Disadvantages**: Wire insulation is costly (much more than vegetation management) and is less effective than undergrounding

Cost Range: $200k - 1,430k / Mile [18-20]



[21] Source: Edison Electric Institute



[22] Source: Stefenon, et al. (2022)

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Customer-focused Strategies

[8] Source: EPRI

- DERs encompass a diverse array of small-scale, modular, and decentralized energy technologies that can be employed individually or in combination to deliver power and energy services in close proximity to end-users.
- Customer-focused strategies include:
  - Microgrids / community resilience hubs
  - Solar PV
  - Solar + storage
  - Electric vehicles (EVs) w/ bidirectional charging
  - Smart thermostats
  - Energy efficiency

Cost Ranges:

- Microgrids / resilience hubs: $1M-6M / MW [23, 24]
- Solar: $3-5 / W [25]
- Solar + Storage: $4-7 / W [25]
- EVs w/ bidirectional charging: $30-70k / vehicle (not including chargers) [26]
- Smart thermostats: $80-300 / thermostat [27]
- Energy efficiency: Varies by approach [28]

Energy Efficient and Grid-Interactive Buildings

	During ***Normal*** Grid/Fuel Supply Operations	During Grid/Fuel Supply ***Outage***
Energy Efficiency	• Reduced disruptions from demand spikes • Lower costs for total energy required • Greater comfort, higher indoor air quality	• Increases passive survivability – the ability of buildings to maintain habitable conditions in the event of a heating/cooling system loss [29]
Energy Efficiency with Onsite Generation + Storage	• Cost savings from reduced demand charges and sale of excess power • Support renewable energy target/goals • Reduced disruptions due to demand spikes • Provision of other grid services	• Continuity of energy services

[30] Table adapted from DOE's Better Buildings Resilience Website

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Redundancy and Backup

Strategies for transmission include: [31]

- If in an open, flood-prone location, move to higher ground and/or a more secure building (e.g., control room)
- Assure adequate fuel availability/storage
- Increase quantity and security of local fuel storage/supply
- Shock-mount for vibration protection
- Pre-stage replacement equipment

Strategies for distribution and customers include: [31]

- Portable or pad-mounted generator w/ adequate fuel
- Resilient PV + storage
- Grouping end-users (e.g., islanding) and ensuring local fossil generation has adequate fuel source (or resilient PV + storage)

[32] Source: Foremost

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Grid Modernization Technologies

- **Advanced Distribution Management System (ADMS):** Enterprise software platform that enables utility engineers, field crews, and operations personnel to better monitor, control and optimize distribution grids

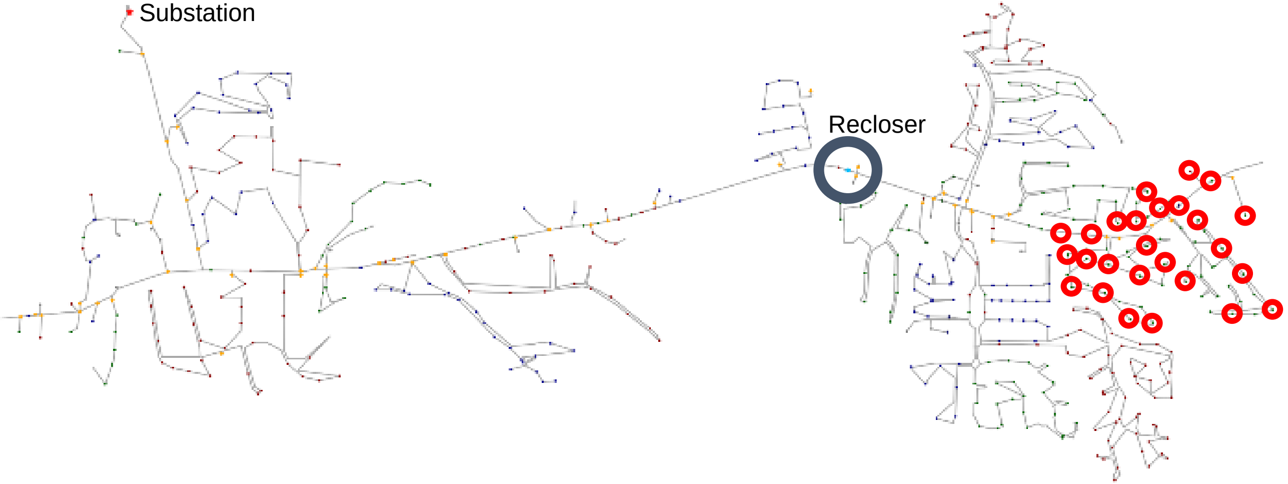
- **Fault Location, Isolation, and Service Restoration (FLISR):** Grid sensors and software that integrate with ADMS to quickly locate and isolate faults on the grid and automatically restore power to as many customers as possible

- **Distributed Energy Resource Management System (DERMS):** Enterprise software that monitors and controls DERs and optimizes of dispatch based on grid needs

Cost Ranges:

- ADMS and/or DERMS: $10.7 - 20.9 / customer [33, 34]
- Comprehensive plans: ~$200 / customer [35, 36]

[8] Source: EPRI



Resilience Strategy Case Studies

Florida Power & Light: Grid Hardening

Florida Power & Light's Modified Storm Protection Plan [37]

- Following extreme weather events in Florida (e.g., Hurricane Matthew (2016) and Irma (2017)), the state began requiring utilities to file Storm Protection Plans (SPPs) detailing the utility's 10-year transmission and distribution needs

- Must file a report at least every 3 years

- The scope of the plans should include all transmission and distribution facilities: poles, fixtures, towers, overhead conductors, substations, land and land rights, underground materials, etc.

Docket No. 20220051
FPL's 2023-2032 Storm Protection Plan
Modified Exhibit MJ-1, Page 1 of 51

FPL.

Florida Power & Light Company

Modified

Storm Protection Plan

2023-2032

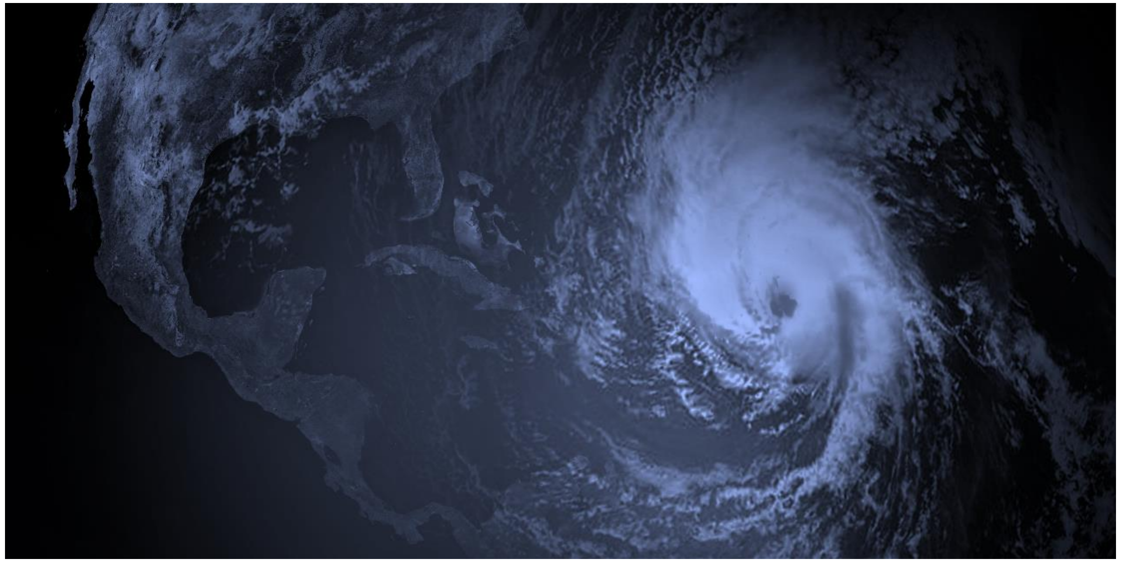
(Rule 25-6.030, F.A.C.)

Docket No. 20220051-EI

November 14, 2022

FPL's Hardening Strategies

- The 2023 SPP is largely a continuation of programs approved in the 2020 SPP:
  - Distribution Inspection Program
  - Transmission Inspection Program
  - Distribution Feeder Hardening Program
  - Distribution Lateral Hardening Program
  - Transmission Hardening Program
  - Distribution Vegetation Management Program
  - Transmission Vegetation Management Program
  - Substation Storm Surge/Flood Mitigation Program



[8] Source: EPRI

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Distribution and Transmission Inspection Programs

- **Distribution Inspection Program:**
  - Commission requires IOUs to implement an eight-year pole inspection cycle for all distribution poles
  - FPL utilizes a contractor to inspect 1/8 of poles annually:
    - Must meet National Electrical Safety Code's (NESC) standards
    - Visual inspections for above-ground
    - Wood poles: 18" underground inspection – "Shell Boring"
    - Chromium Copper Arsenate (CCA) (wood preservative) poles are only excavated if > 28 yrs old
- **Transmission Inspection Program:**
  - Commission requires IOUs to implement a six-year inspection cycle for all transmissions structures
  - All of FPL's transmission structures (e.g., substations) are visually inspected annually
  - Climbing/bucket truck inspections are performed on wooden structures every six years; steel structures every 10 years

Improvements ***before inspection programs*** (Hurricane Wilma – 2005) and ***after inspection programs*** (Hurricane Irma - 2017) for distribution and transmission systems, respectively:

	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

[37] Source: FPL

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

[37] Source: FPL

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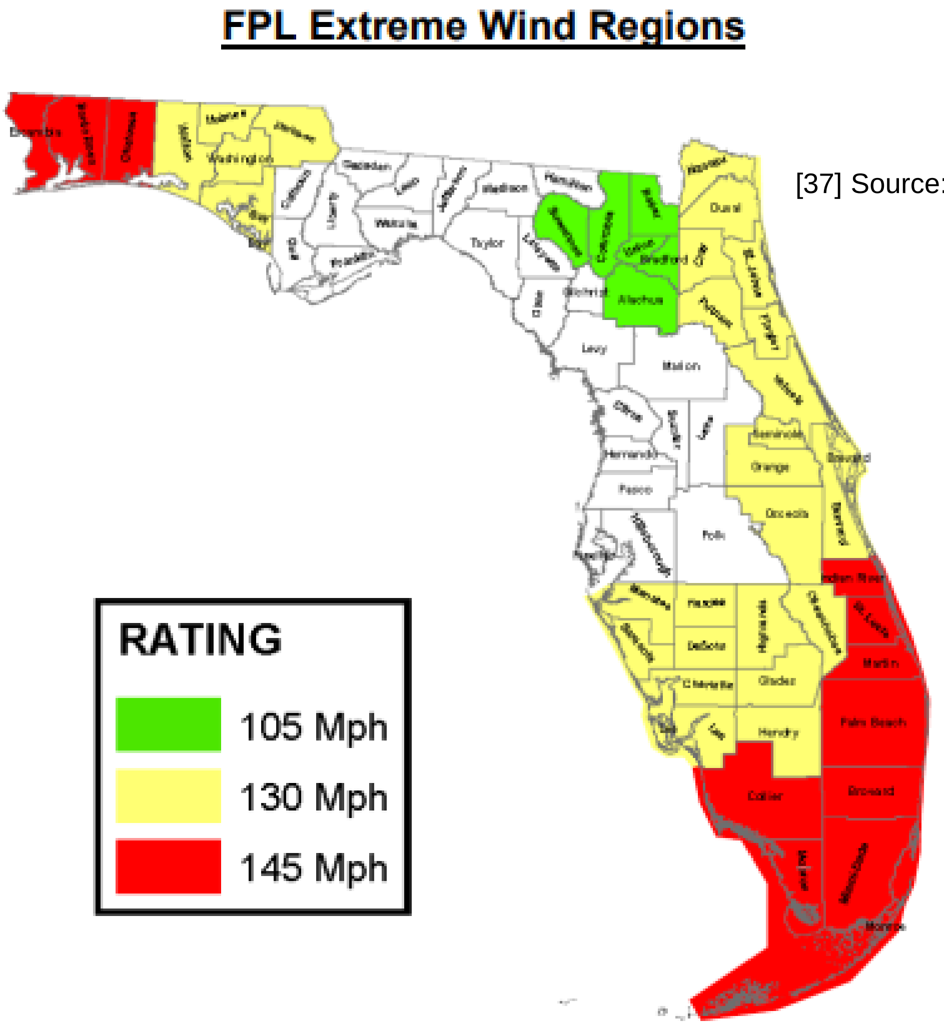
Distribution Feeder and Lateral Hardening Programs

- **Distribution Feeder Hardening Program:**
  - After Hurricane Wilma, FPL realized that “wind only” threats were the driver for downed distribution poles
  - They apply NESC’s “extreme wind loading” (EWL) criteria to ***harden existing*** distribution feeders and critical poles and for the ***design of new*** poles
  - FPL’s design toolkit: storm guying, equipment relocation, intermediate pole, upgrading pole class, and undergrounding facilities

- **Distribution Lateral Hardening Program:**
  - This is a continuation of the 2020 SPP undergrounding pilot; the 2023 SPP targets overhead laterals impacted by recent storms and prioritizes them for undergrounding
  - Lessons learned from undergrounding pilots:
    - Place underground lines in public or rights-of-way to reduce easement approvals
    - Utilize directional boring
    - Utilize Ground Penetrating Radar
    - Initiate community meetings for education and to address concerns



[37] Source: FPL

Transmission Hardening Programs

- A transmission-related outage can affect tens of thousands of customers compared to a distribution-related outage, which can affect several thousands of customers
- Transmission outages can also lead to cascading failures
- During the 2004 and 2005 storms, FPL's transmission infrastructure experienced significantly less damage than distribution facilities
- The focus of transmission hardening in FPL is to convert all wood transmission structures (~70%) with steel or concrete structures

Improvements from ***before transmission hardening program*** (Hurricane Wilma – 2005) and ***after transmission hardening program*** (Hurricane Irma - 2017) for distribution and transmission systems, respectively:

	Hurricane Wilma	**Hurricane Irma**
% Line Section Outages	37%	17%
Transmission Structure Failures	100	5 (all non-hardened)
Transmission Substations De-energized	241	92
Days to Restore Substation Outages	5	1

[37] Source: FPL

Consumer Energy's
Grid Modernization Investments

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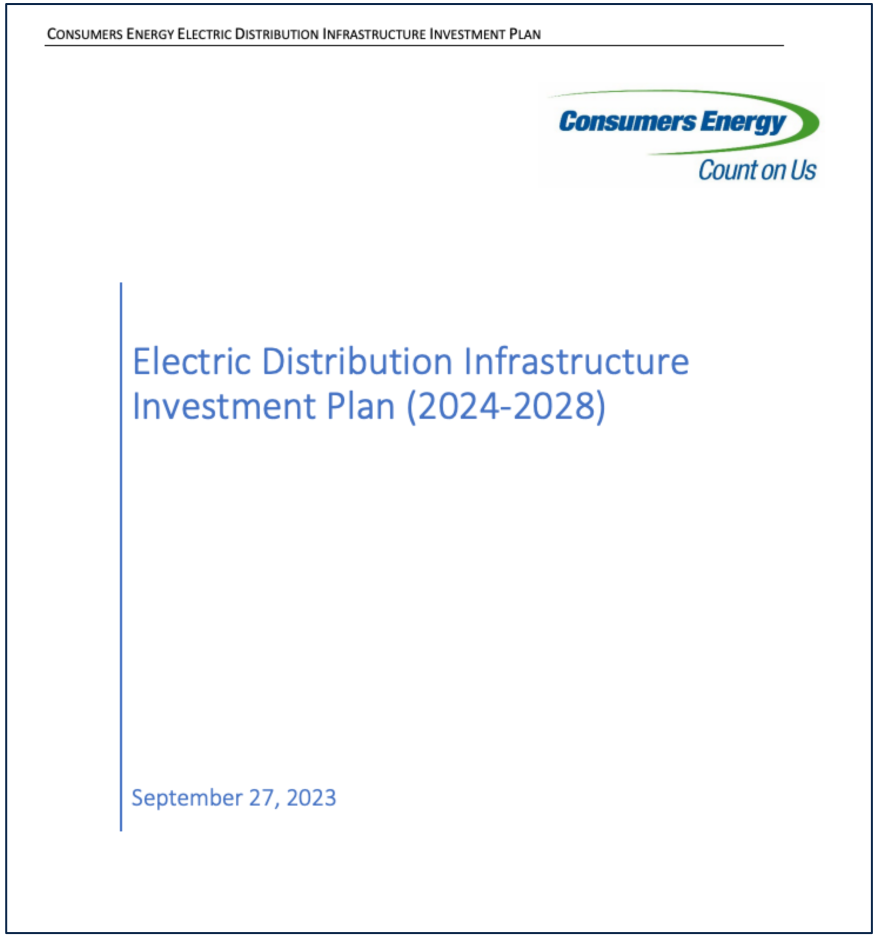
Consumer Energy's Electric Distribution Infrastructure Investment Plan (EDIIP) [38]

- Since 2017, the Michigan Public Service Commission (PSC) has required regulated utilities to develop distribution investment plans every two years, with a five-year planning horizon

- Consumers Energy delivered its first Electric Distribution Infrastructure Investment Plan (EDIIP) in 2018 and filed its most recent plan in September 2023

- The utility developed a Grid Modernization Roadmap and prioritized deploying devices on the grid to enable automated response to improve reliability and resilience


CONSUMERS ENERGY ELECTRIC DISTRIBUTION INFRASTRUCTURE INVESTMENT PLAN

Consumers Energy
Count on Us

Electric Distribution Infrastructure Investment Plan (2024-2028)

September 27, 2023

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Consumer Energy’s Grid Mod Strategies

Isolated Technologies Limit Benefits

Line Sensors

- Quickly locate faults to restore power
- ~11,000 installed sensors by 2024

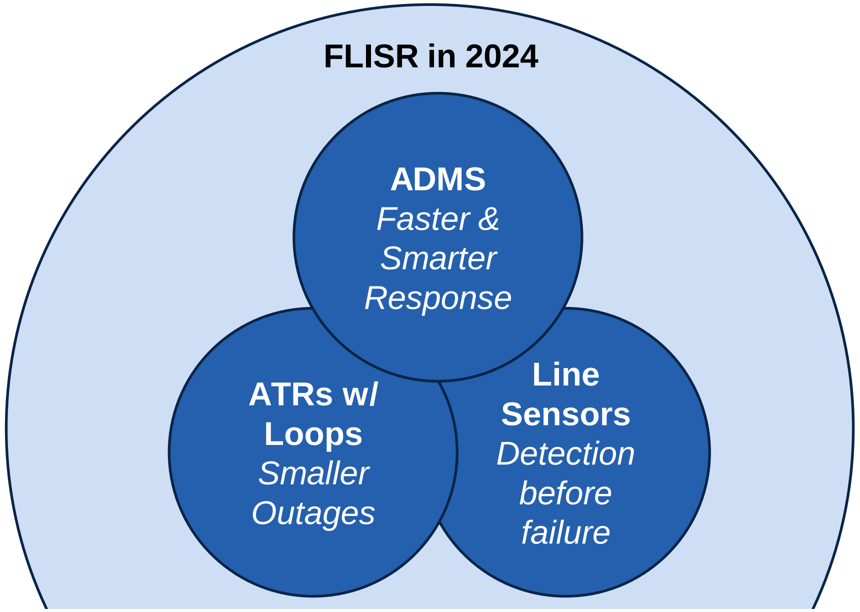
Automatic Transfer Reclosers (ATRs) w/ Loops

- Remotely restore customers
- ~235 loops installed by 2025

ADMS

- Manage outages through real-time data
- Operate the system safely and efficiently

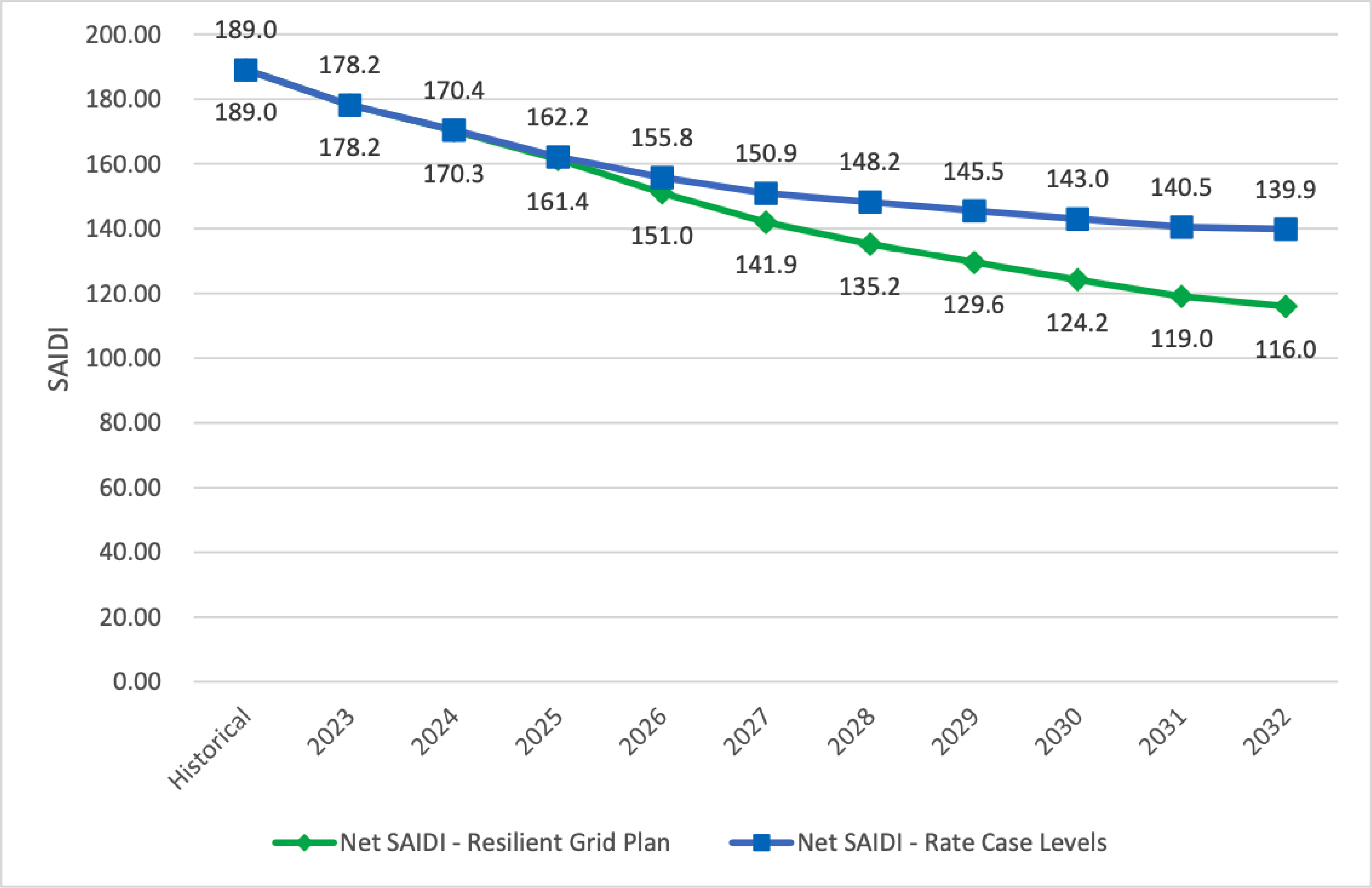
Integrated Technologies Amplify Performance



[38] Adapted from: Consumers Energy

ADMS Enhancement	2023 Capital	2024 Capital	2025 Capital	SAIDI Savings (excluding MEDs)
OMS Electra incl Live Wire Down	$800k	$900k	$0	5 minutes
Field Mapping Application DMS complete FLISR and SOM	$0	$1,600k	$0	4 minutes
Outage Applications Integration	$250k	$250k	$0	4 minutes
AMI Automation Use Case	$150k	$0	$0	2 minutes
Total	**$1,200k**	**$2,750k**	**$0**	**15 minutes**

Consumers Energy SAIDI Projections
Resilient Grid Plan Vs. Existing Approved Levels



Delivering a grid where:

- No single outage event will affect more than 100,000 customers
- No customer will be without power for more than 24 hours following an outage event

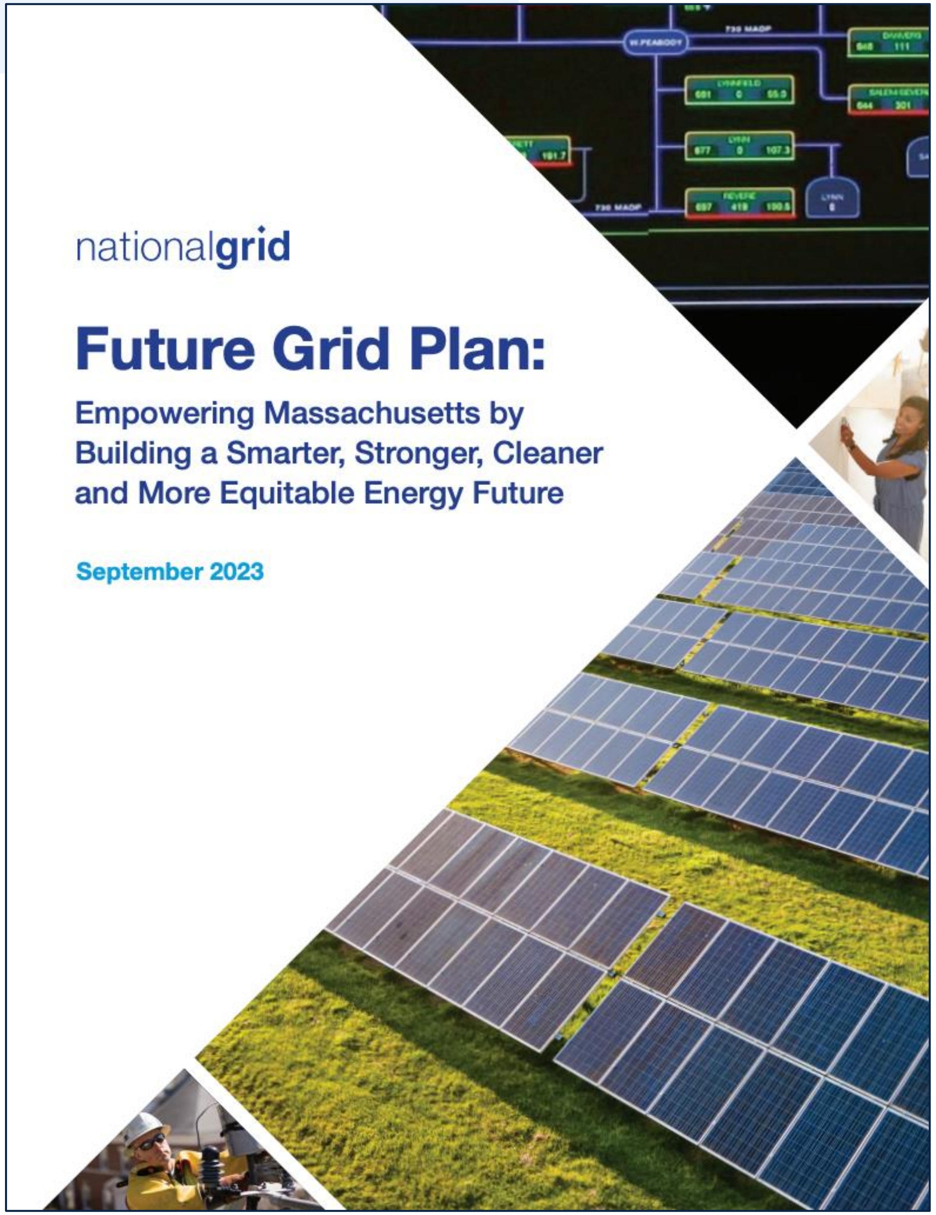
National Grid's Grid Modernization Investments

National Grid's Future Grid Plan [39]

- Massachusetts' **"2022 Climate Act"** sets statewide 2050 goals that require the grid to connect "at least twice the amount of energy storage, 10 times the amount of renewable energy, 75 times the number of EVs, and 100 times the number of heat pumps than we see today"

- The Act also directed each of the state's electric distribution companies to file an **Electric Sector Modernization Plan** detailing distribution and transmission upgrades for a 5- and 10-year horizon, as well as out to 2050

- National Grid's plan is designed to address the needs outlined in Section 53 of the 2022 Climate Act – proposing investments that will enable a resilient clean energy future



National Grid's Grid Mod Strategies

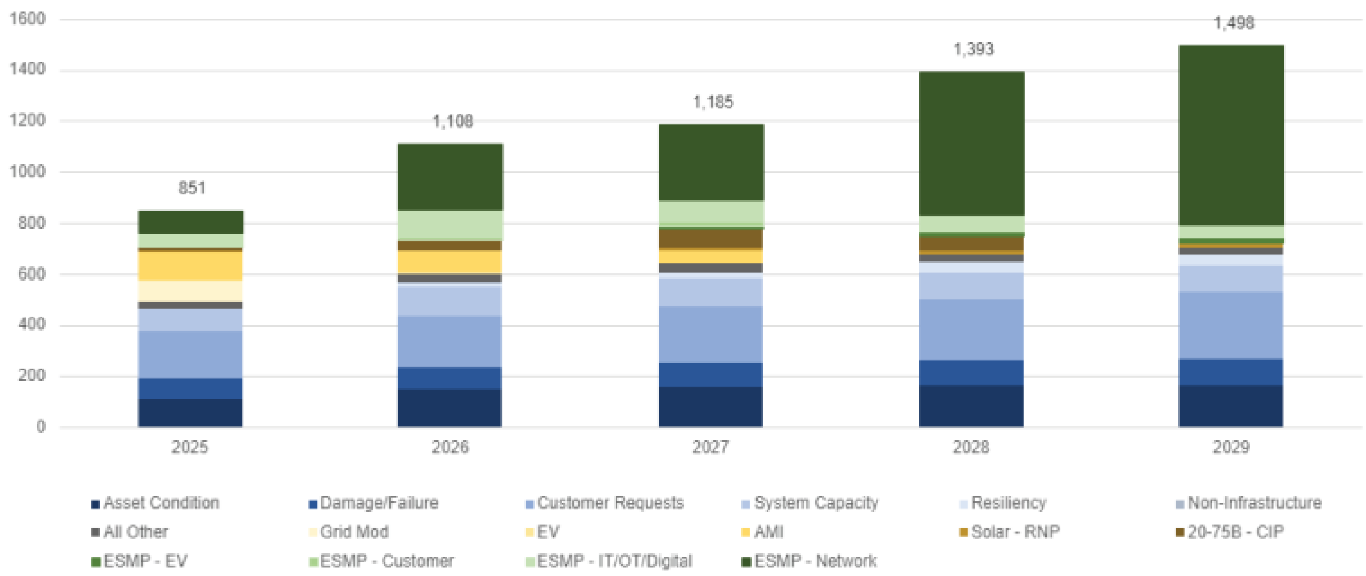
The Plan calls for leveraging existing and future IT technology – ADMS and DERMS – to better enable and optimize smart devices, EVs, and demand response

	Scale Existing	Deliver In-Flight	Deploy New (via ESMP or related filing)
Customer Programs	• EE • System Peak DR (curtailment, ESS, controllable thermostats, EVs) • Off-peak managed EV charging	• ARI for solar (flexible connections pilot)	• Targeted EE • Targeted DR • TVR • Virtual Power Plant (VPP) • Flexibility Market • Scale flexible connections for EVs and ESS
Enabling Technology		• AMI • ADMS • DERMs (pre-authorized)	• DERMs (expanded features) • Supporting data, security, and communications

[39] Source: National Grid

The utility is expecting to make $2B in incremental investment over 2025-2029 to meet customer needs and build a network that supports the state's 2050 goals

Exhibit 7.1: 2025-2029 Capital Investments ($M)



Questions to Ask

- What are the biggest threats (natural or manmade) that your grid faces today?
- What resilience investment attributes are most important to your grid (e.g., implementation cost, operations and maintenance cost, time to implement, reduced outage duration, reduced outage frequency)?
- Which type of resilience investments are top of mind for your stakeholders? Why?
- Which type of resilience investments are at the top of your mind? Why?
- If you have multiple resilience investments in mind, how would you stage their implementation for optimal performance?

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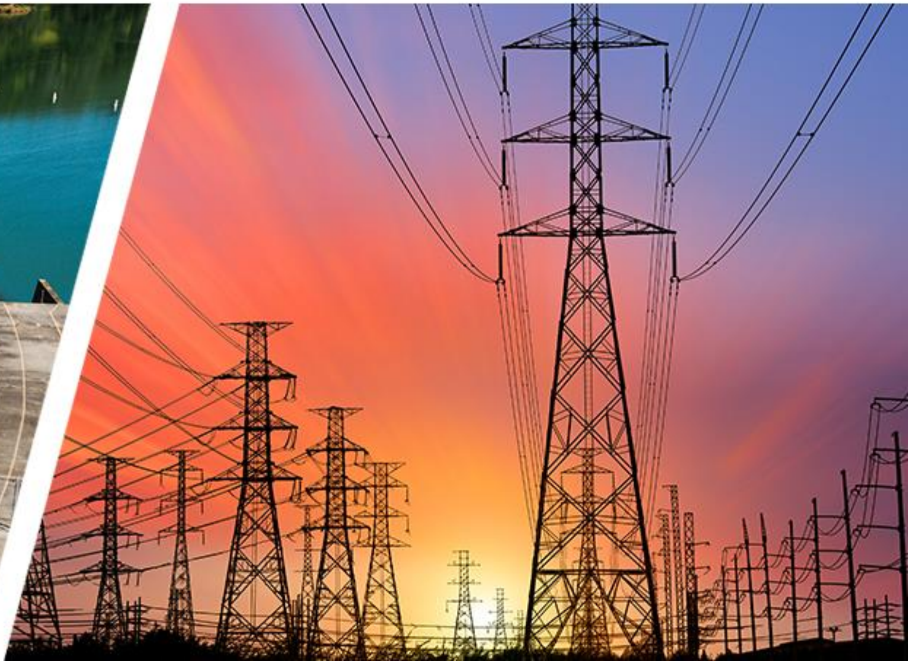

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STATE CRITERIA FOR EVALUATING RESILIENCE PROJECTS

Presented by Tom Wall, Ph.D., Argonne National Laboratory

Resilience Training for States
Nashville, Tennessee

March 21, 2024

Principles of Resilience*

What makes a resilience project a resilience project?

- Proactive
- Whole-System
- Equitable and Just
- People-Centered
- Collaborative and Inclusive
- Durable
- Multi-Benefit

National Climate Resilience Framework, September 2023.
https://www.whitehouse.gov/wp-content/uploads/2023/09/National-Climate-Resilience-Framework-FINAL.pdf

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Design Criteria with the End in Mind

- Be clear about what resilience means for your context
  - To or from what?
- Identify the outcomes you're trying to achieve
  - For who?
  - How much?
- Outcomes → Projects → Evaluation criteria

Types of Evaluation Criteria

- **Quantitative**
  - Numerical
  - Objective
  - Subject to local data availability
  - Numbers may not tell whole story
  - E.g., % reduction in risk, % total population protected, % of grid protected
- **Qualitative**
  - Story or narrative descriptions
  - Subjective
  - Can get a fuller picture than just numbers
  - Depends on applicant capacity
  - Can be harder to score due to required analysis or interpretation
- **Likely want a mix of both in order to understand project holistically**

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Potential Evaluation Criteria

Outcome Focused Criteria:

- Physical impacts
- Operational impacts
- Public health and safety impacts
- Economic impacts
- Social impacts
- Equity impacts
- Environmental impacts
- Cascading impacts and interdependencies

Process Focused Criteria

- Feasibility
- Effectiveness
- Achieves multiple community objectives
- Administrative impacts
- Financial implications
- Timeframe for implementation
- Return on investment
- Useful life

Things to Consider (1/2)

- Mechanics of the criteria
  - Number of criteria
  - Availability of data
  - Scoring rubric
  - Scoring weights
- Review process
  - Who’s involved?
  - How do you evaluate consistently?
  - Timeframe for review

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Things to Consider (2/2)

- Unintended consequences
  - Too complex?
  - Is there potential for bias?
  - Cancel each other out?

FEMA BRIC Program – Technical Evaluation Criteria

FY20

- Infrastructure project
  - 20 points
- Mitigating risk to one or more lifelines
  - 15 points
- Incorporation of nature-based solutions for hazard mitigation
  - 10 points
- Mandatory Building Code Adoption
  - 20 points
- BCEGS Rating
  - 15 points
- Project results from previous Project Scoping
  - 10 points
- Increased non-federal cost share
  - 5 points
- Small impoverished community
  - 5 points

FY23

- Infrastructure project
  - 15 points
- Incorporation of nature-based solutions for hazard mitigation
  - 5 to 15 points
- Building Code Adoption and Enforcement
  - 5 to 15 points
- Project results from previous Project Scoping or TA
  - 10 points
- Justice40 community OR EDRC or CDRZ
  - 30 points OR 40 points

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FEMA BRIC Program – Qualitative Evaluation Criteria

FY20

- Risk Reduction/Resilience Effectiveness
  - 35 points
- Future Conditions
  - 15 points
- Implementation Measures
  - 15 points
- Population Impacted
  - 15 points
- Outreach Activities
  - 5 points
- Leveraging Partners
  - 15 points

FY23

- Risk Reduction/Resilience Effectiveness
  - 30 points
- Climate Change and Other Future Conditions
  - 20 points
- Implementation Measures
  - 15 points
- Population Impacted
  - 25 points
- Community Engagement and Other Outreach Activities
  - 5 points
- Leveraging Partners
  - 5 points

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Questions to Ask

- What are we trying to achieve and what criteria will help us get there?
- Are the criteria clear and actionable?
- Do we have a clear evaluation process?
- Are we creating unintended consequences with the criteria we’ve selected?

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Example Approaches

Wisconsin

- Eligibility and Experience
- Quality Jobs
- Disadvantaged Community Benefits
- Diversity, Equity, Inclusion and Accessibility
- Economic Impact and Effects on Annualized Cost
- Build and Deploy
- Impact
- Greatest Community Benefit
- Innovation
- Priority Activity Type

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Example Approaches

Colorado

- Prioritize funding for projects based on:
  - Demonstrated need
  - Impact
  - Project readiness
  - Proposed cost match

- Evaluation Criteria:
  - Demonstrated need - 40%
  - Project Impact - 30%
  - Project Readiness - 20%
  - Labor Impact - 10%

Example Approaches

Kansas

- Preference to:
  - Monitoring and control technologies
  - Utility pole management
  - Hardening of power lines, facilities, substations and of other systems
  - Replacement of old overhead conductors and underground cables
- Prioritize projects that will
  - Generate the greatest community benefit in reducing the likelihood and consequences of disruptive events
    - Historical measurements of resilience and reliability for the targeted areas of each proposed project
    - Expected changes because of each proposed project
  - Located in rural, underserved and/or disadvantaged communities
- Scoring Matrix:
  - Project Description and Scope: 20 points
  - Need for Funding: 20 points
  - Complete Budget and Narrative: 10 points
  - Project Timeline: 15 points
  - Bids and Estimates: 10 points
  - Community Benefit: 25 points

Example Approaches

Ohio

- Objective #1: Improve reliability, including reducing the frequency and duration of outages in disadvantaged communities. 20 points
- Objective #2: Enhance resilience to address all hazards, including future climate implications. 20 points
- Objective #3: Demonstrate beneficial community impact. 25 points + 10 points for GHG reduction
- Objective #4: Improve customer experience. 17.5 points
- Objective #5: Ensure project success. 17.5 points
- Complete and compliant application. 5 points

Example Approaches

- South Carolina

STEP 1: SCREENING CRITERIA		
☑ Is the application complete?	☑ Does the response meet 1 of the 4 objectives?	☑ Does the application meet workforce standards

STEP 2: PROPOSAL EVALUATION CRITERIA

Evaluate the proposed improvements of the submitted projects and proposed metrics for tracking against a weighted scoring system

PROJECT RESILIENCY IMPACT (60%)	COMMUNITY BENEFIT IMPACT (40%)
Does the project demonstrate significant improvements to: • Reduce the number of outages due to extreme weather events • Improve the restoration times due to extreme weather events	Does the project demonstrate community benefits in any of key areas: • Community population impacted beneficially • Community and Labor Engagement • Workforce Continuity and Good Jobs Plan: • Diversity, Equity, Inclusion, and Accessibility (DEIA) Plan: • Justice40 Initiative

Example Approaches

Michigan

- Project Scope & Objectives (20 Points)
- Project Feasibility (10 Points)
- Project Impact (35 Points)
- Program Priorities (15 Points)
  - Hardening of power lines (not pole management or conductors), facilities, substations, or other systems
  - Vegetation and fuel-load management.
  - Relocation of power lines
  - Replacing old overhead conductors and underground cables
  - Undergrounding of electrical equipment
  - Non-Wired Alternative Projects that focus on using distributive energy resources (DERs), battery storage, and capacity relief, including microgrids.
- Diversity Equity and Inclusion (15 Points)
- Environmental Justice (5 Points)
- Overmatch (5 Points - bonus)

Example Approaches

Idaho

- Project Resiliency (70%)
  - Provides a clear and cost-effective work plan for improving grid resilience. (45%)
  - Demonstrates a strong need for alleviating probable risk (35%)
  - Provides clear metrics for tracking measurable improvements to resiliency (20%)
- Community Benefit (25%)
  - Generates community benefits (55%)
  - Creates and maintains jobs (30%)
  - Serves low-income Idaho residents to alleviate energy burden (15%)
- Administrative Compliance (5%)
  - Adheres to administrative requirements (100%)

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