Introduction to Resilience for Electricity Systems

Presented by Sara Peterson, NREL

Resilience Training for States – Western Region

January 25, 2024

Agenda

- Introducing Resilience:
  - Defining Resilience
  - Understanding Risks
  - Causes and Consequences
  - Qualitative and Quantitative Approaches
- Mitigation and Resilience Solutions
  - Example of Stakeholder Driven Approach
- Resources for more information
- Q&A

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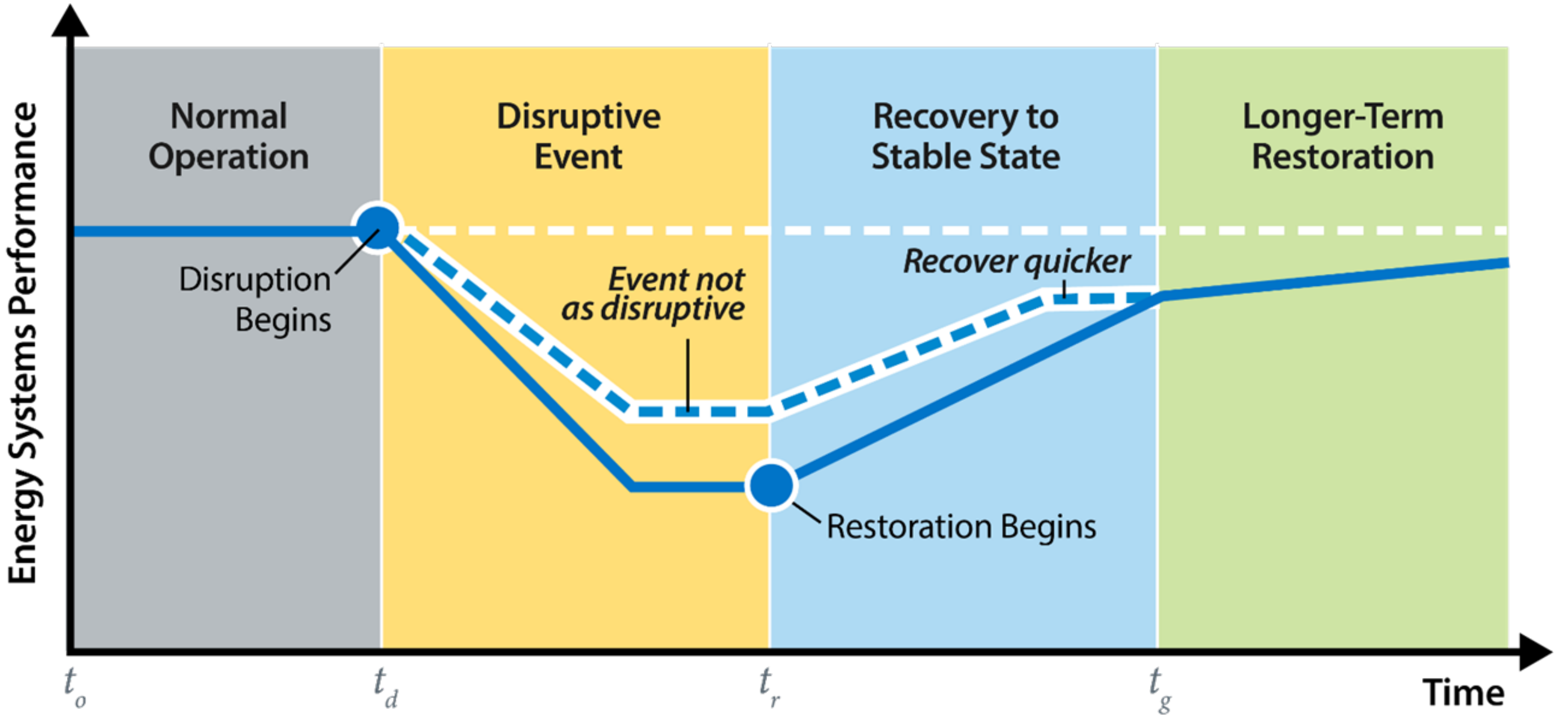
Introducing Resilience

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 <u>system's</u> performance subject to both <u>acute</u> shocks and <u>chronic</u> stresses.

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

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).

[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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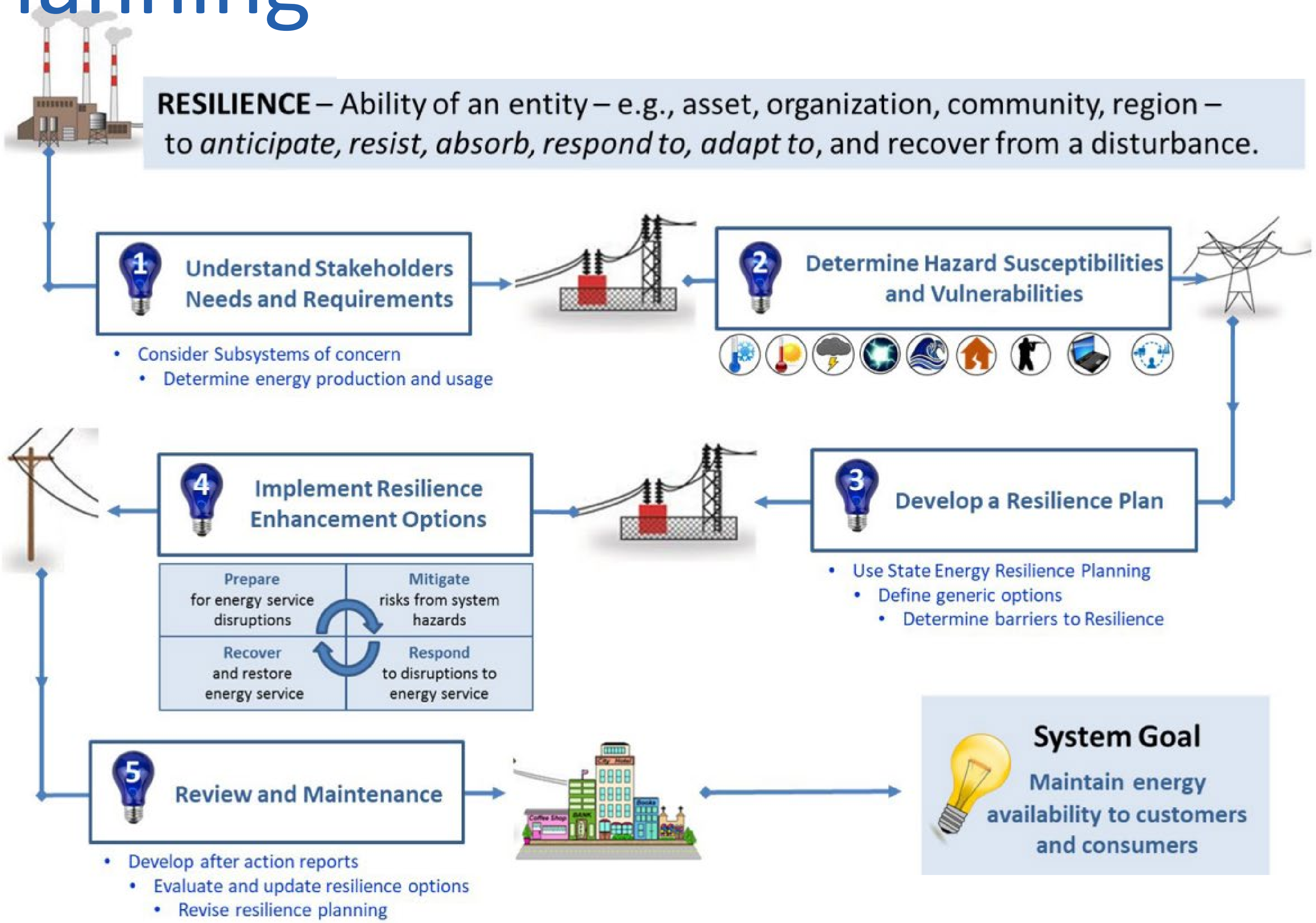
A Risk Informed Approach to Resilience Assessments and Planning

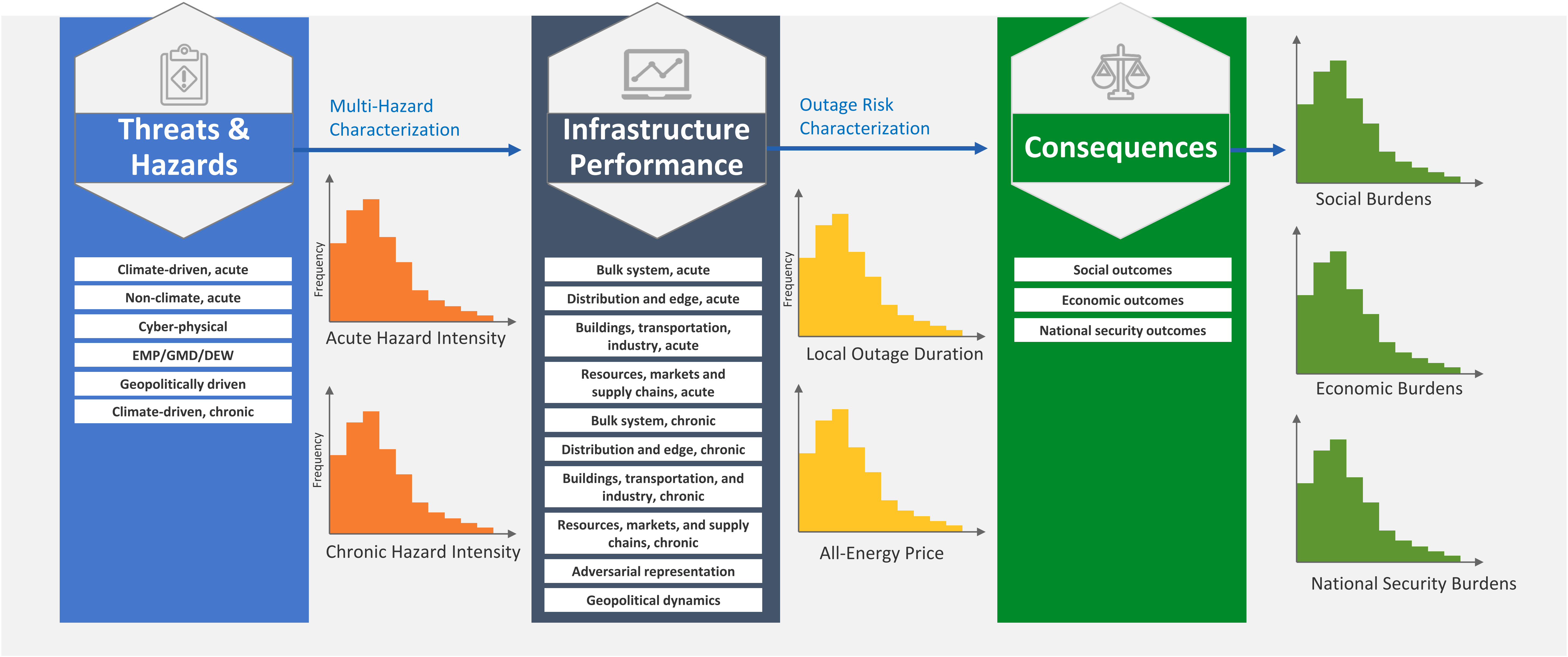
Illustration by Jennifer Breen Martinez, NREL



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.

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)
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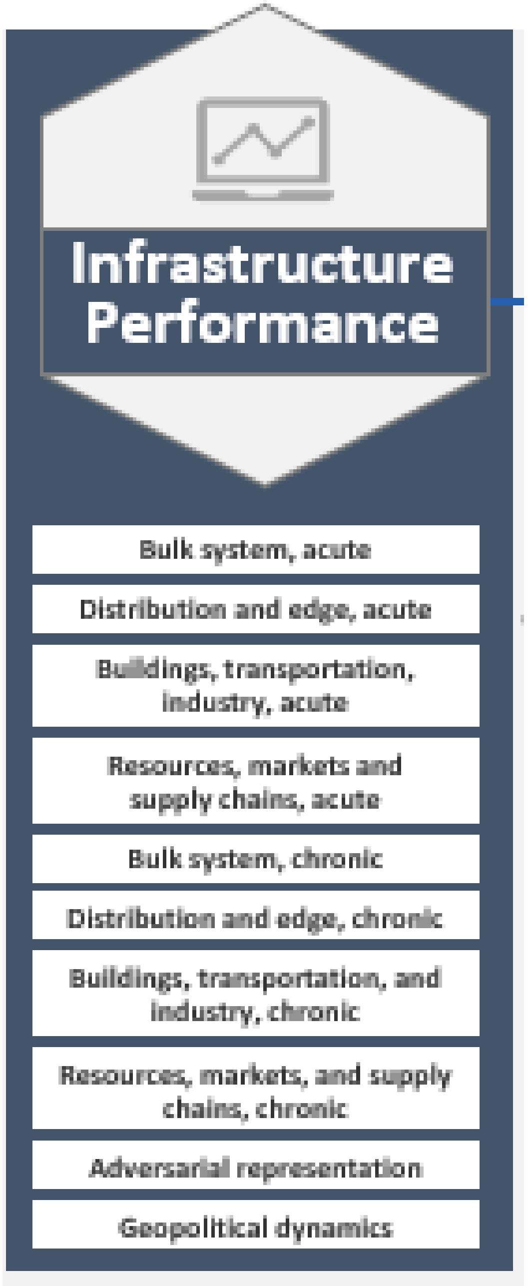
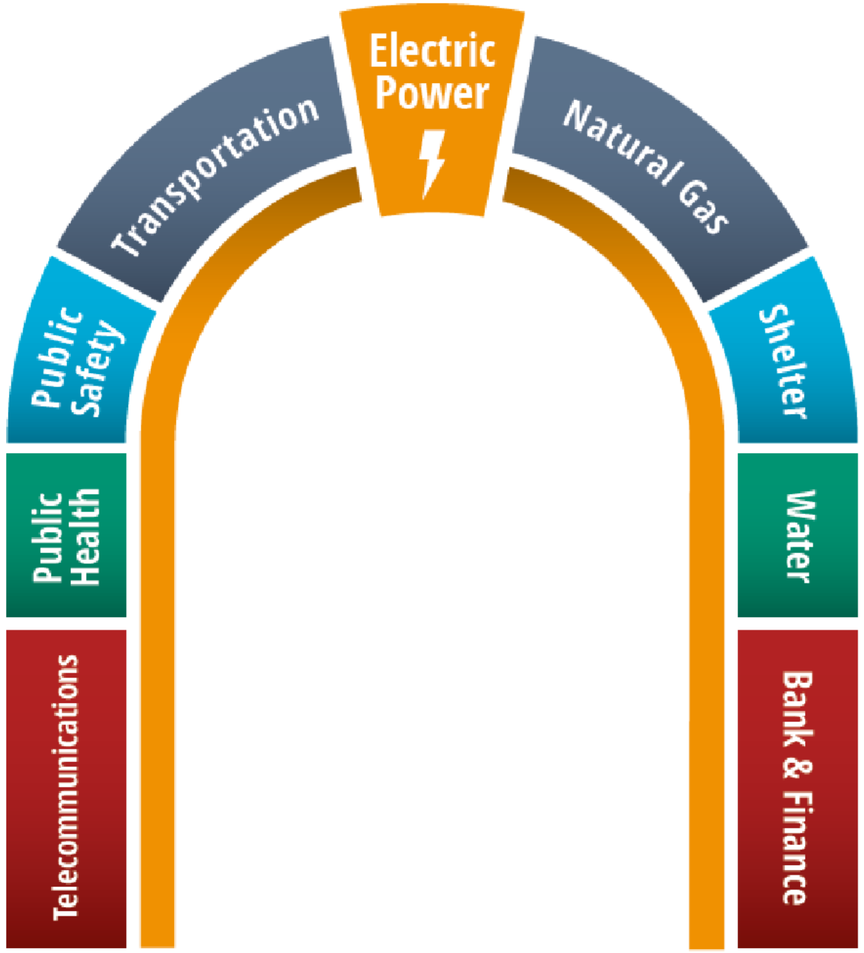
Vulnerabilities



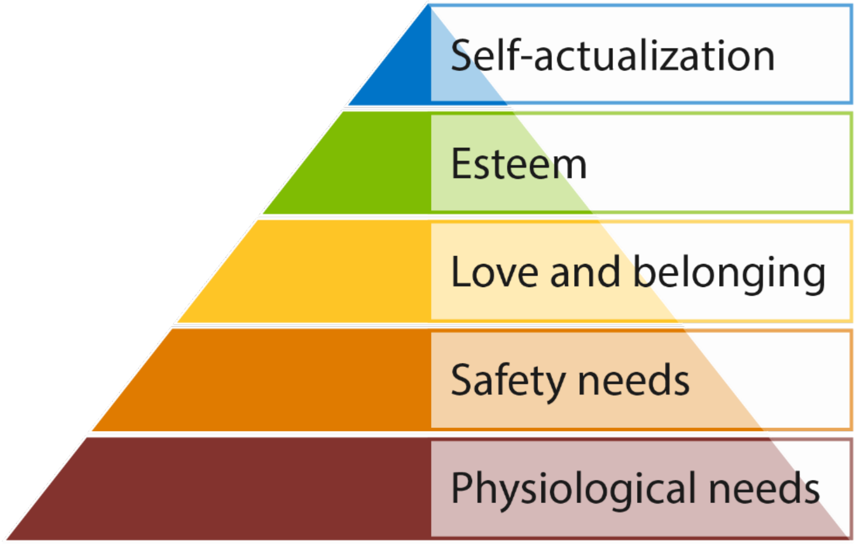
- Power sector vulnerabilities usually fit into two categories:
  - Infrastructure
  - Process
- Both types of vulnerabilities need to be considered when assessing resilience options for the power sector
- Infrastructure vulnerabilities are often easy to address but tend to be very expensive
  - Power 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

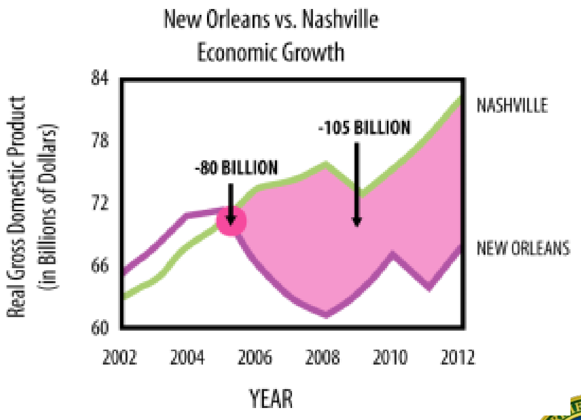
Consequences

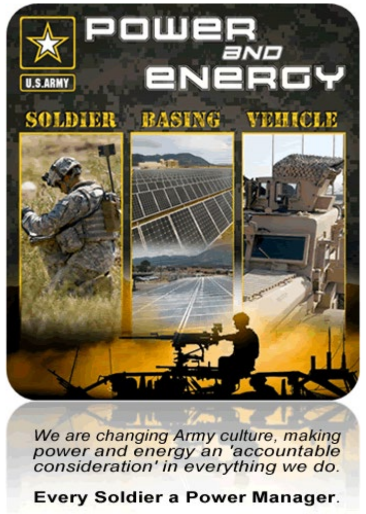
Within resilience, there are three major dimensions of consequence. These better define the externality and **lead to different internalization pathways**.

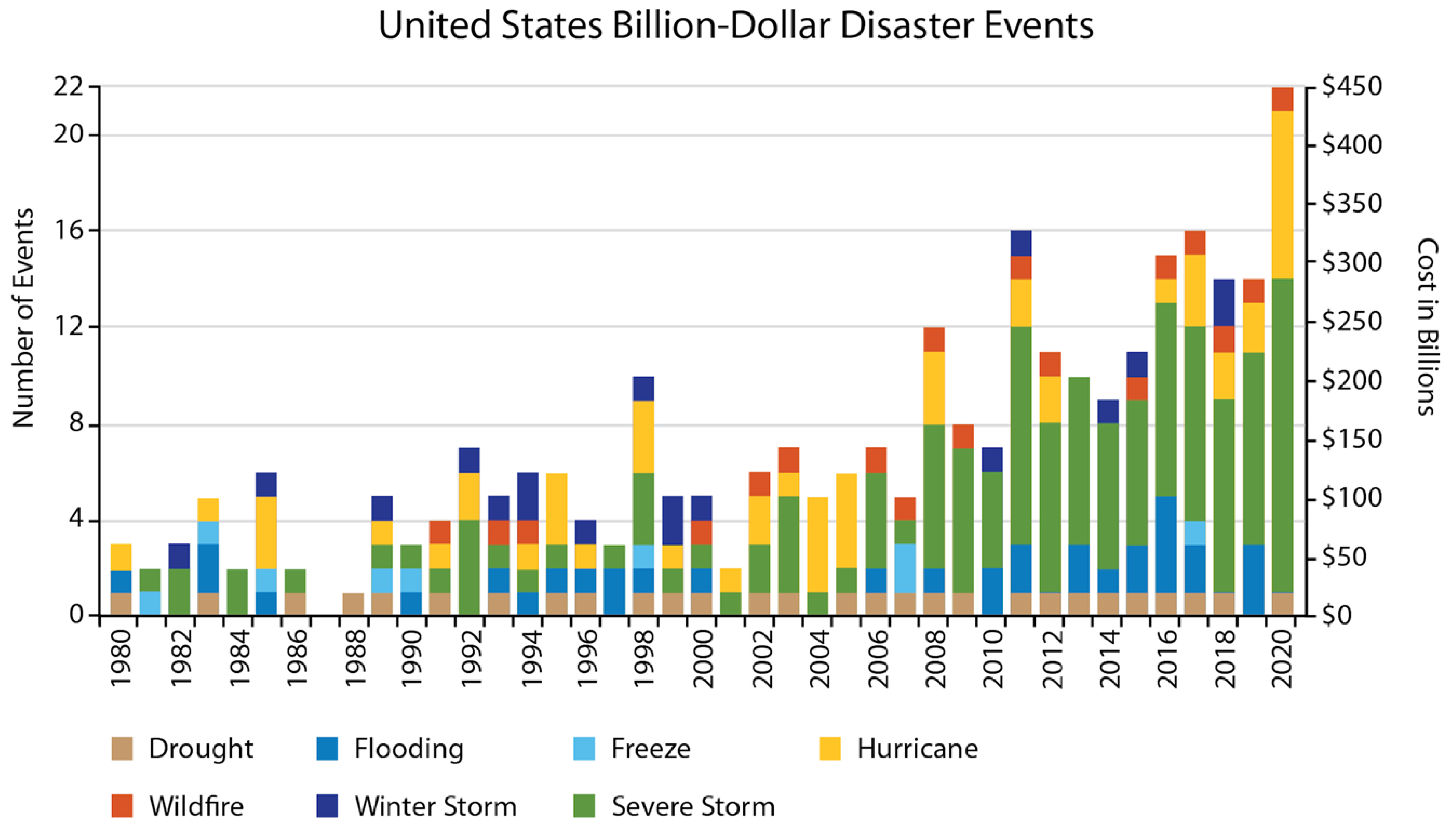


- **Society**
- **Economy**
- **National Security**

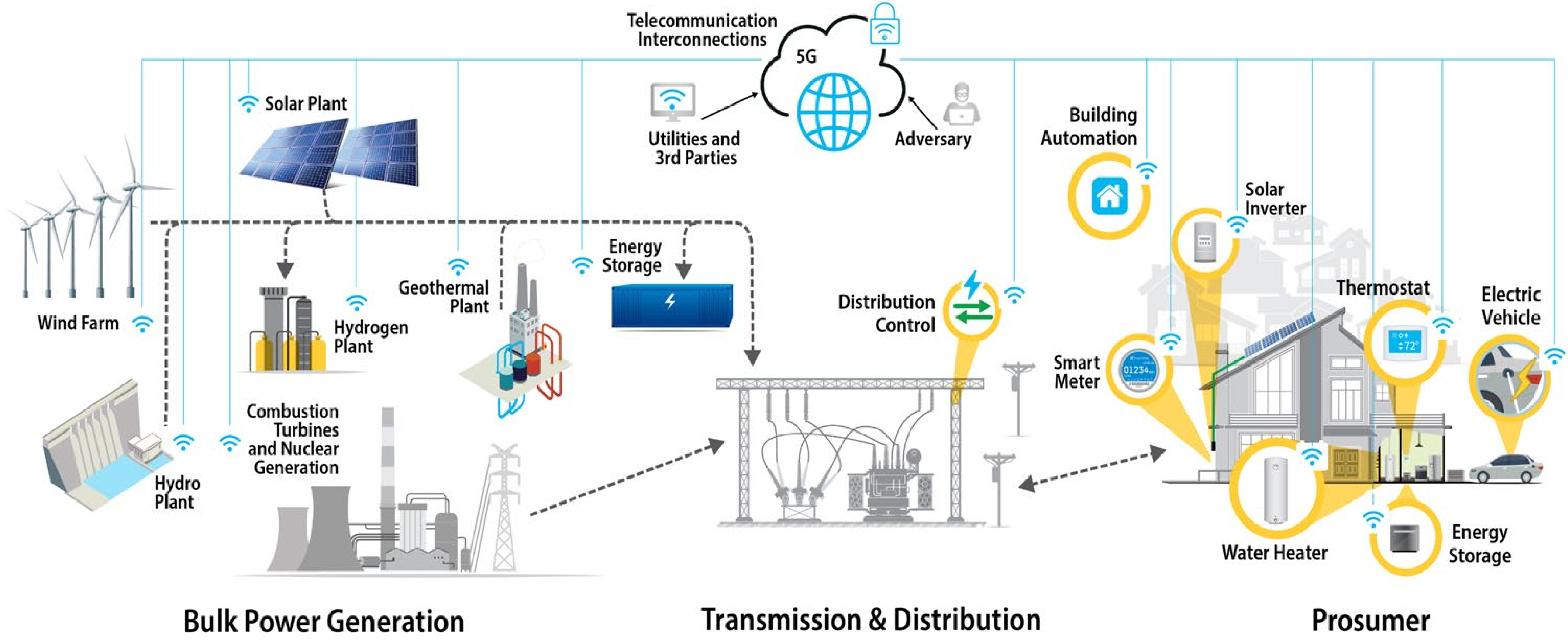








Source: NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2021). https://www.ncdc.noaa.gov/billions/, DOI: 10.25921/stkw-7w73



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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Risk Informed Approach to Assessments and Planning

Data Gathering and Goal Setting

Vulnerability and Risk Assessment

Resilience Options

Prioritization and Implementation

Assessment and Review

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.

- **Grid Hardening**
  Weatherizing equipment, installing fire-resistant technologies, undergrounding lines, and strengthening utility poles can reduce the likelihood of power outages.

- **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.

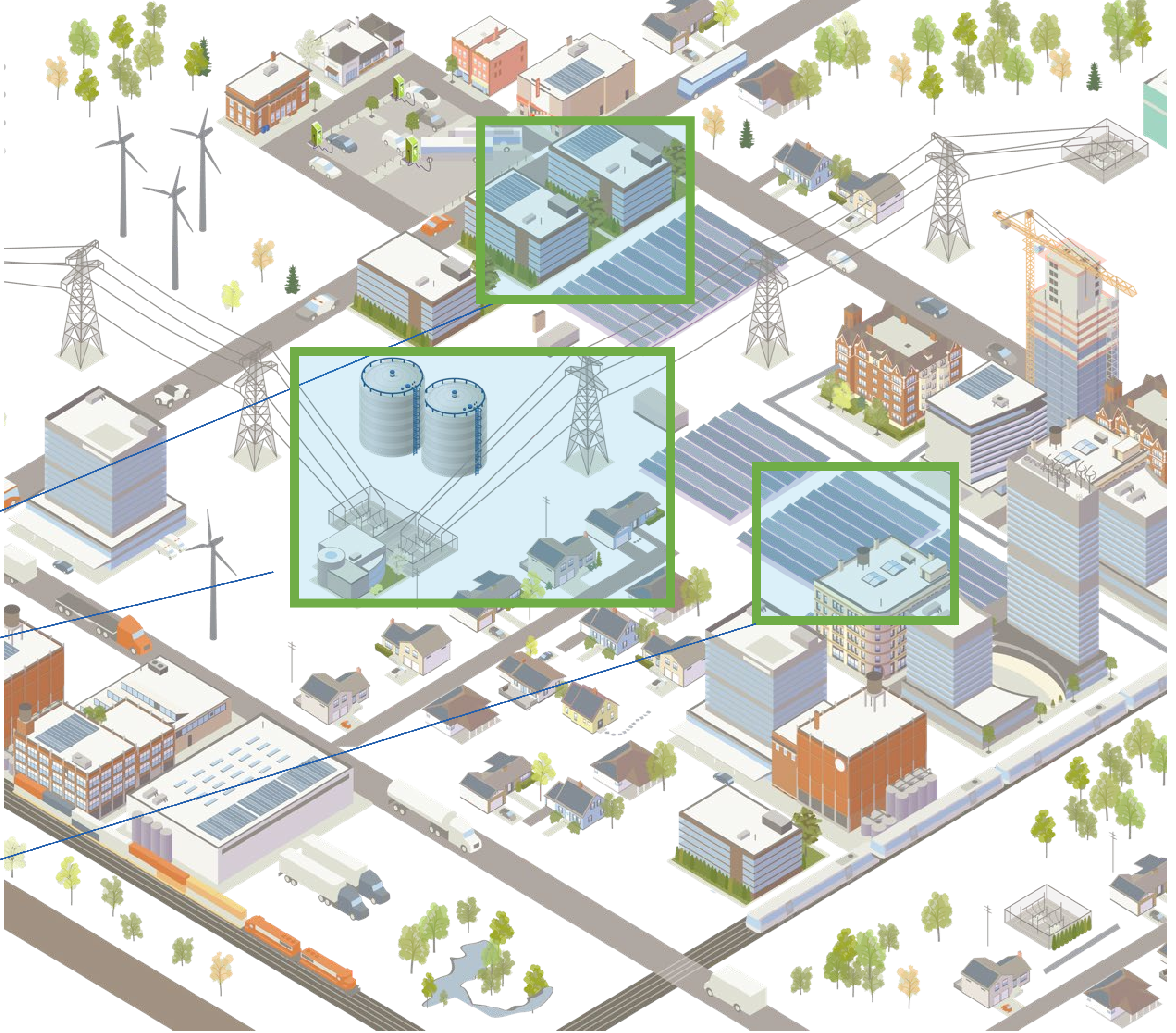

Image credit: Anthony Castellano, NREL

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.

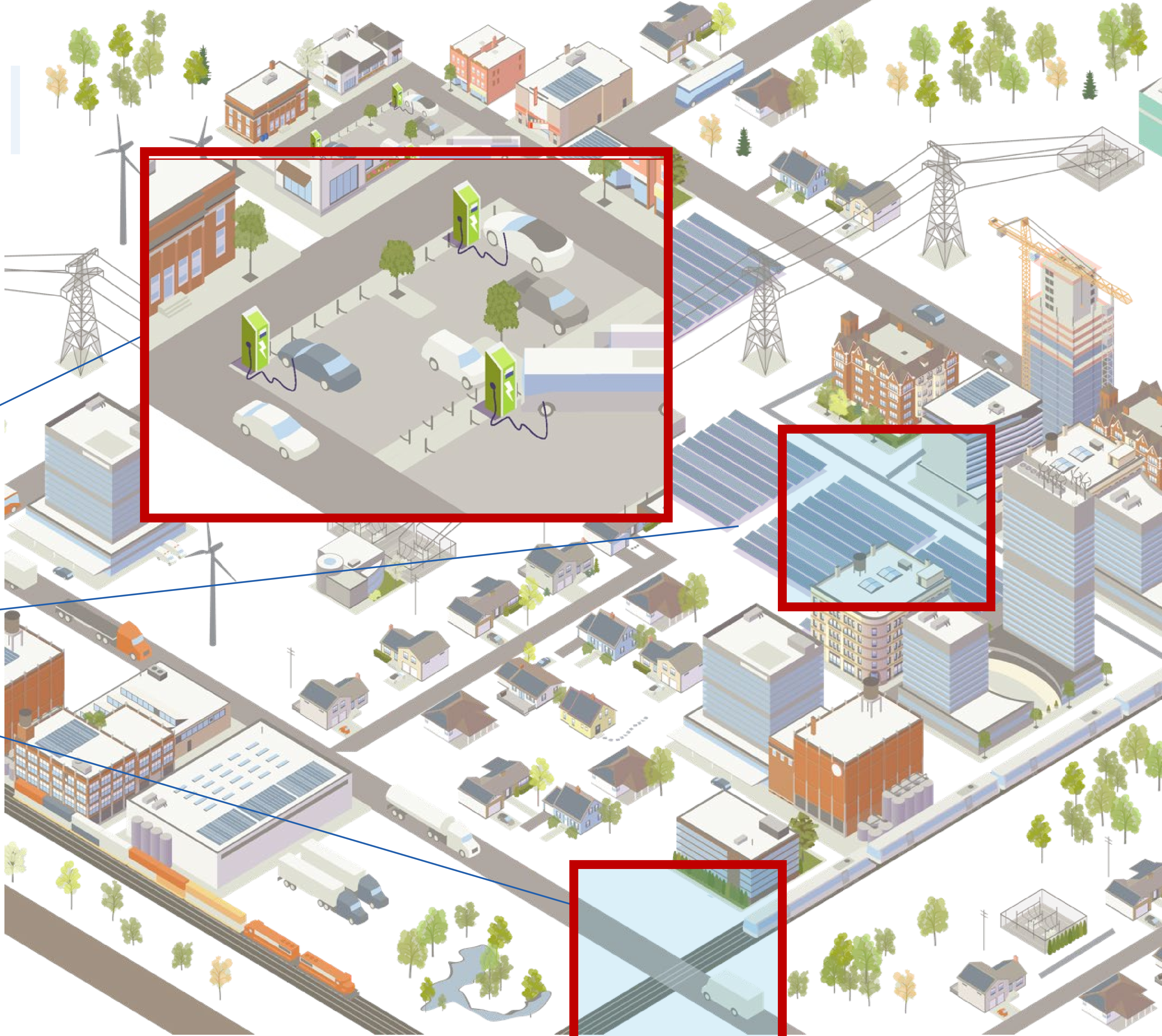

Image credit: Anthony Castellano, NREL

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.

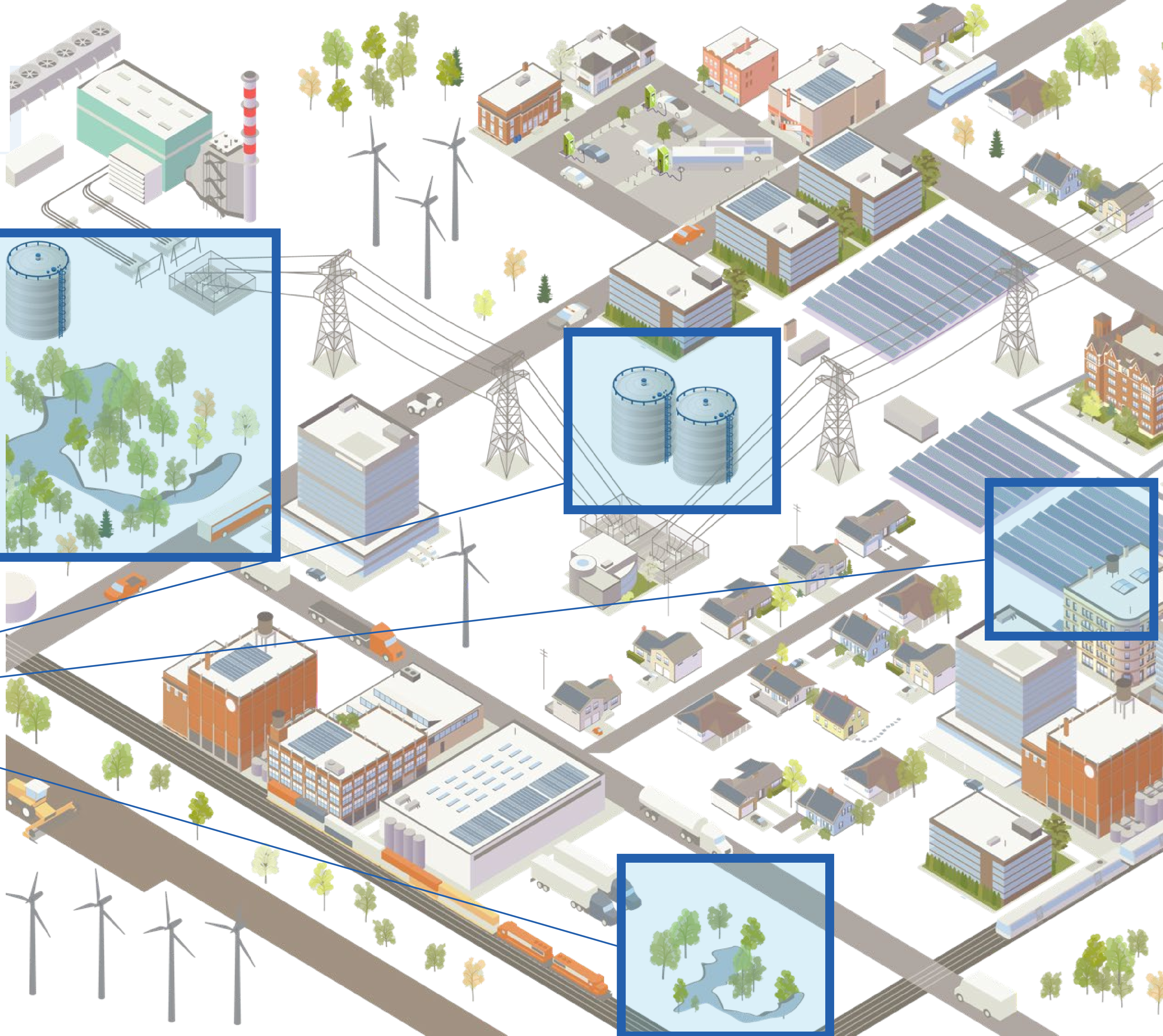

Image credit: Anthony Castellano, NREL

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.

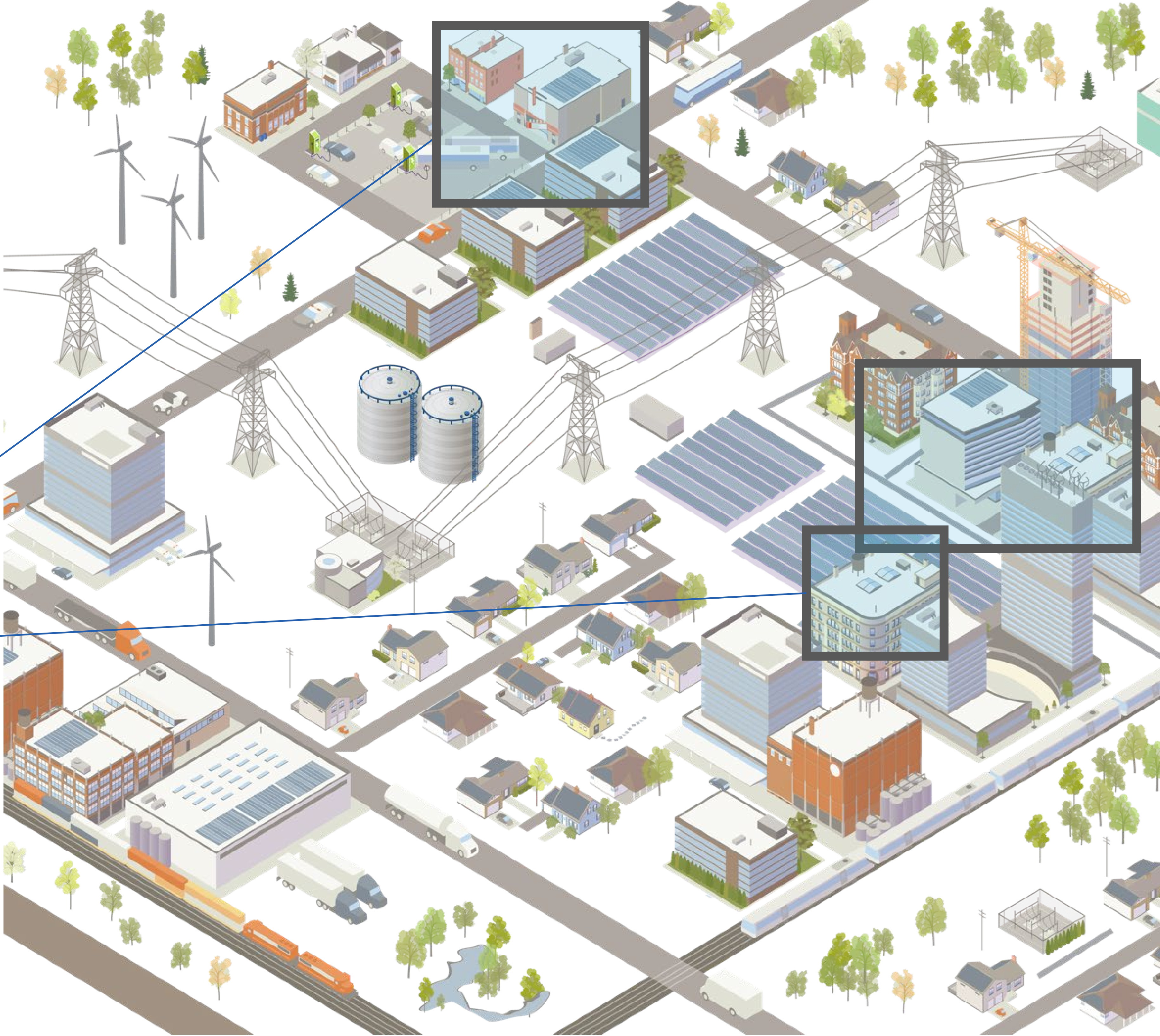

Image credit: Anthony Castellano, NREL

Questions to Ask Utilities

- What hazards, threats, or vulnerabilities are you most concerned with for your utility, community, or state?
- 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 the costs and benefits of 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?

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Resources for more information

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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 State & Tribal Formula Grant Program: Grid Resilience State/Tribal Formula Grant Program | Department of Energy
- 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

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Contact

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

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Identifying Threats, Predicting Vulnerabilities, and Assessing the Risks

Tom Wall, Ph.D., Argonne National Laboratory

Resilience Training for States – Western Region

January 25, 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

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

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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

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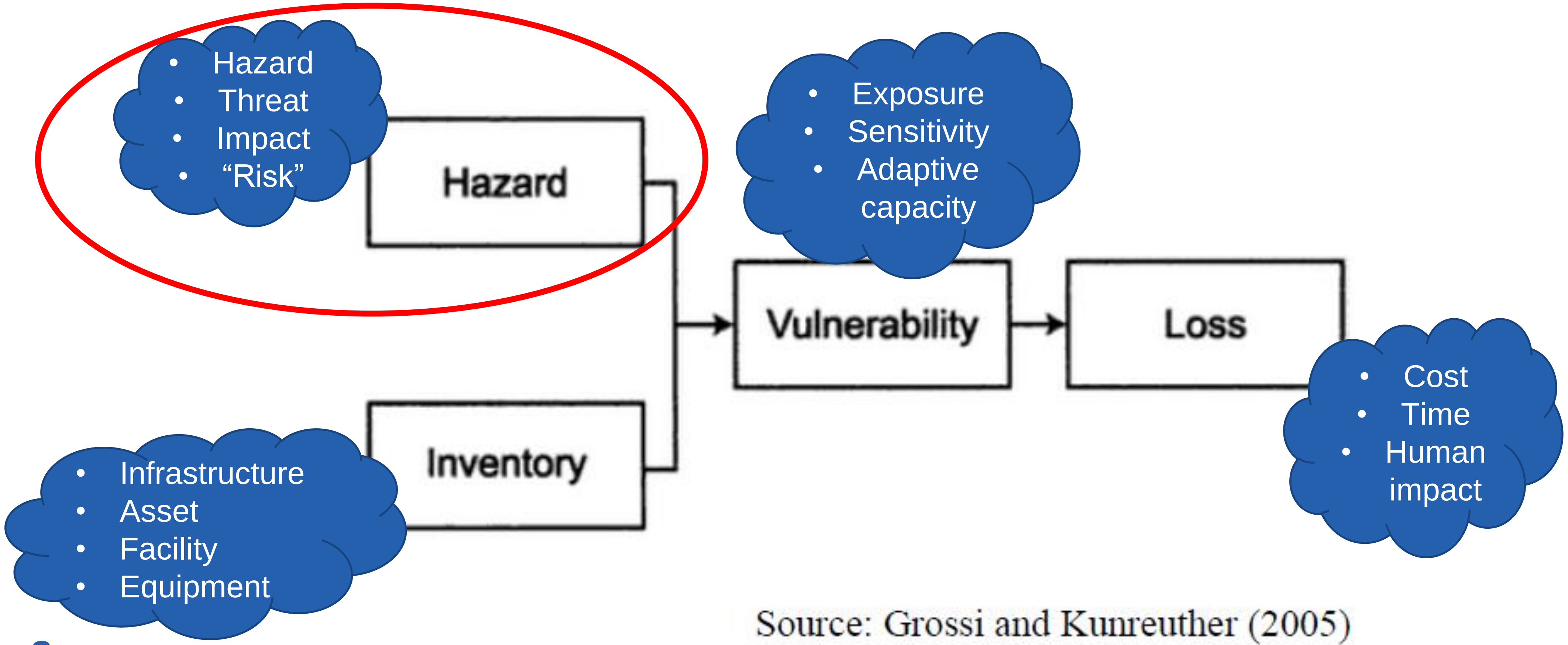
Integrating Threat Information into Risk-Based Assessments (1)

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

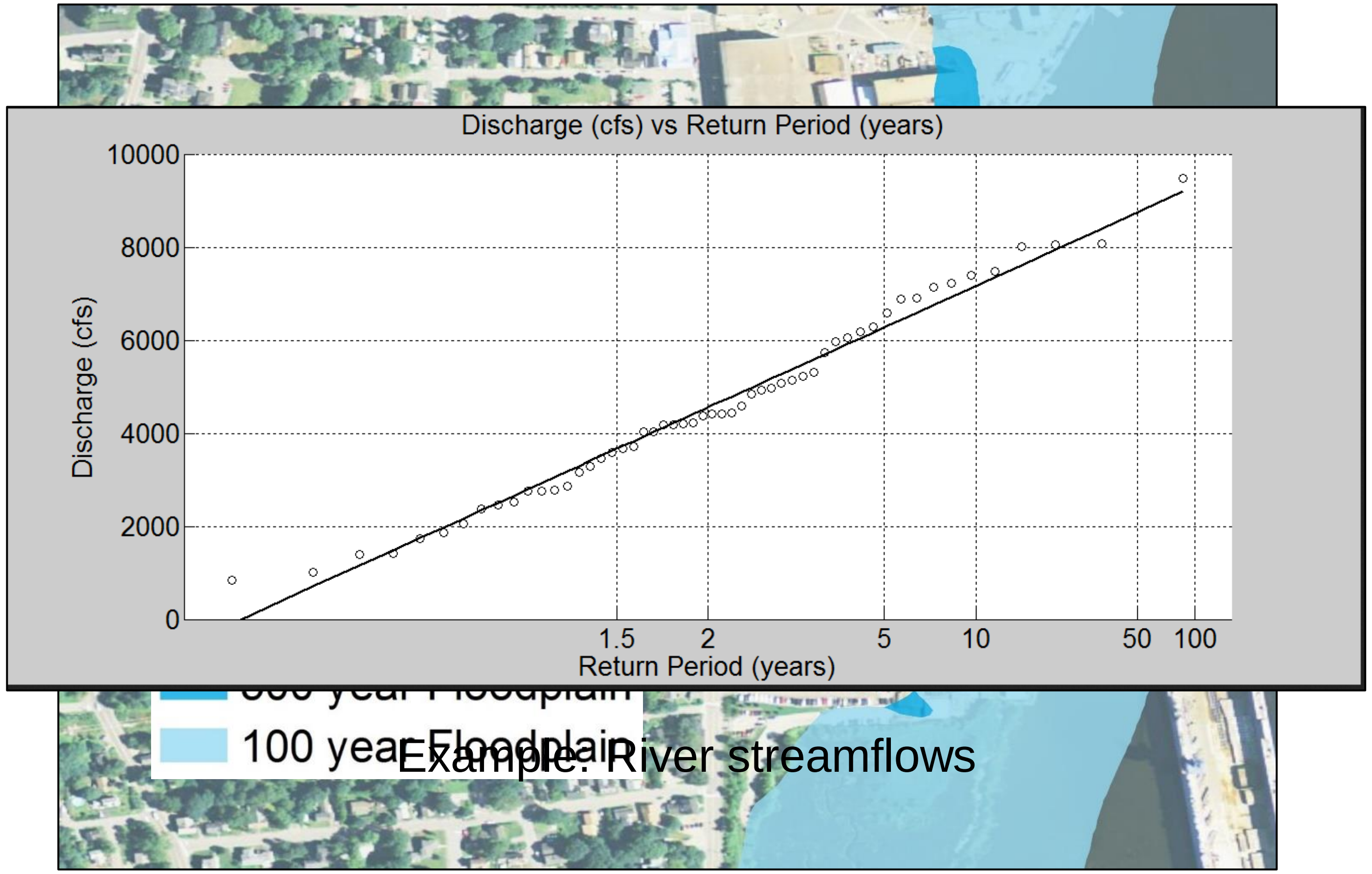
- Likelihood or probability based threat information
- Deterministic/scenario-based threat information

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

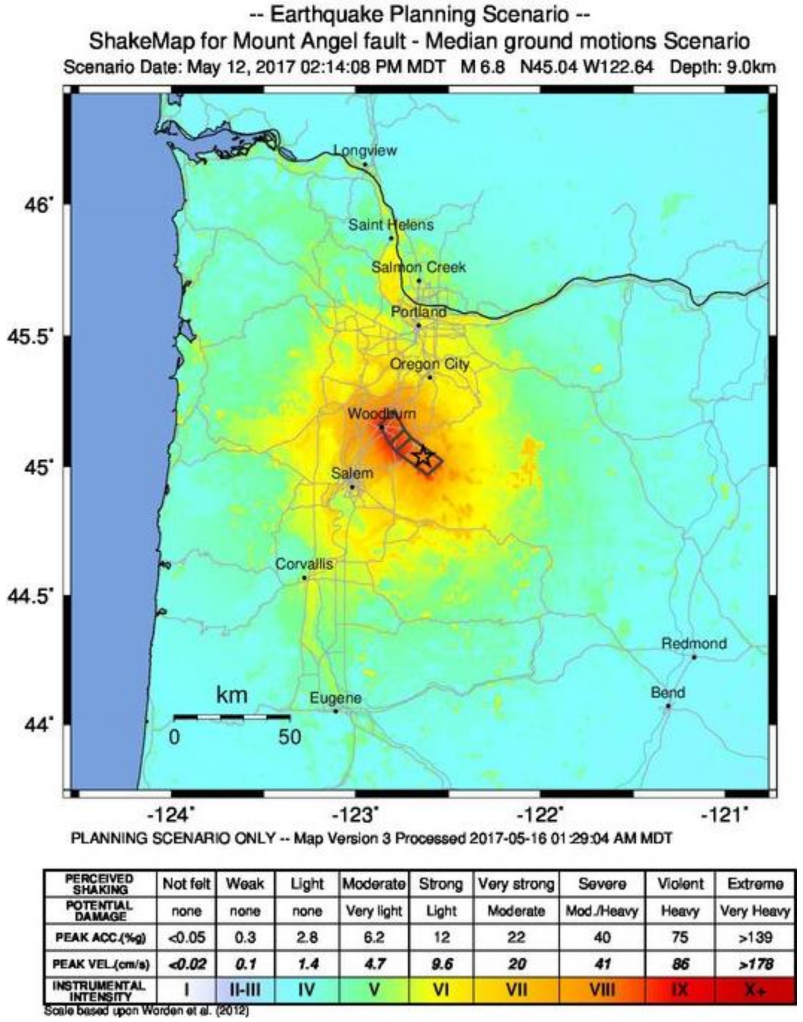
Integrating Threat Information into Risk-Based Assessments (3)

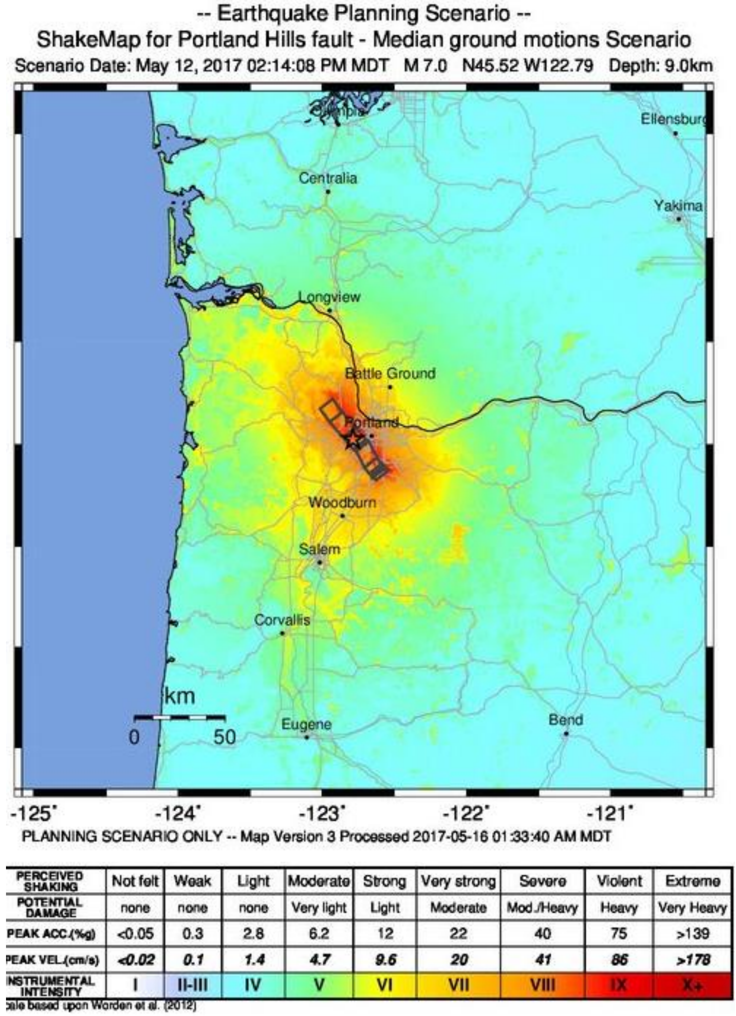
Probabilistic vs. Deterministic Hazard Information

- 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

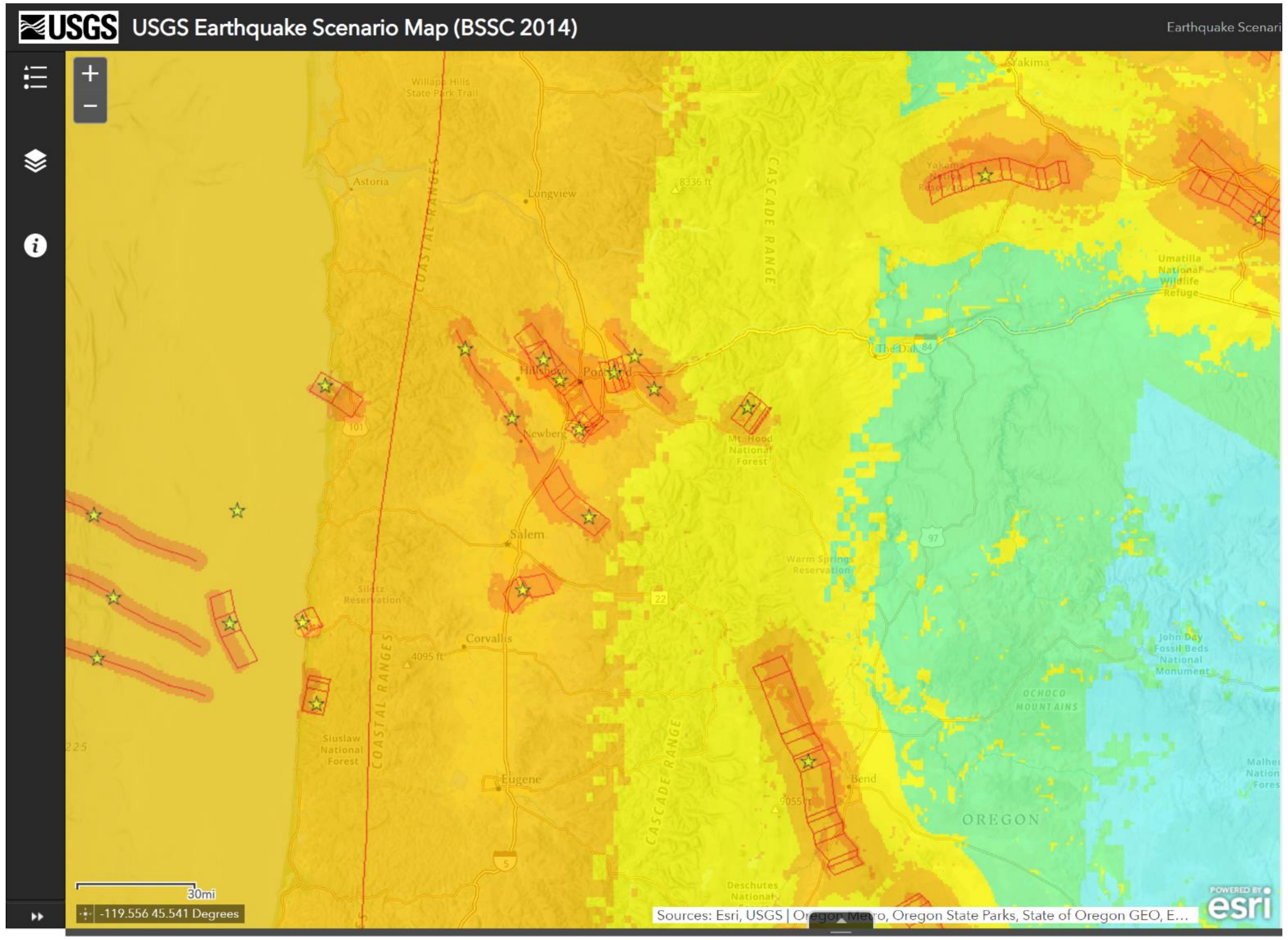
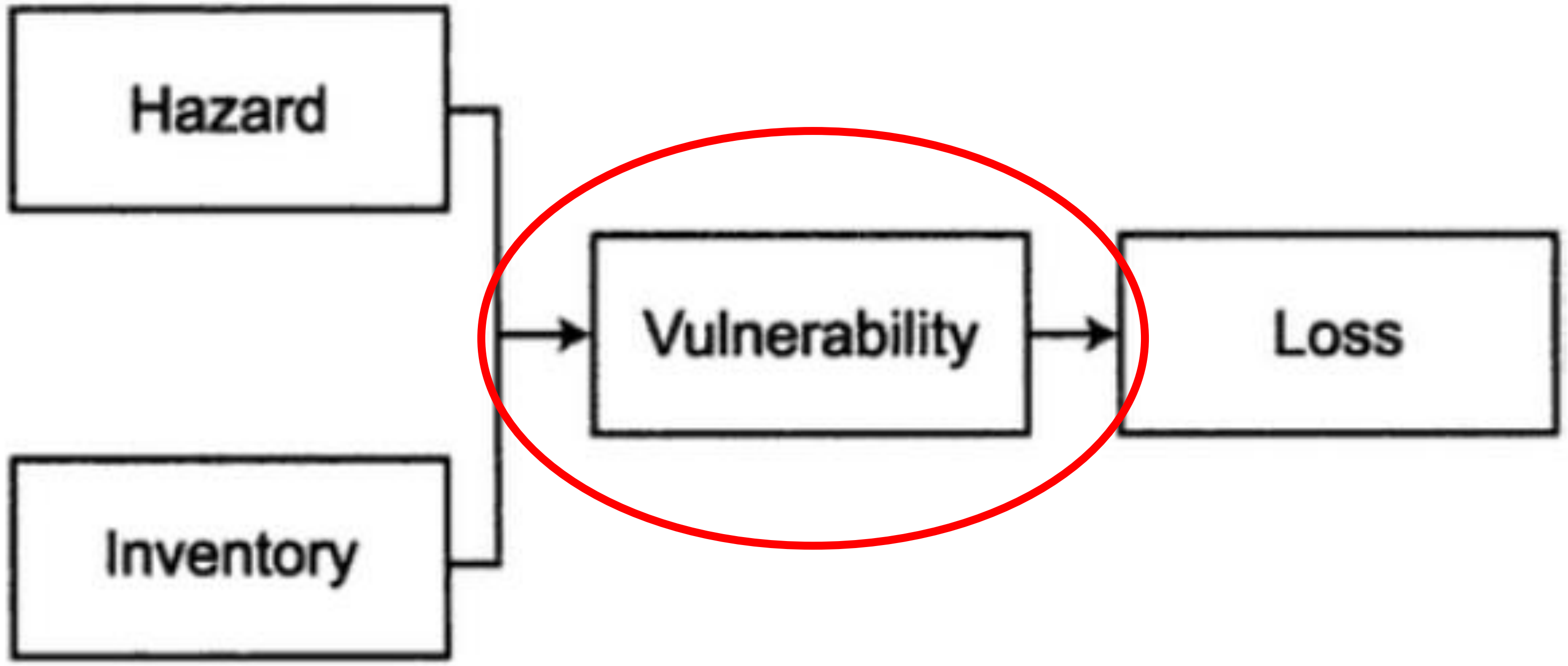


Image: https://usgs.maps.arcgis.com/apps/webappviewer/index.html?id=14d2f75c7c4f4619936dac0d14e1e468

Assessing Infrastructure Vulnerability

The Importance of Place-Based Information & Data



Source: Grossi and Kunreuther (2005)

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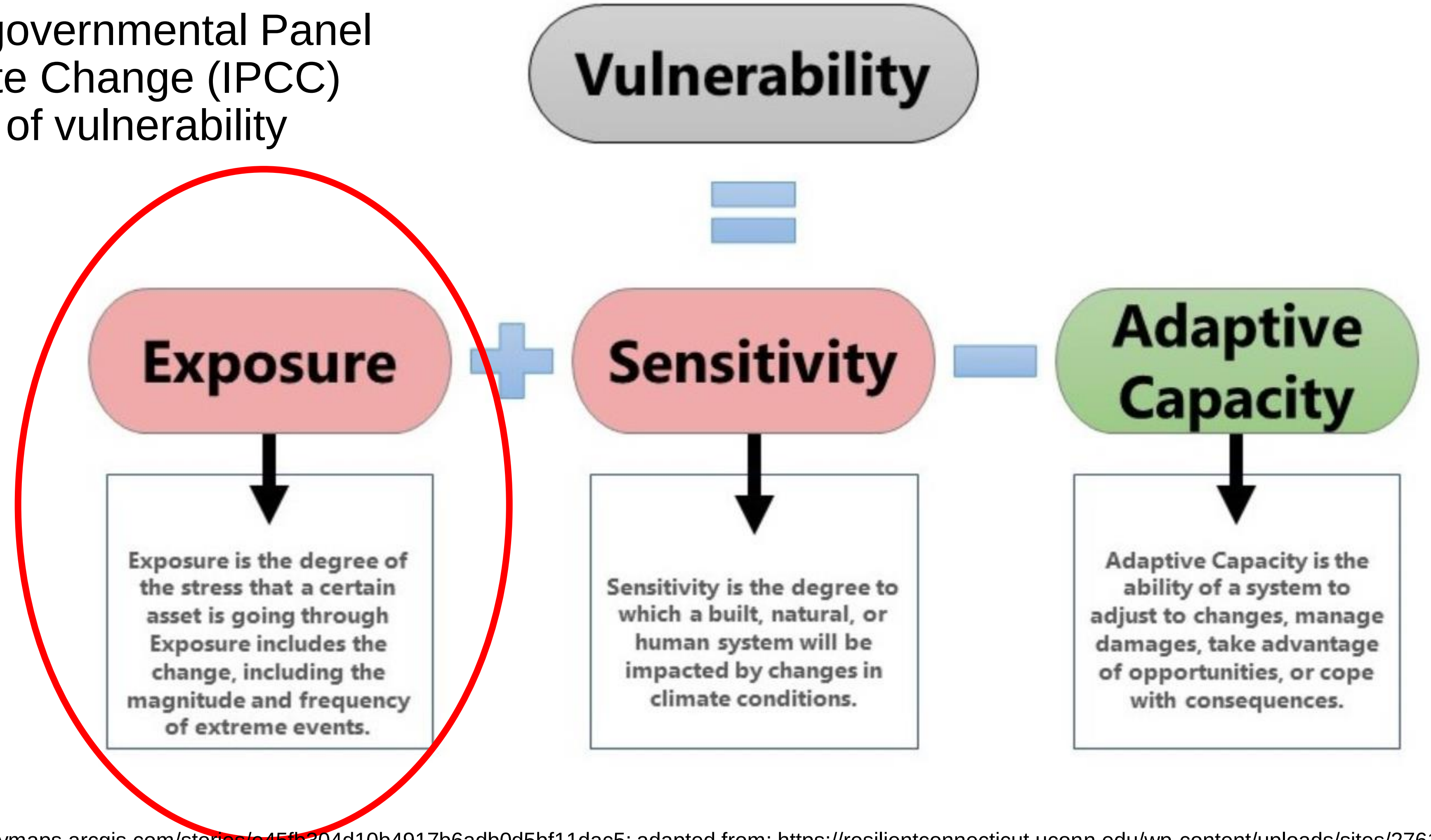
Assessing Infrastructure Vulnerability

The Importance of Place-Based Information & Data

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



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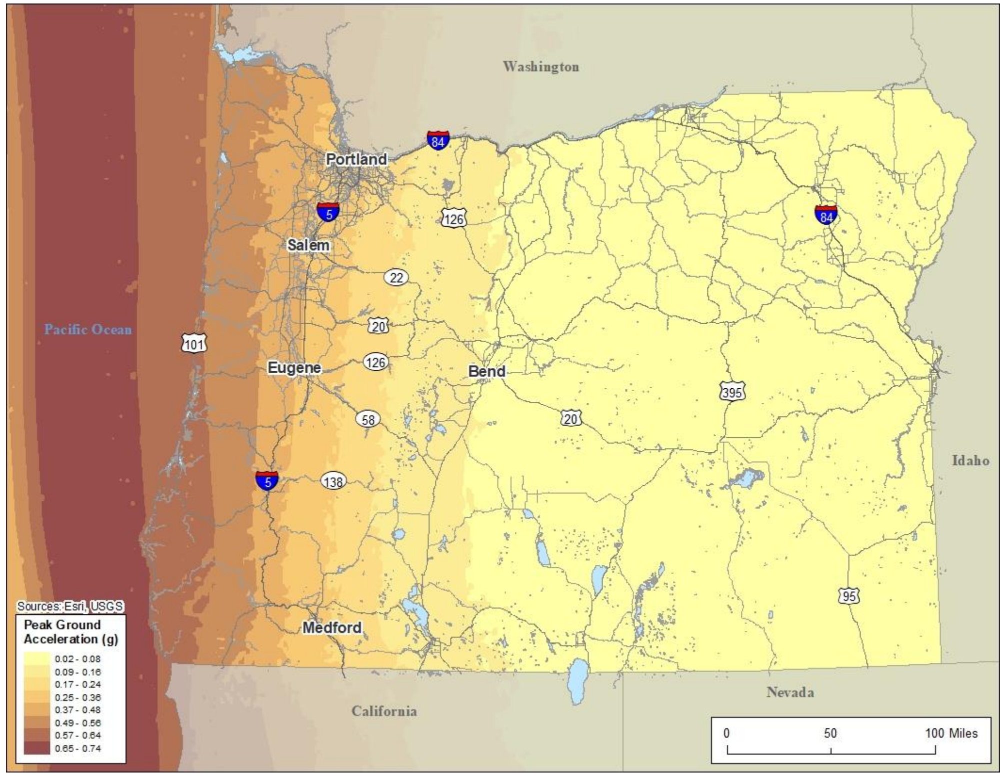
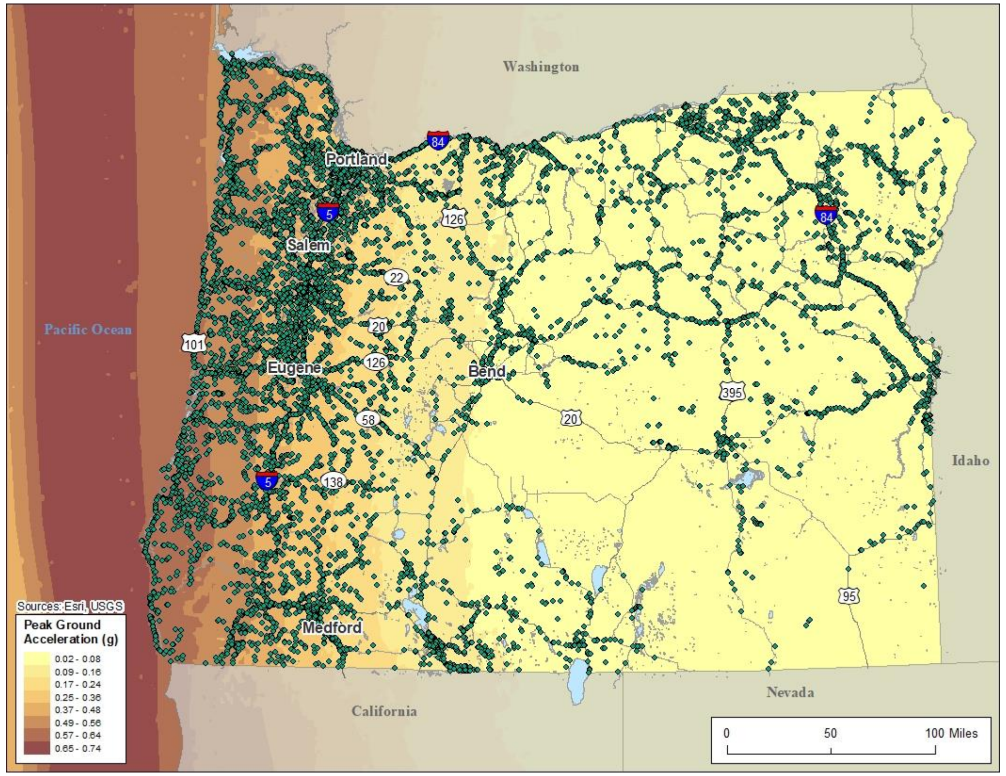
Assessing Infrastructure Vulnerability

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

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Assessing Infrastructure Vulnerability

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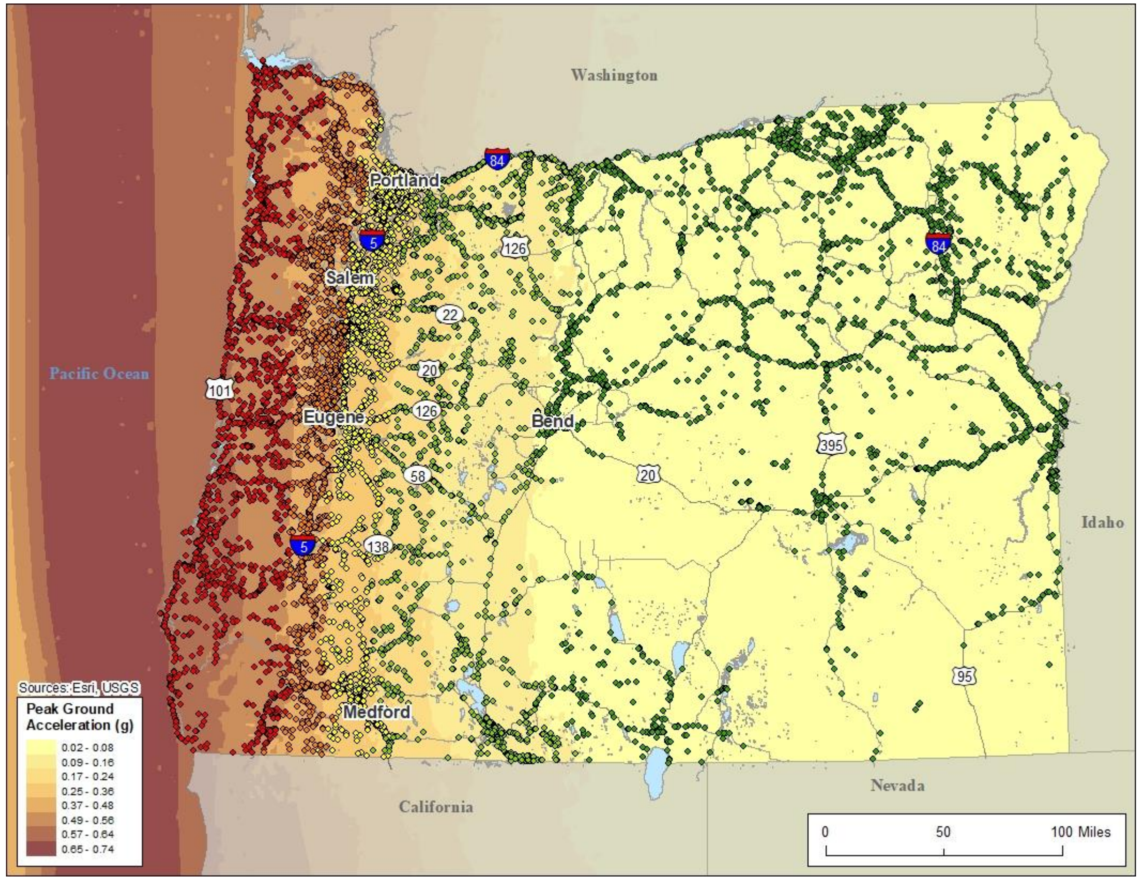

- Recall: Per ISO31000:2018, *risk analysis* concerns modeling, quantifying, or measuring level of risk

Images: Argonne National Laboratory

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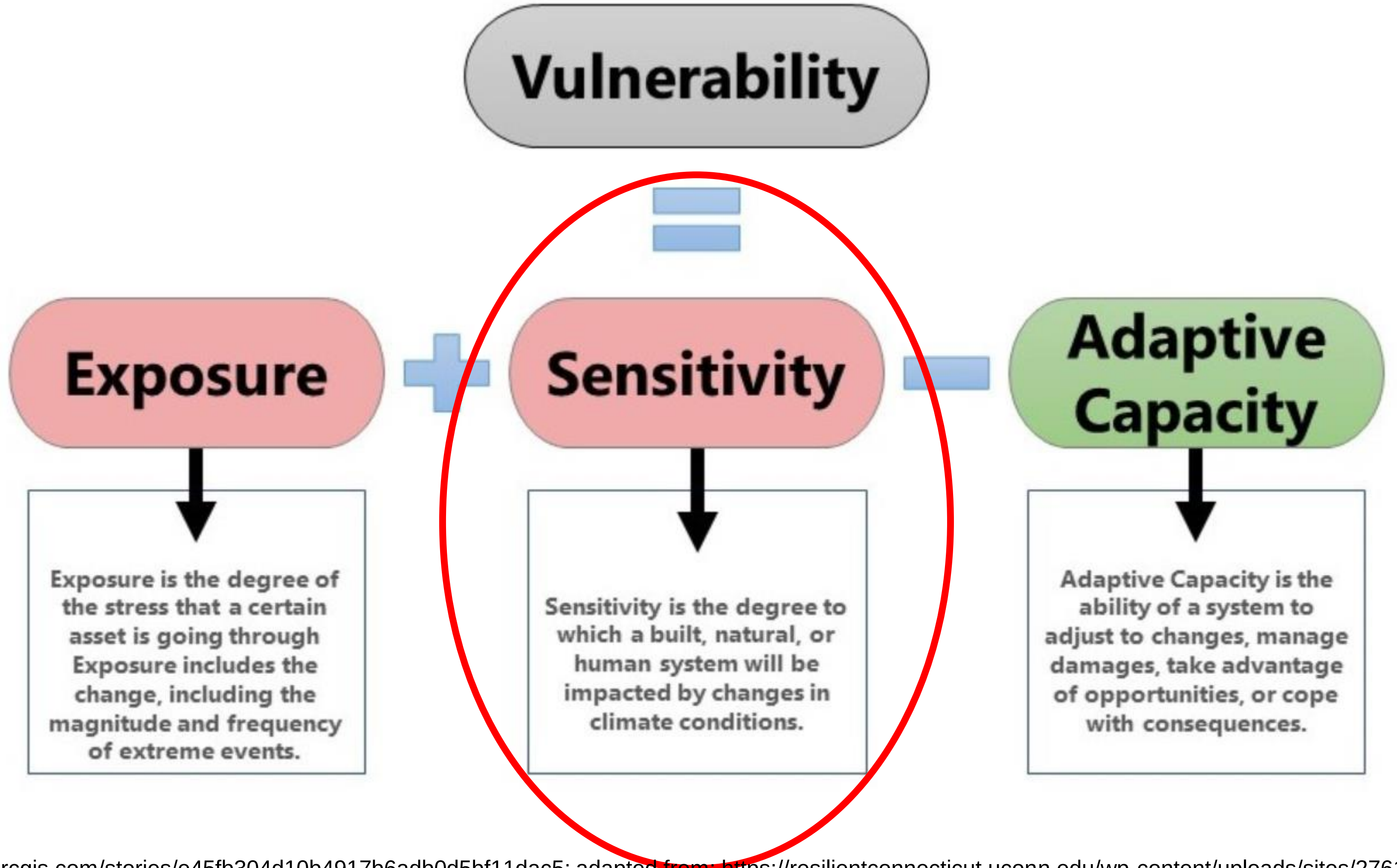
Assessing Infrastructure Vulnerability

Infrastructure Sensitivity Information



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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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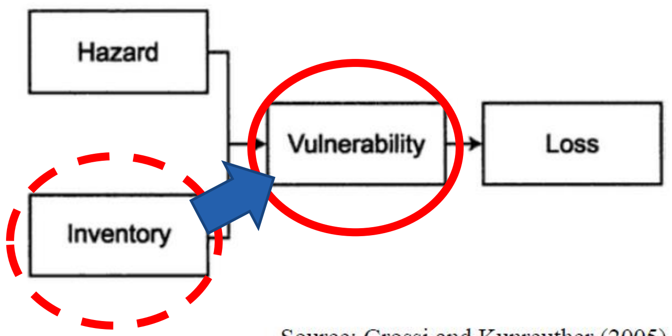
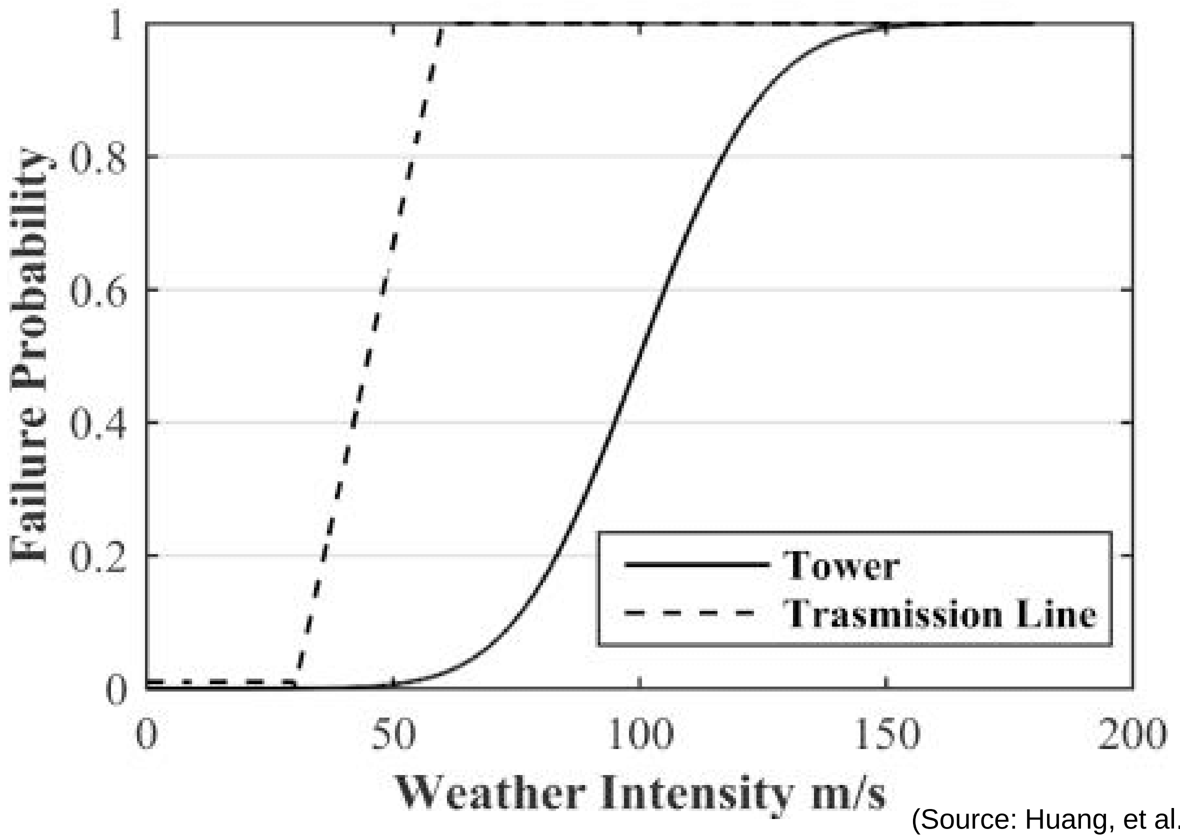
Assessing Infrastructure Vulnerability

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)

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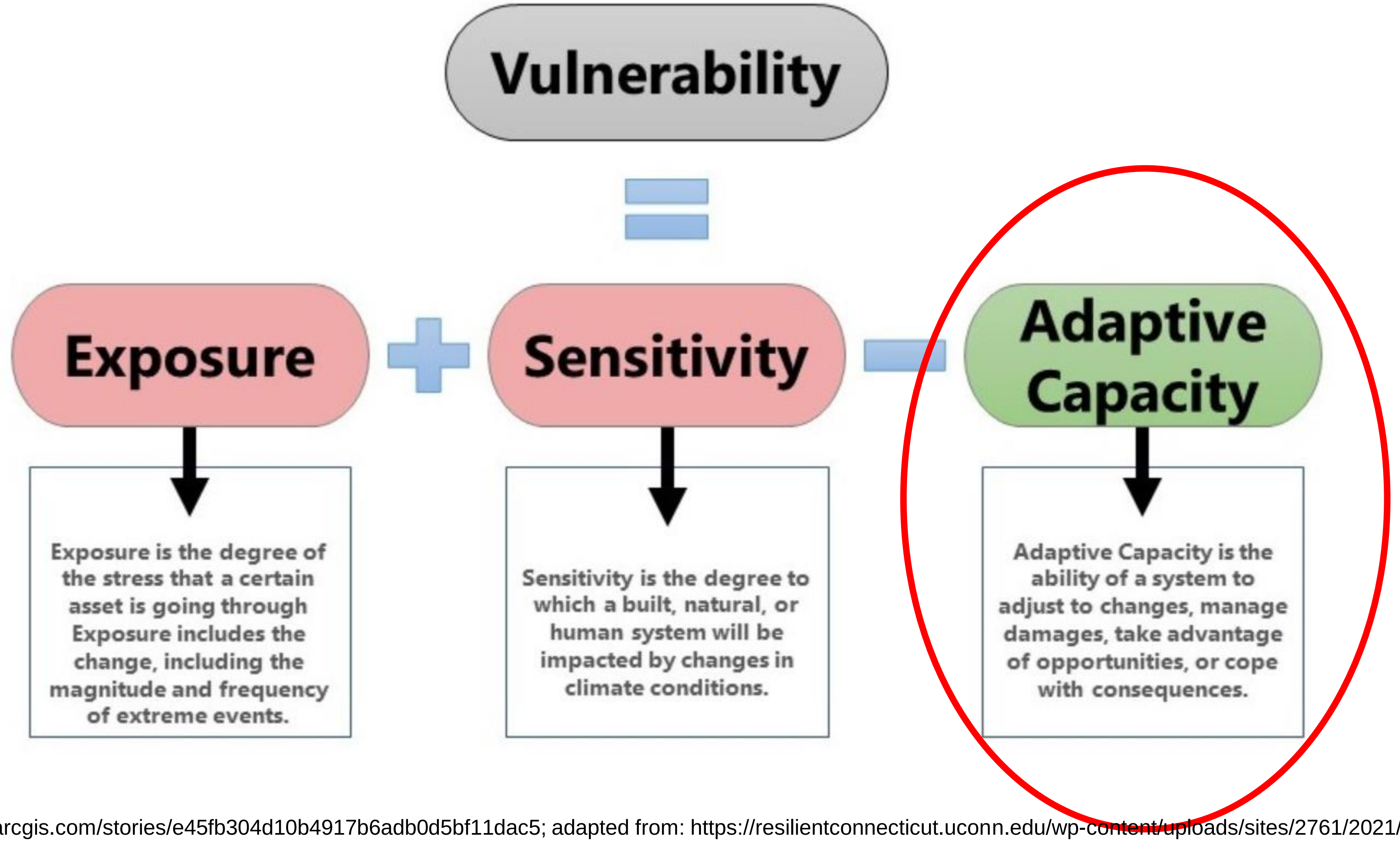
Assessing Infrastructure Vulnerability

Infrastructure Adaptive Capacity



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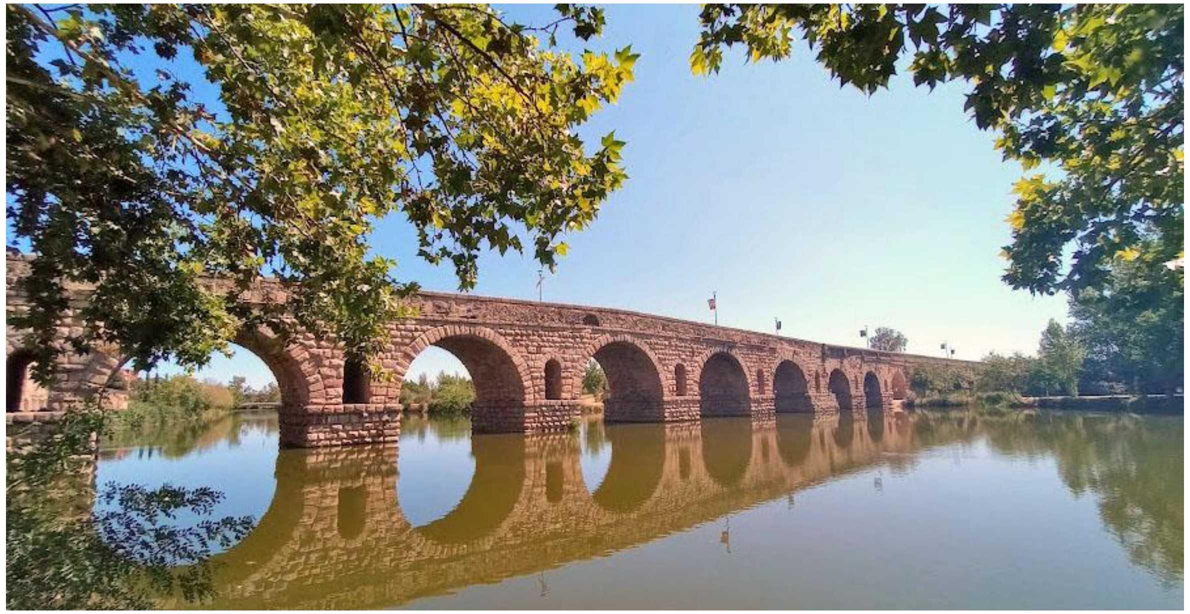
Assessing Infrastructure Vulnerability

Infrastructure Adaptive Capacity

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

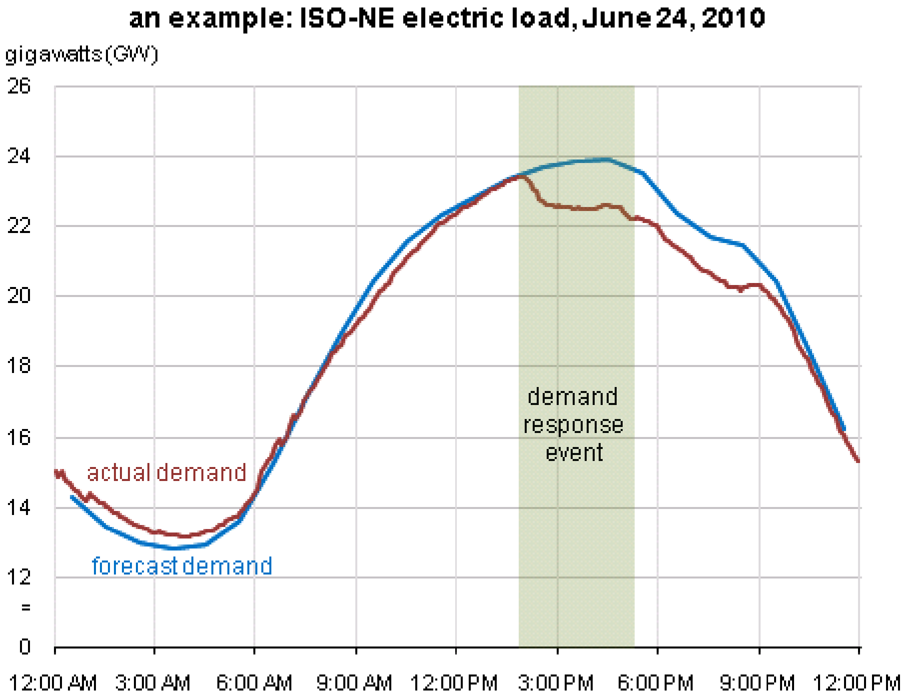


Images: https://en.wikipedia.org/wiki/Ponte_Milvio; https://en.wikipedia.org/wiki/Puente_Romano

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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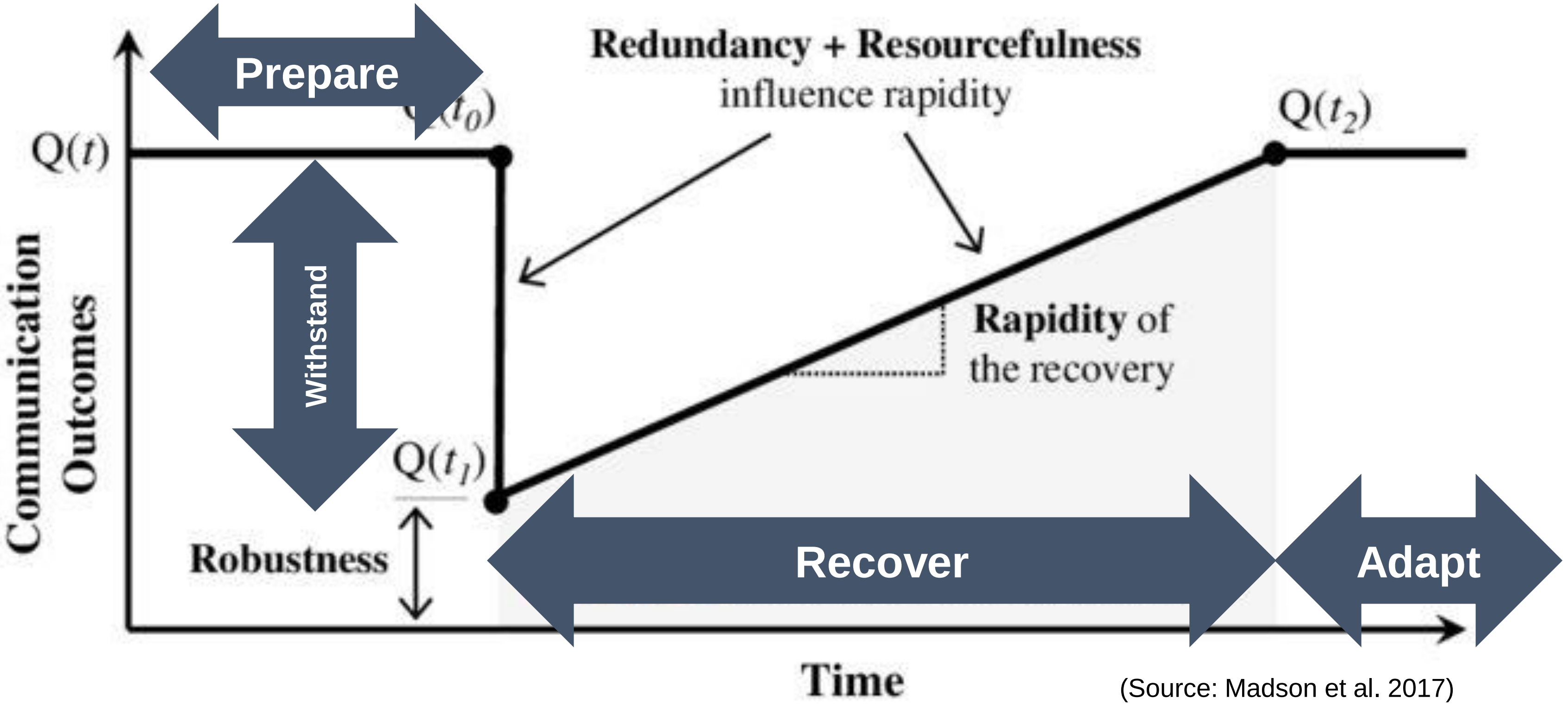
Assessing Infrastructure Vulnerability

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

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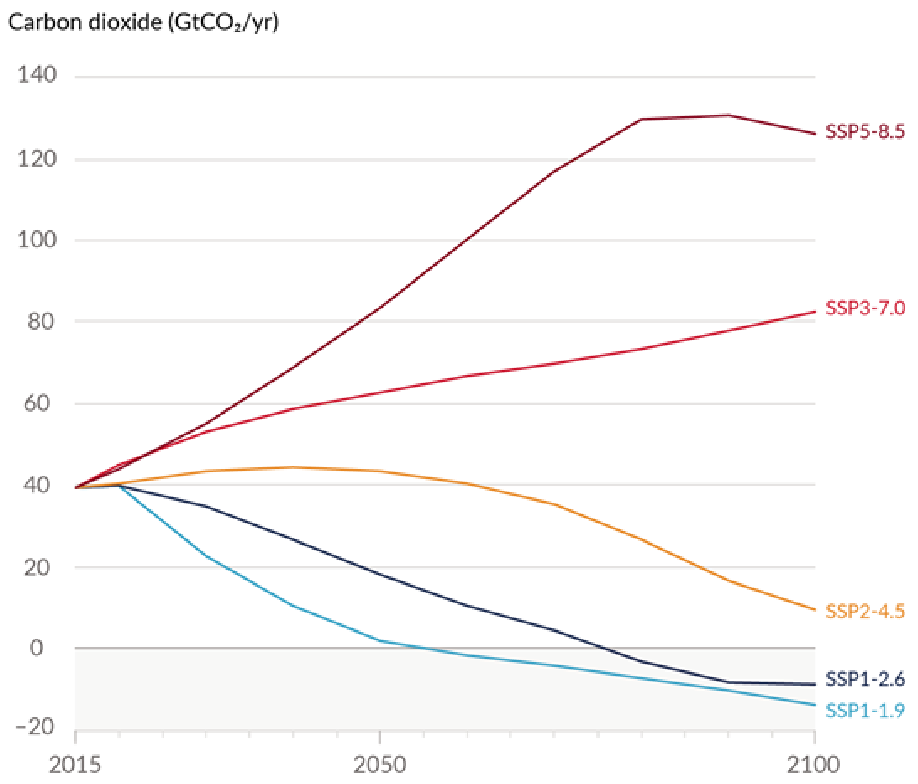
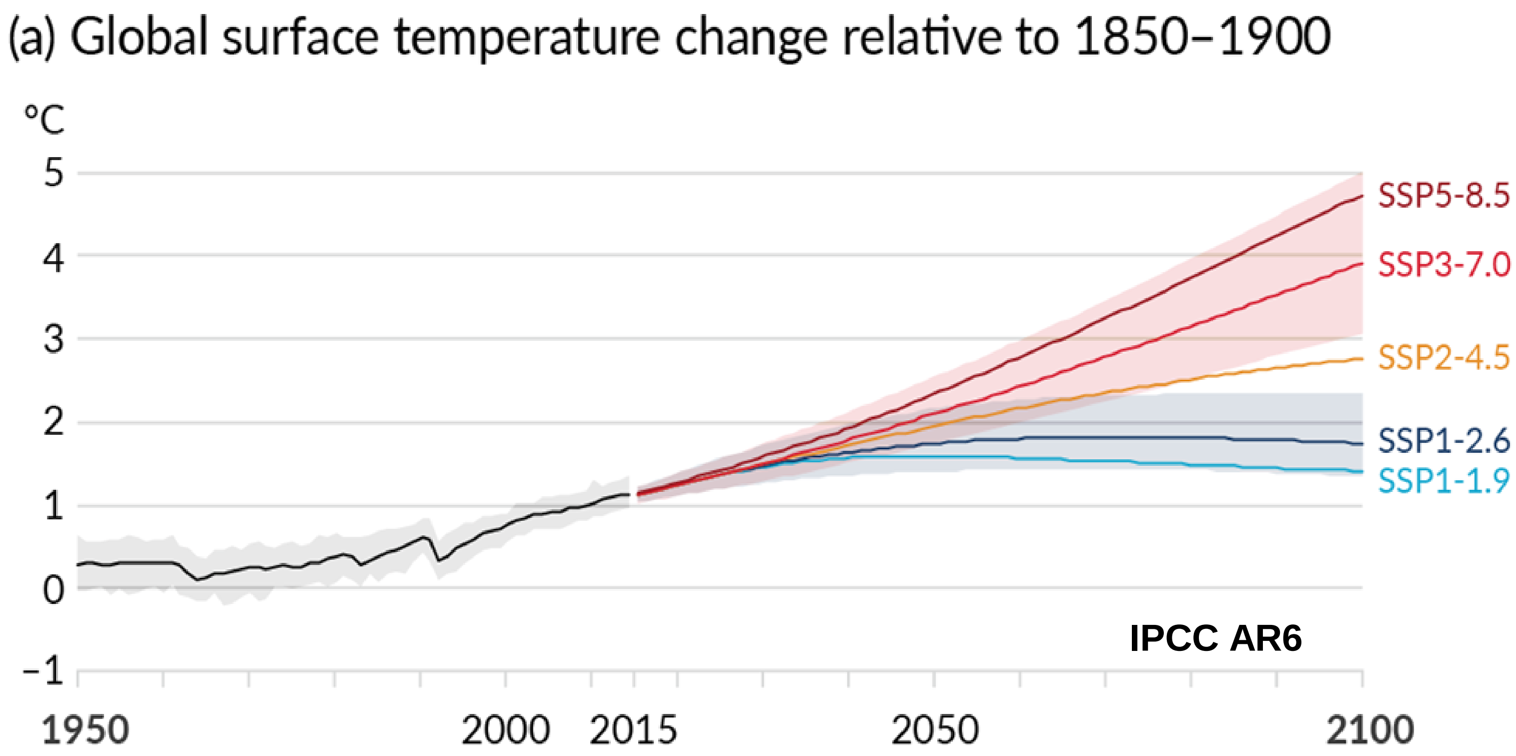
Climate Science & Modeling 101

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



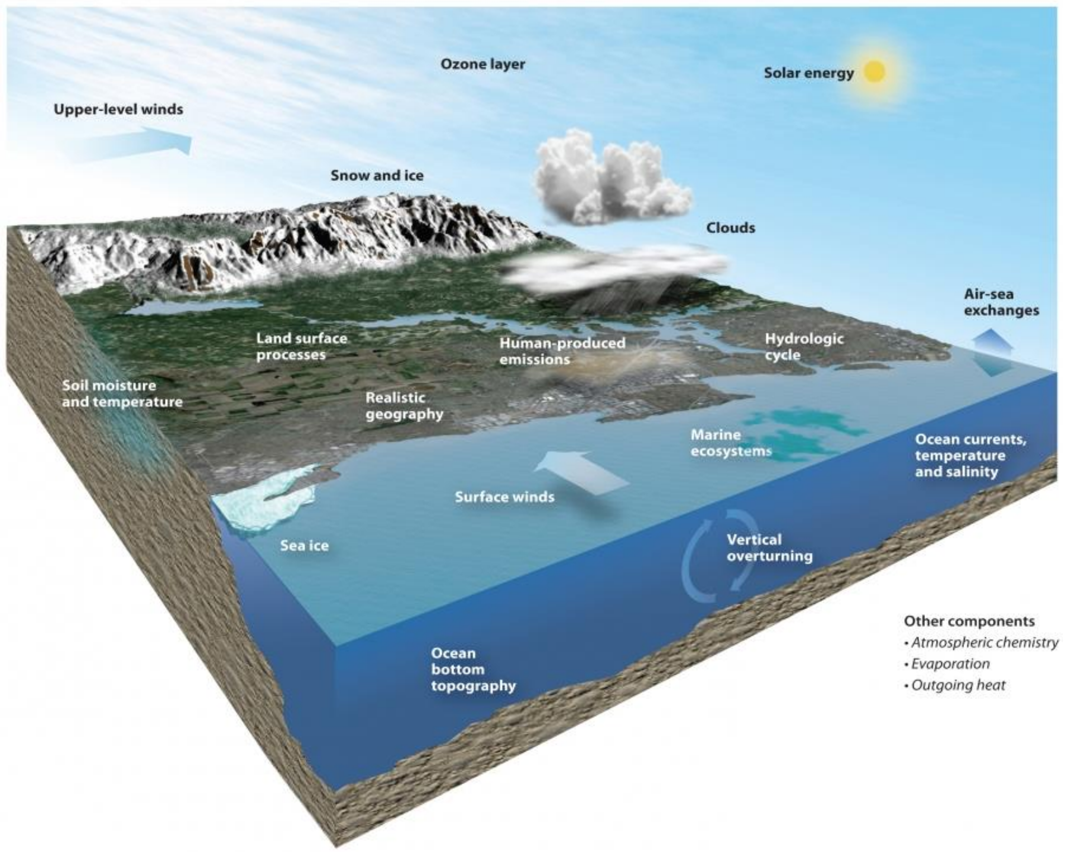


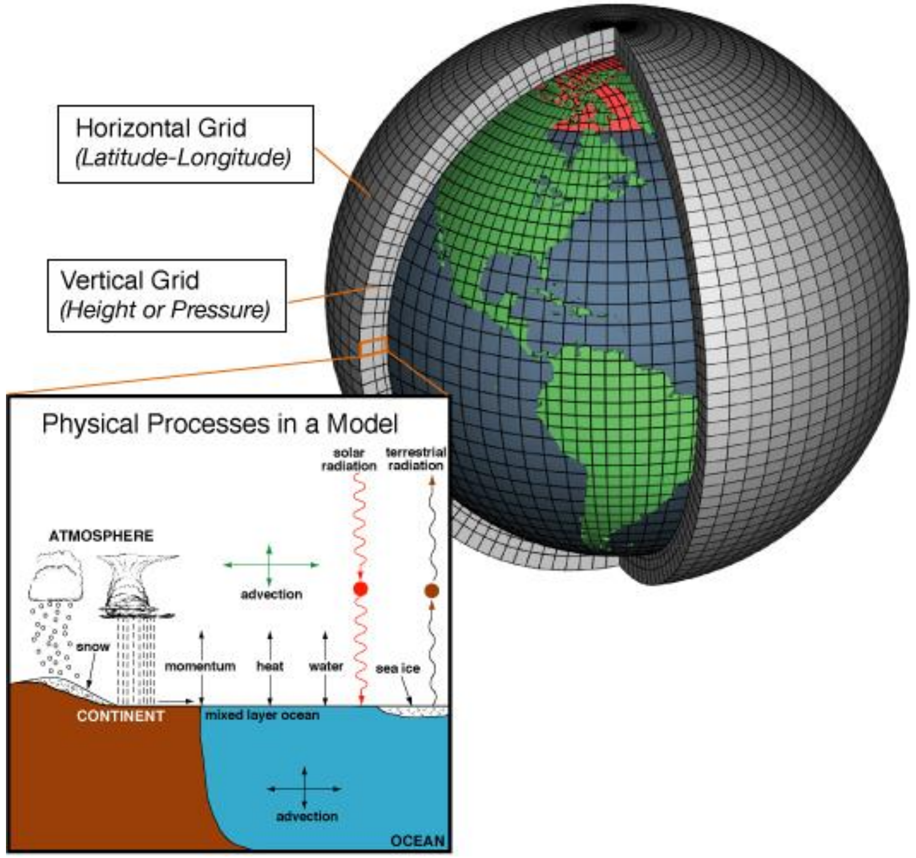
Images: https://www.ipcc.ch/report/ar6/wg1/figures/summary-for-policymakers

Climate Science & Modeling 101

Global Climate Models

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



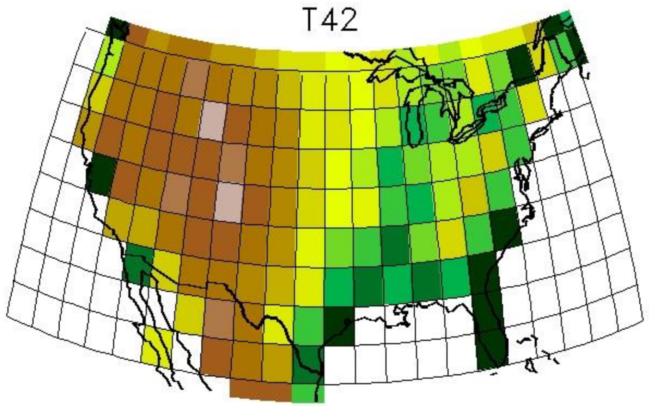


Images: https://scied.ucar.edu/image/community-earth-system-model; https://www.climate.gov/maps-data/climate-data-primer/predicting-climate/climate-models

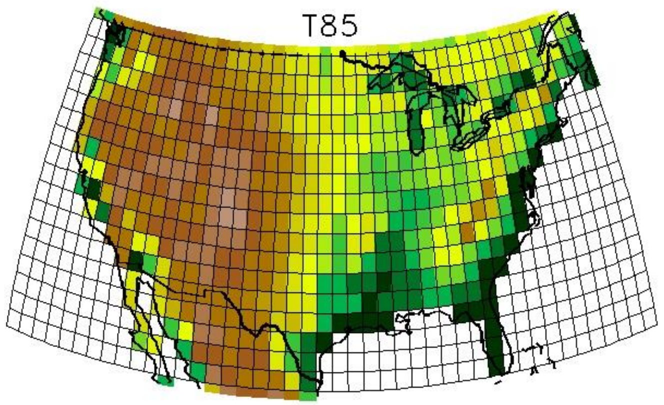
Climate Science & Modeling 101

Global Climate Models

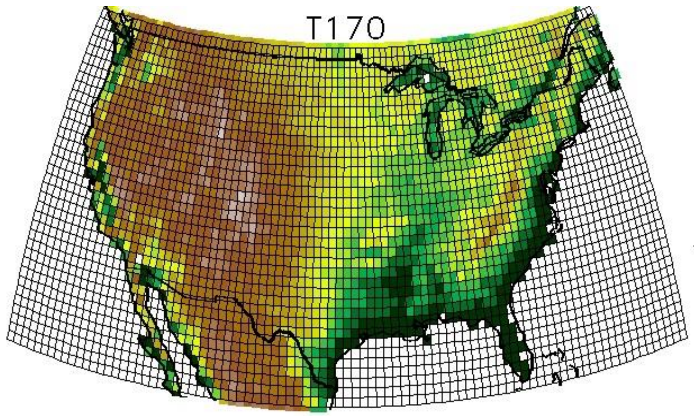
- As computing resources have improved over time, models have become increasingly complex and more detailed
- Smaller grid squares or “pixel sizes” enable more place-specific and detailed projections of locally relevant climate



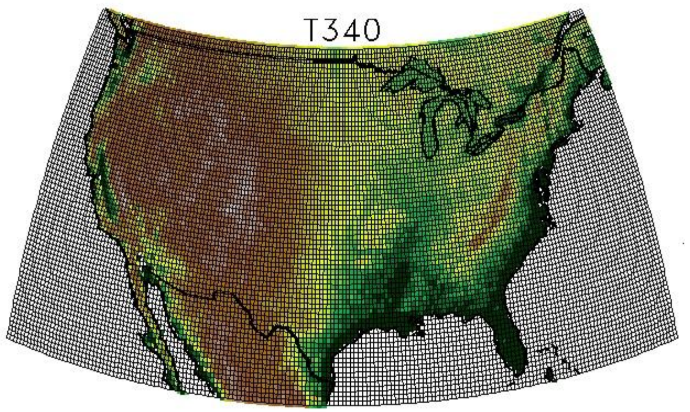
Mid-1990s 200~300 kms



2000s 100~150 kms



Current 50~100 kms



Future. 25~40 kms

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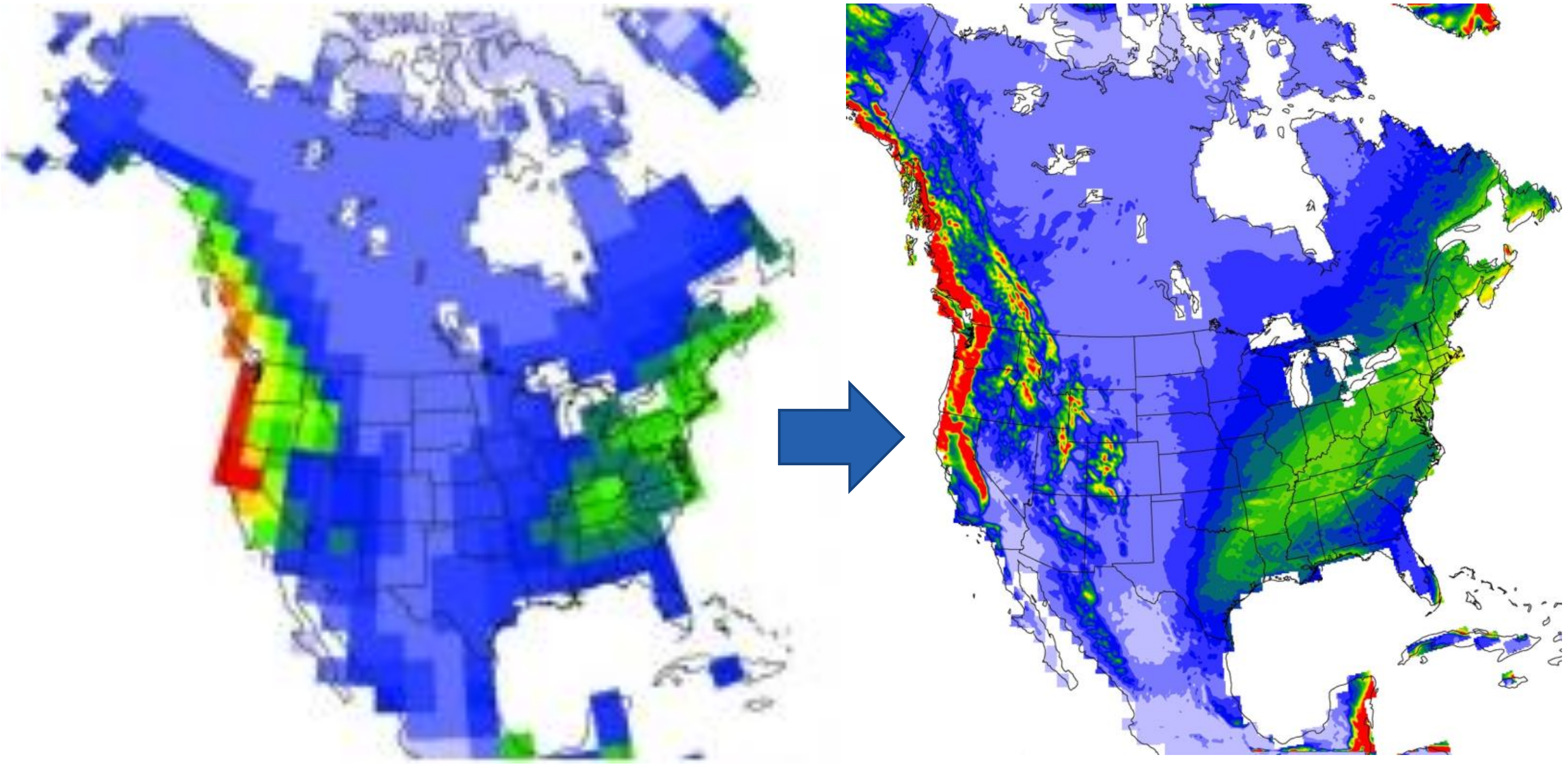
Image: https://eo.ucar.edu/staff/rrussell/climate/modeling/climate_model_resolution.html

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.

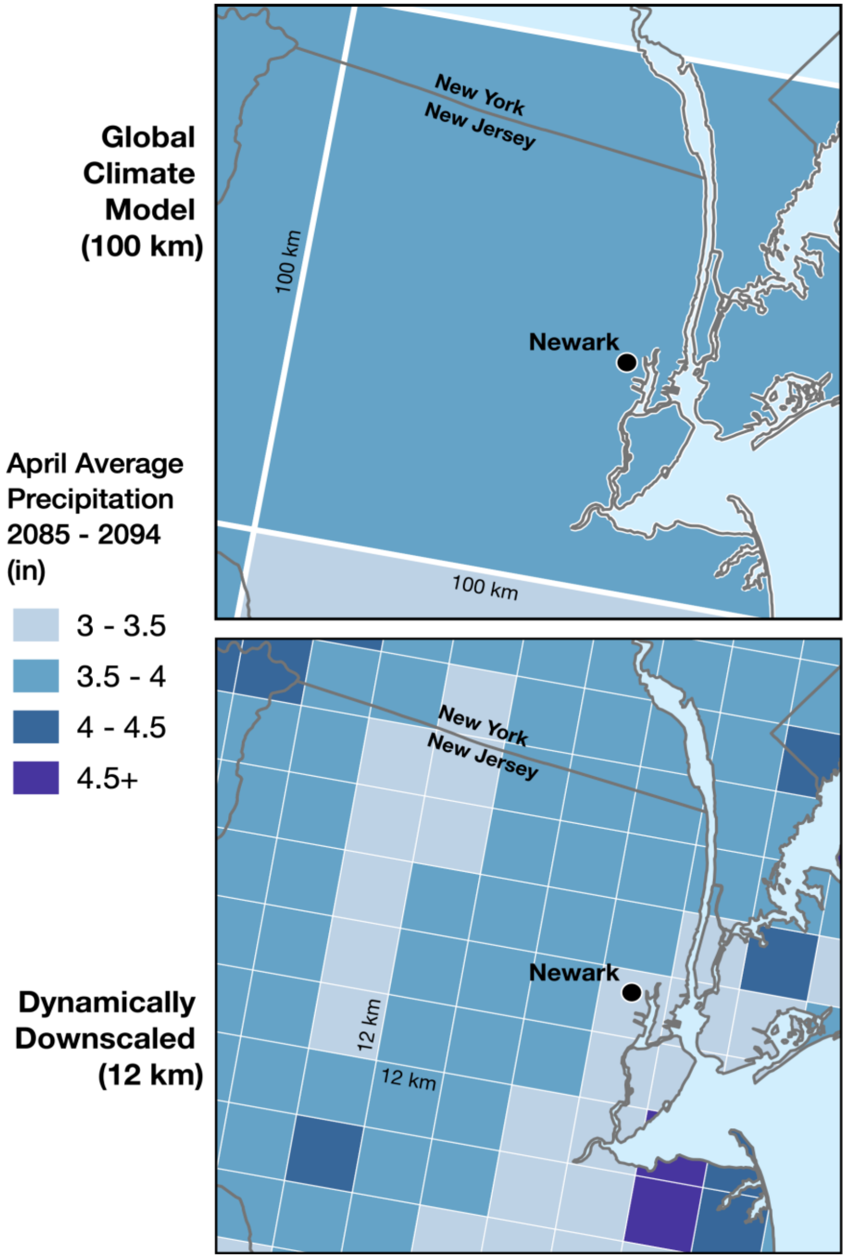


Source: Copernicus.EU, Undated
Images: Argonne National Laboratory

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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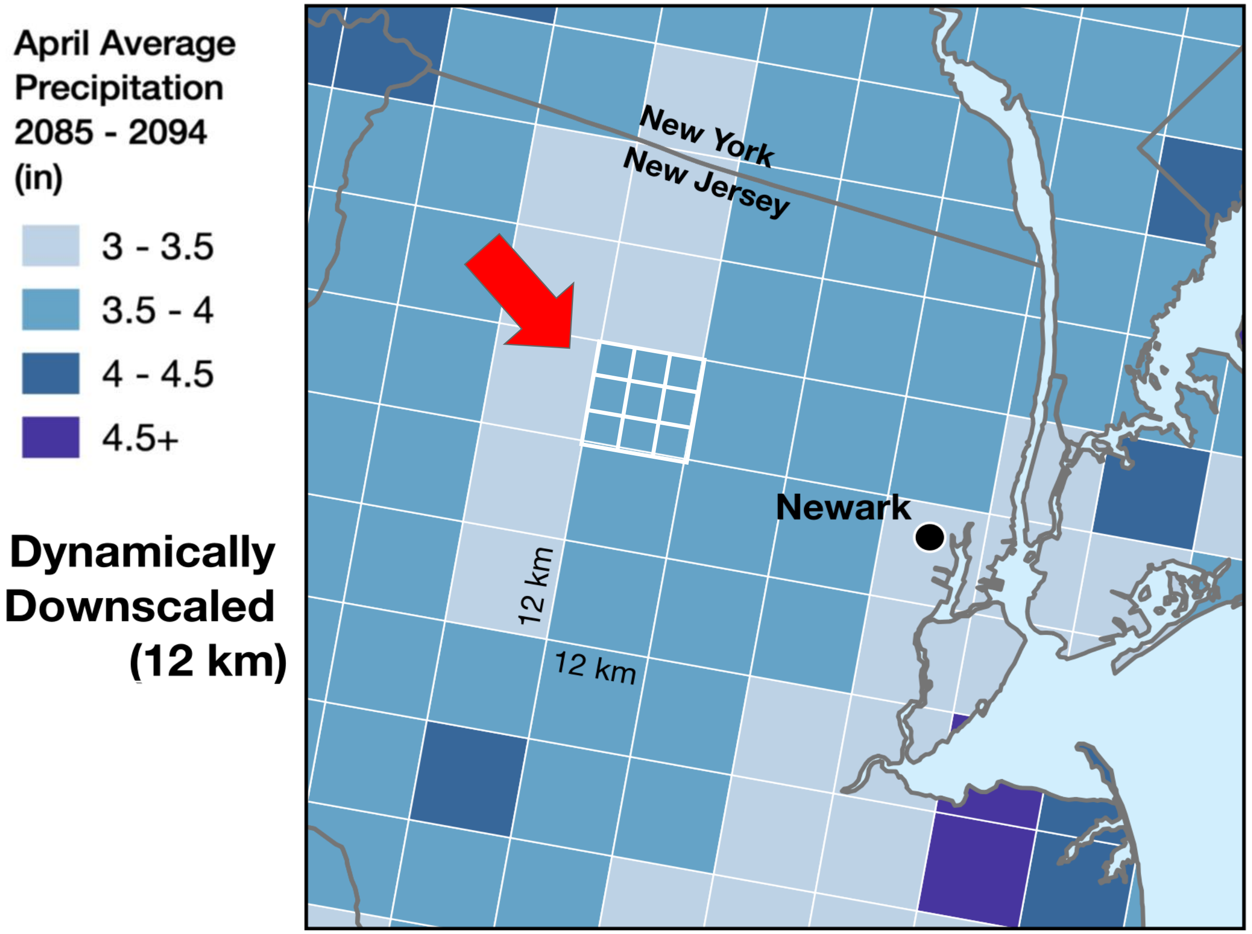
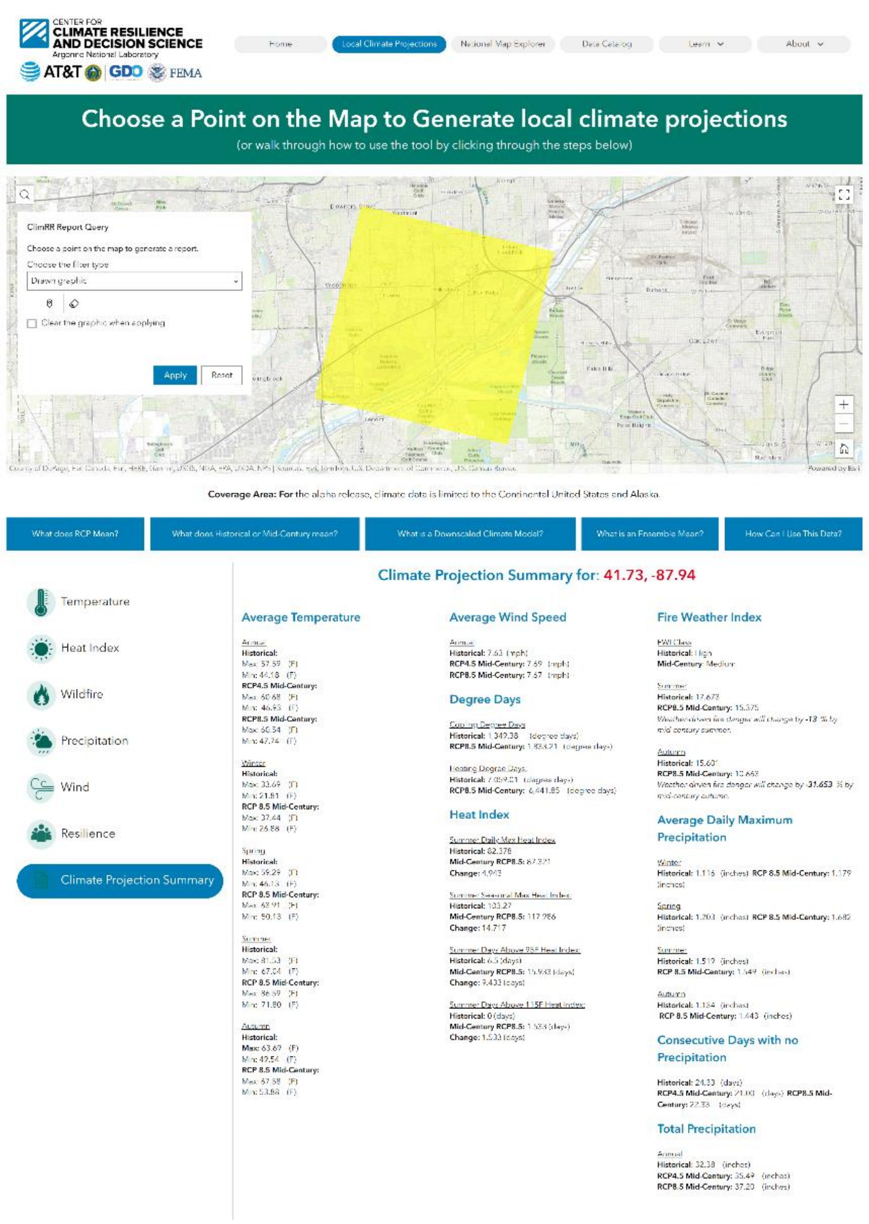
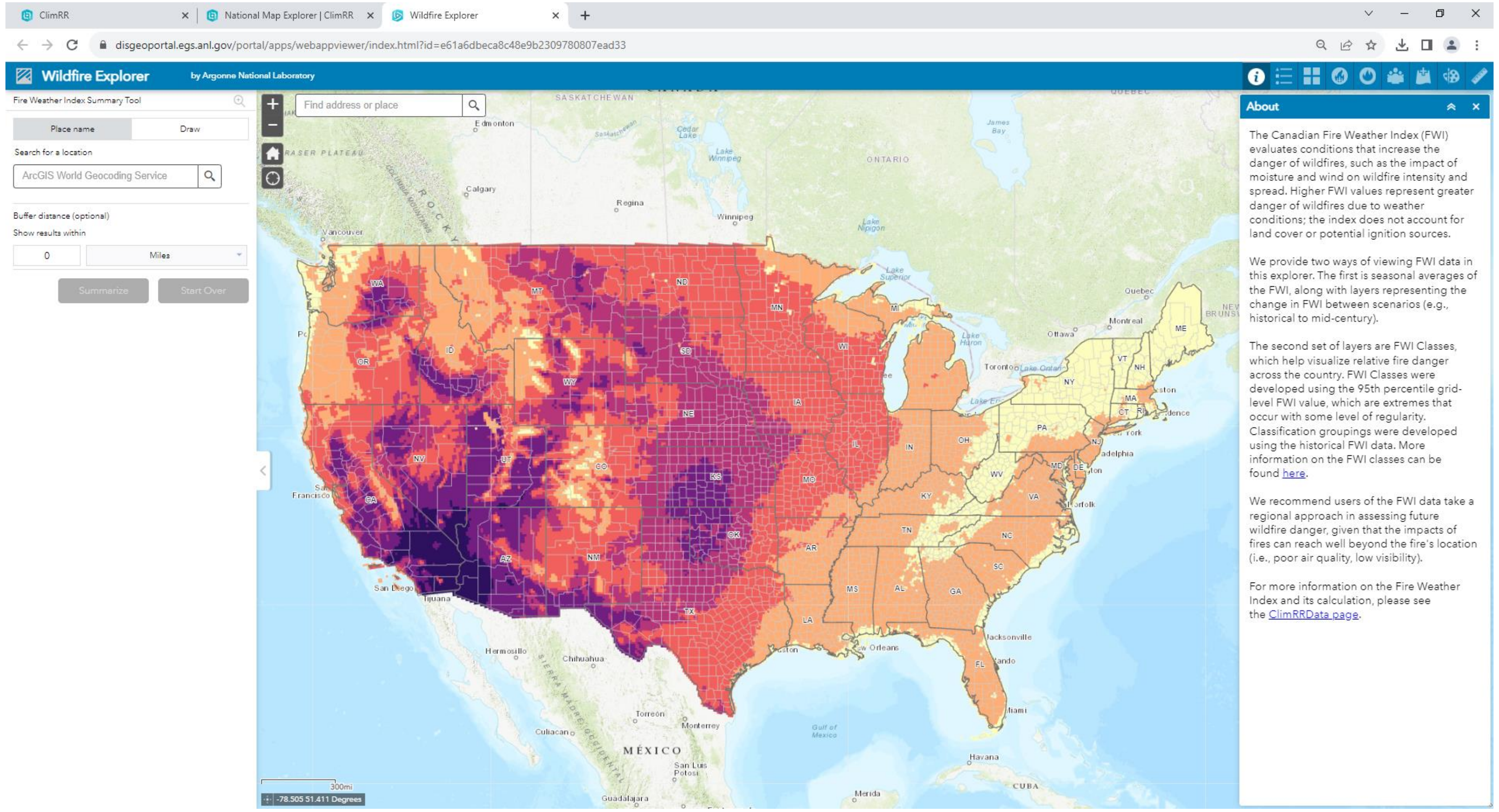


Images: Argonne National Laboratory

Climate Impact Data Resources

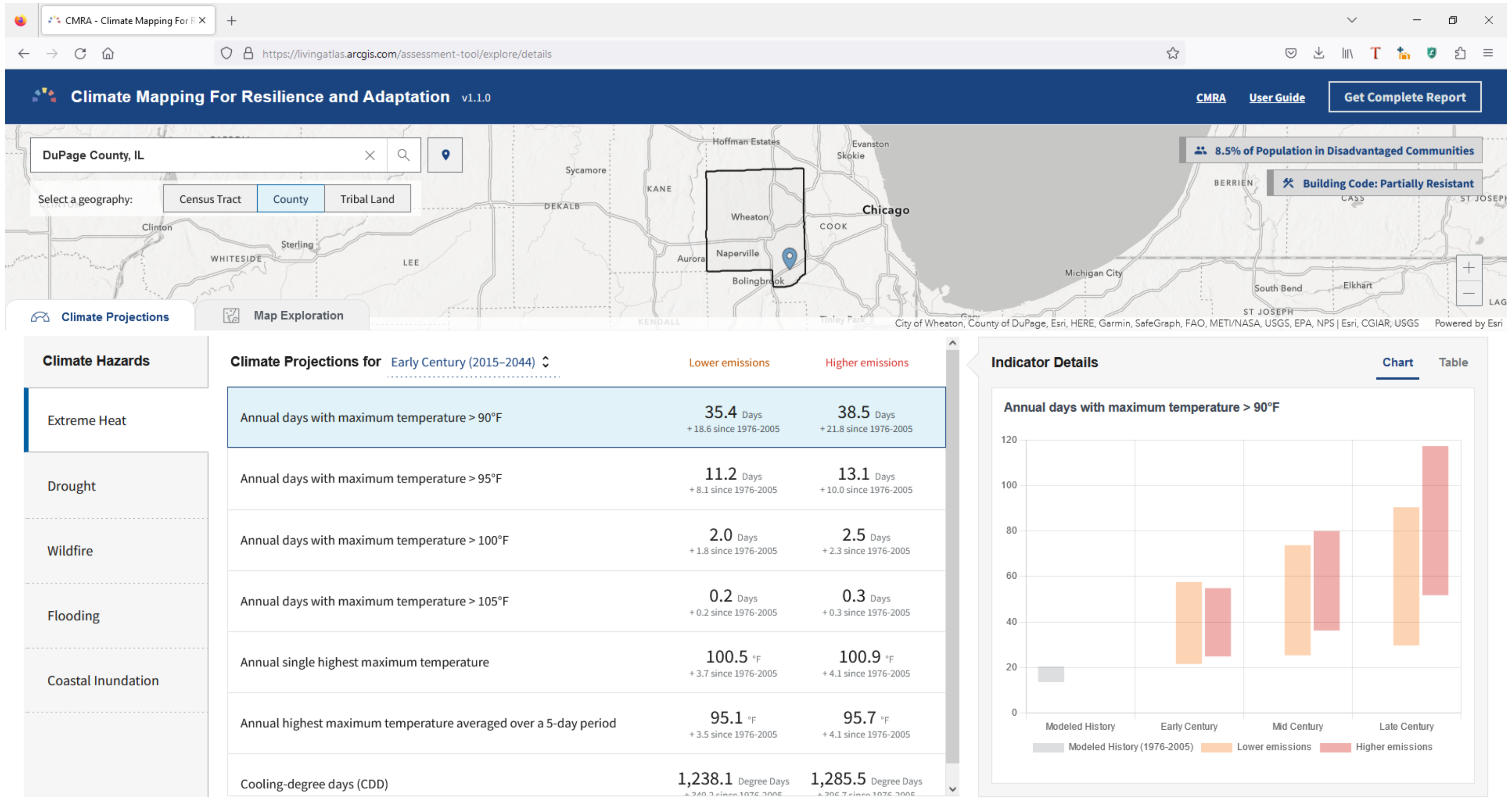
- Climate Risk and Resilience Portal (ClimRR) – Argonne National Laboratory, Federal Emergency Management Agency, DOE Grid Deployment Office, AT&T
- https://climrr.anl.gov





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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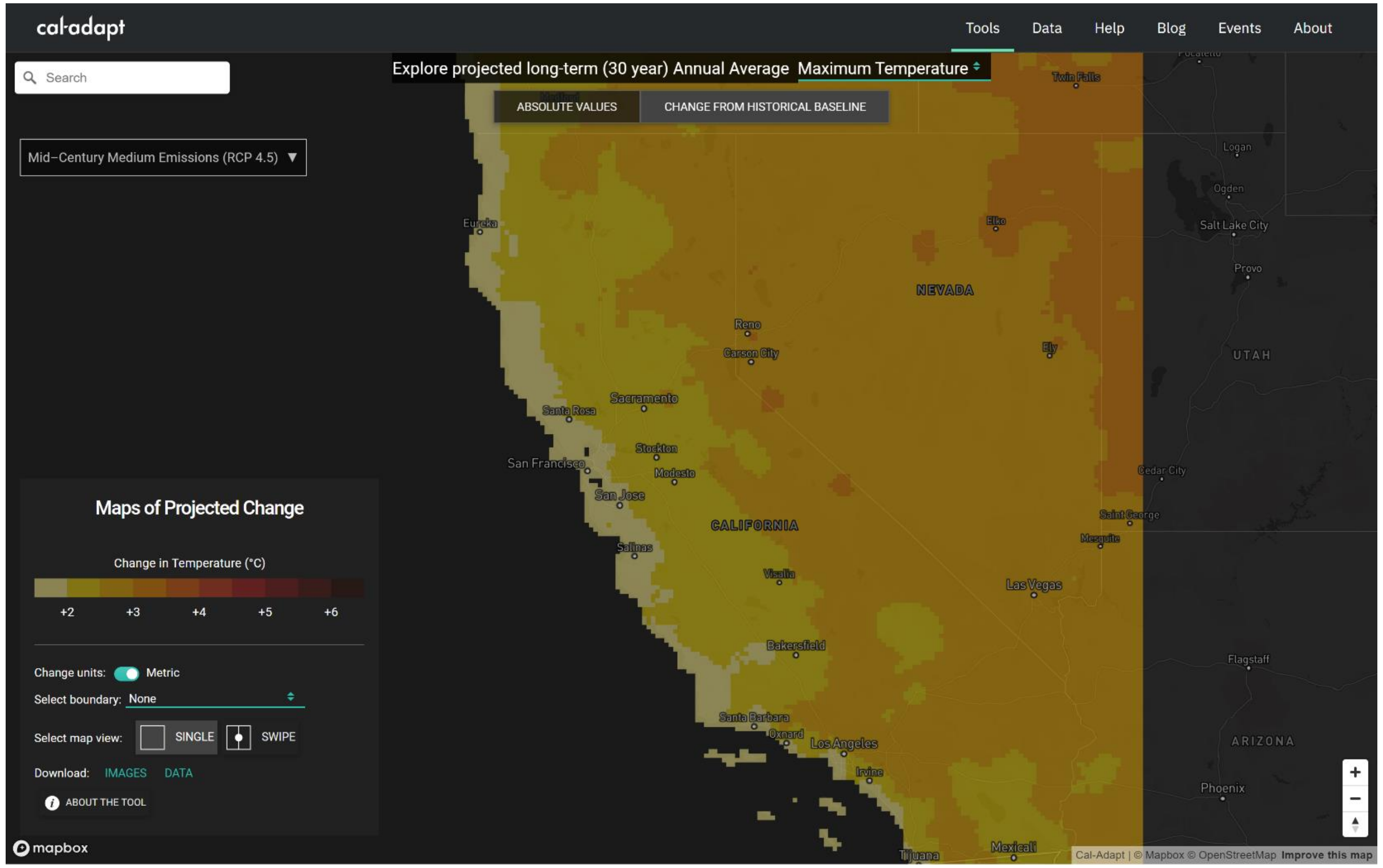
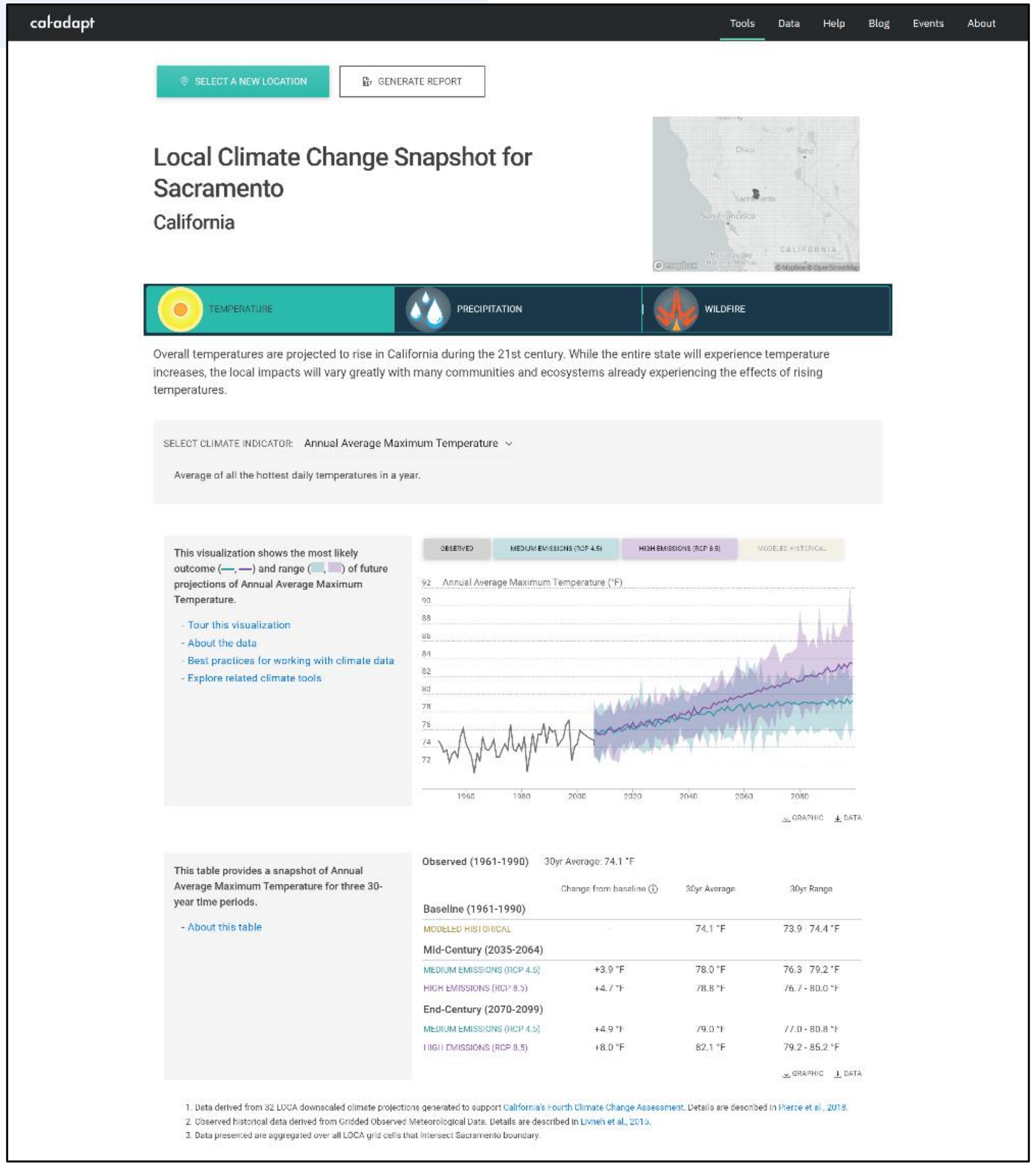
Climate Impact Data Resources

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





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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 will 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

GDO
GRID DEPLOYMENT OFFICE

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Contact

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

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

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Southern California Edison's Climate Adaptation Vulnerability Assessment (CAVA)

January 25, 2024

Grid Resilience Planning Training for NARUC and NASEO

Stephen Torres, Principal Manager – Climate Adaptation and Resilience Planning

Climate Adaptation – Regulatory Framework for CA's IOUs

Vulnerability Assessment

- IOUs must identify actual or expected climatic impacts to **assets, operations, services, and communities**
- Climate scenarios to assess vulnerability must adhere to projections from the most recent **California Statewide Climate Change Assessment**, specifically the "business as usual" **RCP 8.5 projections**
- Climate variables in scope: **Temperature, Sea-level Rise, Wildfire, Precipitation** & Cascading Impacts
- Primarily assess mitigation needs for **20-30 years in the future, as well as 10-20 and 30-50 years out**
- Frequency: Every four years, with first one due April 22 of 2022

Disadvantaged and Vulnerable Communities (DVCs)

- IOUs required to identify and collaborate with DVCs around climate adaptation
- Must file and implement a **Community Engagement Plan (CEP)** informed by community input
- Consult DVCs during the Vulnerability Assessment (VA) process to **ensure equity in adaptive capacity**

SCE's Climate Adaptation and Resilience Planning Scope

Climate Adaptation and Resilience Planning

Understand risks and opportunities associated with climate change across the enterprise, utilize CPUC filing as a foundational risk management tool, and incorporate results into strategic initiatives and processes

Initial 18 months

CPUC Decision: Defines Vulnerability Assessment and Community Engagement Filing Requirements and Timeline (May 2021 and 2022)

Vulnerability Assessment

Identifies asset groupings at risk, quantifies consequences and prioritizes risks to be mitigated

Community Engagement

Identifies Disadvantaged and Vulnerable Communities (DVC) and executes engagement plan to address impacts to DVCs

Capabilities

Builds climate adaptation organization, processes and technologies to support corporate climate strategy

RAMP and ERM

Provides framework and standards to evaluate risk and opportunities, and to quantify and prioritize mitigation options

RTG and Strategic Initiatives

Incorporates climate projections into next iteration of Pathway 2045 and RTG. New RTG architectures inform future adaptive capacity.

Long Term Planning

Incorporates climate projections into load forecasting, resource and grid planning

Dynamic Mitigation

Develop signposts, mitigation options, and inform asset mgmt. strategy

Sustainability Reporting

Disclose climate risks, mitigations and opportunities to shape industry practices

EIX / SCE Climate Strategy
Centered on Climate Mitigation, Adaptation, and Resilience

The Vulnerability Assessment work was foundational for identifying major risks and developing internal capacity to inform future efforts

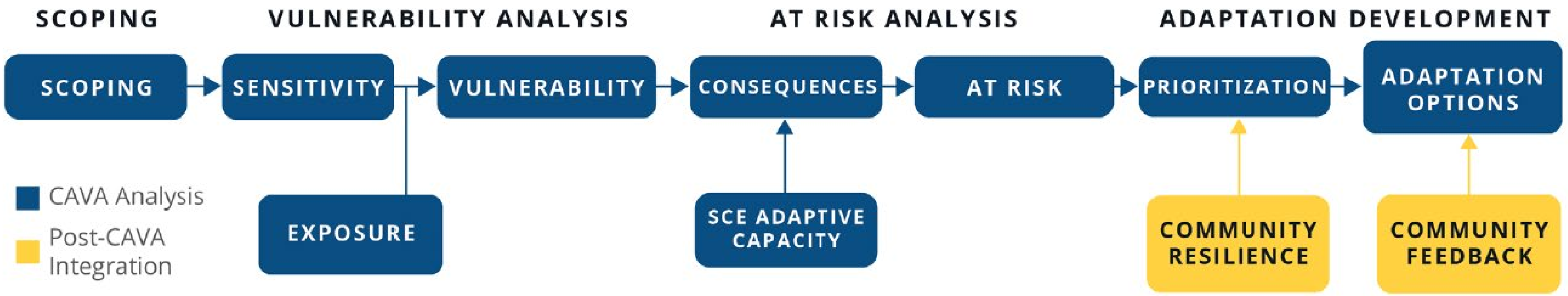
SCE’s Climate Adaptation Vulnerability Assessment (CAVA)

IPCC 5th Report (2014)
Climate scenarios based on a set of Global Climate Models (GCMs)

California’s 4th Climate Change Assessment (2018)
Regionally-specific set of GCMs and defined climate scenarios

CPUC's Climate Adaptation Rulemaking (2020)
Requires IOU’s to submit a CAVA one year before GRC filing

SCE’s CAVA (2022)
Vulnerability and consequence assessment of climate change impacts* on SCE’s assets, operations, and services



SCE’s General Rate Case (2025-2028)

Climate-informed planning (2022-)

*Temperature, sea level rise, precipitation and flooding, wildfire, and cascading events

CAVA 2050 exposure results and findings

Adapting for Tomorrow: Powering a Resilient Future

Key Findings Demand Urgent Action:

- The cost to invest in climate adaptation now is far less than the cost of inaction — both for the economy and public health and safety.
- As society decarbonizes in a changing climate, we need modernized planning for the grid to power communities in an uncertain future.
- Given the interdependencies of critical infrastructure, it takes all of us working together to confront the climate crisis.

AVERAGE TEMPERATURE **5°F** projected* increase relative to historical averages	- Existing infrastructure will become less efficient, resulting in reduced line capacity and higher transformer losses - Useful life of assets will decrease
PRECIPITATION **40%** projected decline in snowpack and more variable year-to-year precipitation with more intense drought and fewer, more intense precipitation events	- Infrastructure will need to be designed to withstand more intense storm surges and flooding - Hydroelectric generation could become less reliable if current drought continues or in the event of future prolonged droughts
SEA LEVEL RISE **2.6 feet** projected sea level rise relative to the year 2000	- Infrastructure and communities in some coastal areas will be at higher risk of flooding
EXTREME HEAT **7X** more likely, on average, to experience temperatures as hot as or hotter than historical 99th pctl. temp	- Worker safety standards will need to account for heat - Peak load could increase significantly - Equipment will not cool overnight during intense heat waves, reducing capacity and useful life of some equipment
WILDFIRE **23%** more land projected to burn in summer fuel-driven wildfires; wildfire season expected to be longer	- Conditions more conducive to wildfire ignition and spread - Impacted service centers may not be able to operate or perform key functions during wildfires

*All projections assume an RCP 8.5 scenario
https://www.edison.com/home/our-perspective/adapting-for-tomorrow.html

Southern California Edison's Path to Climate Adaptation Investments

SCE's Climate Adaptation Vulnerability Assessment (CAVA)

Filed May 13, 2022

California's first CAVA

- Required by CPUC Decision 20-08-046.
- Envisioned by CPUC as an intermediate step to identify the risks of climate change and adaptation options.
- CPUC directed IOUs to seek approval of specific projects for climate adaptation in their General Rate Case (GRC) or other proceedings.

SCE's 2025-2028 General Rate Case (GRC)

Filed May 12, 2023

California's first GRC that includes climate adaptation requests

- Incorporates prioritized adaptations for risks identified in the previous CAVA filing across Generation, Transmission, and Distribution, as well as enabling initiatives across the enterprise to deepen its understanding of future physical climate risks.
- Proposed climate adaptation investments include >$100M of capital investments across Generation and T&D, as well as O&M investments across the enterprise to support future climate adaptation assessments.

Translating CAVA Findings into GRC Investment Requests

CAVA Results

- At Risk Assets (2030)
- At Risk Assets (2050)
- At Risk Assets (2070)

GRC Development

Aligned with GRC time frame (2025-28)

Least Regrets investments

- Address both 2030 and 2050 exposure risks
- Increase reliability and/or resilience

Integrated into existing programs

- Climate adaptation scope “fits” within existing O&M, replacement and/or new construction programs
- Increase resilience

Feasibility of Implementation

- Additional adaptation investments can be completed with projected resources
- Utilizes existing technologies or identifies feasible alternate technologies

Overview of proposed adaptations

Climate Variable	At Risk Assets	Adaptation Investments
Transmission and Sub-transmission		
Wildfire	Wood poles, sub-transmission conductors	Pole brushing for wood poles to reduce damage risk to poles and conductors
Distribution		
Wildfire	Distribution lines	Install new wires solutions (circuit tie lines) for increased operational flexibility
Flooding	Distribution lines	Install new wires solutions (circuit tie lines) for increased operational flexibility
	Pad-mounted equipment	Replace and/or upgrade with climate-resilient designs
Temperature	Substation transformers	Expand scope of substation transformer replacements in 2028, informed by climate change
	Distribution service transformers	Pilot program to proactively replace pad-mount transformers due to stress from extreme heat
Generation		
Wildfire	Hydro facility	Site specific vegetation studies leading to Generation, IT, and/or Distribution upgrades to increase wildfire resiliency
Flooding	Hydro facility	Stochastic Event Flood Modeling (SEFM) for all High Hazard dams to identify potential flooding risks
		Monitoring equipment installations informed by 2018 SEFM analysis results
Temperature	Natural gas peaker plant	Upgraded HVAC systems to reduce chance of forced outage during extreme heat events
Cascading events	Hydro facility	Debris Boom installations to protect against debris flow into dams

Next steps – Climate Informed Planning

Planning processes

- Climate-informed changes to:
  - Distribution System Planning
  - Transmission System Planning
  - Infrastructure Replacement
  - Other planning processes and programs
- New/upgraded systems and/or planning tools (to include climate variables and extend planning horizons)
- New IR programs for key distribution assets impacted by climate change

Design standards

- Reflect increased temperature impacts on loading and equipment sizing
  - Temperature-load relationship under revised 1-in-10 peak analysis
  - Equipment loading standards incorporate changing load factor estimates
- Reflect other climate variables in equipment designs
  - Fire, flood, debris flow resistance
- New equipment testing; new supplier classification

Climate Informed Planning Processes - Examples

- Integrated Resource Planning (IRP)
  - Future hourly temperature projections informing demand and supply sides of IRP planning
    - Demand
      - Incorporated temperature projections in HDDs and CDDs which impacted future heating/ cooling loads
    - Supply
      - Incorporated temperature projections in thermal, solar and battery storage outputs, reducing expected performance of these generation assets during high temperature hours

- System Reliability Analysis
  - Climate inform 20+ weather years being used in stochastic Loss of Load Expectation (LOLE) analyses with climate change "adder" to reflect earth warming conditions

- Substation Transformer Replacement
  - Developed climate-informed health index with 2030 temperature projections (number of days over 104F in 2030), resulting in three additional substation transformer replacements proposed in the 2025 GRC

Questions?

Energy for What's Ahead[SM]

SOUTHERN CALIFORNIA EDISON®

Strategies for Valuing and Prioritizing Resilience Investments and Measuring Progress

Presented by Juan Pablo Carvallo, Berkeley Lab
(Contributions by Peter Larsen)

Resilience Training for States – Western Region

January 25, 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

Availability of information

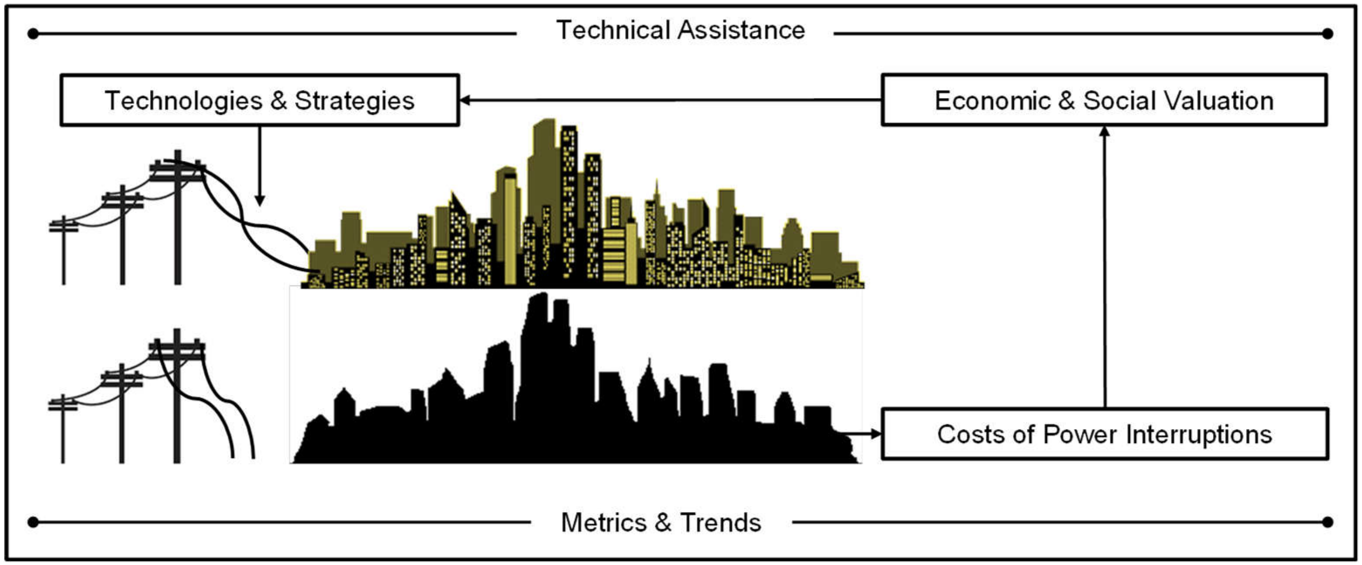
- **Regulatory processes lead to publicly-available information** that can be useful for (1) evaluating projects that have societal benefits and (2) measuring performance after the project has been installed

- For this reason, there tends to be more information in the public domain for regulated utilities and less so for other utilities

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 (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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Selected metrics in practice (2)

State	Metric	Description
North Carolina	Customer interruption cost	• Duke used Berkeley Lab's ICE Calculator to estimate benefits of Grid Improvement Plan
	IEEE 1366 reliability metrics	• Duke uses SAIDI • Duke uses SAIFI
	Reliability metrics	• SAIDI (excluding MEDs) • SAIFI • CEMI-4 (customers experiencing more than four outages of 1 minute or more per year) • Miles of vegetation management
	Resilience metrics	• Number of critical assets without power for more than N hours • Critical asset energy demand not served • Critical asset time to recovery

Sources: NCUC (2018), NCUC (2020), and RMI/RAP (2020)

Selected metrics in practice (3)

State	Metric	Description
Georgia	IEEE 1366 reliability metrics (for ranking)	• Feeder-level and company-wide SAIDI • Feeder-level and company-wide SAIFI
	Loss of Load Expectation (for most planning processes)	• Expected number of loss-of-load days with events (Loss of Load Expectation; 1 day in 10 years)

Sources: Georgia Power (2019) and Georgia PSC (2022)

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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

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?

Kahoot!

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Examples of Valuing and Prioritizing Resilience Strategies

LCS44

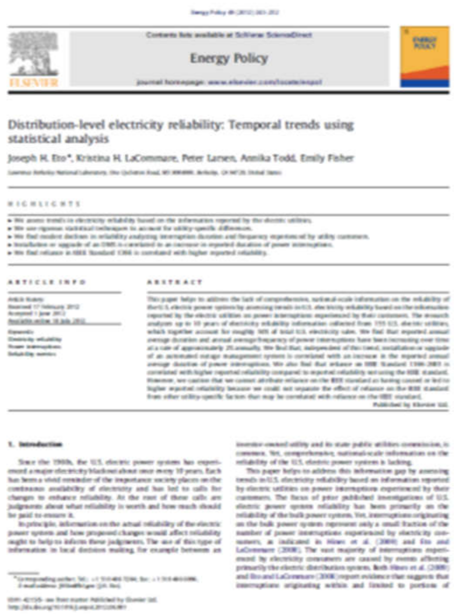
Slide 15

LCS44 Added "Strategies"
Lisa Schwartz, 11/13/2023

Example #1: Valuing a 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](#))


Energy Policy

Distribution-level electricity reliability: Temporal trends using statistical analysis

Joseph H. Eto*, Kristina H. LaCommare, Peter Larsen, Annika Todd, Emily Fisher


Energy

Recent trends in power system reliability and implications for evaluating future investments in resiliency

Peter H. Larsen, Kristina H. LaCommare, Joseph H. Eto, James L. Sweeney

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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?

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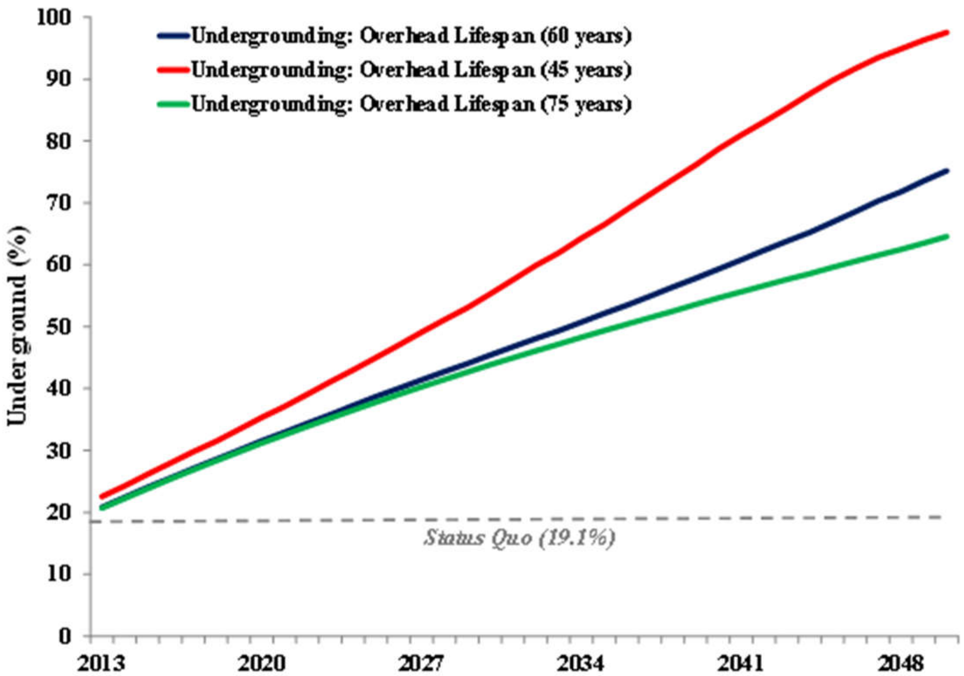
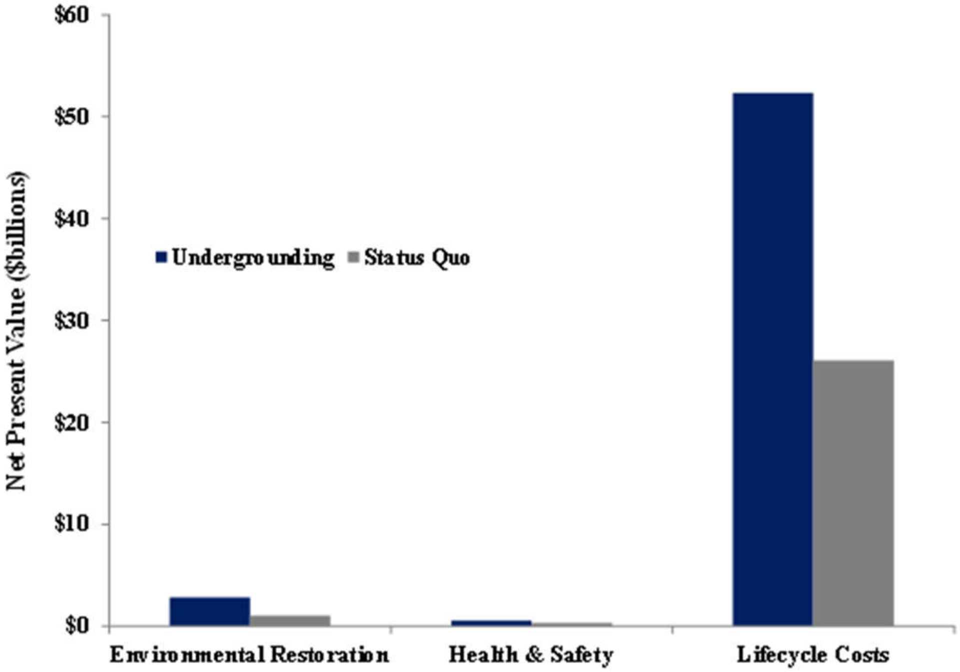
Estimated costs





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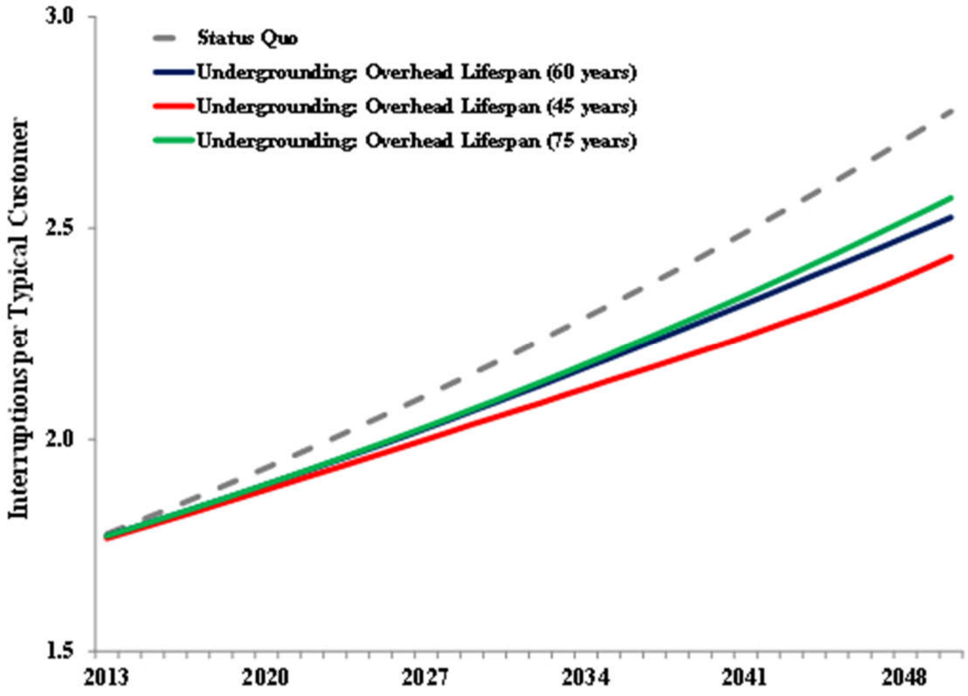
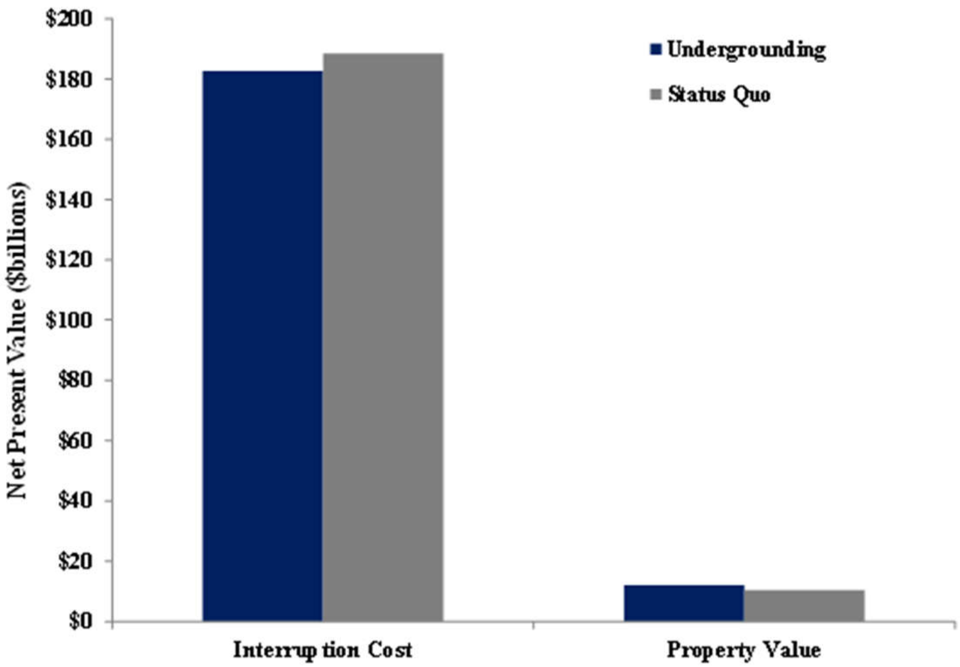
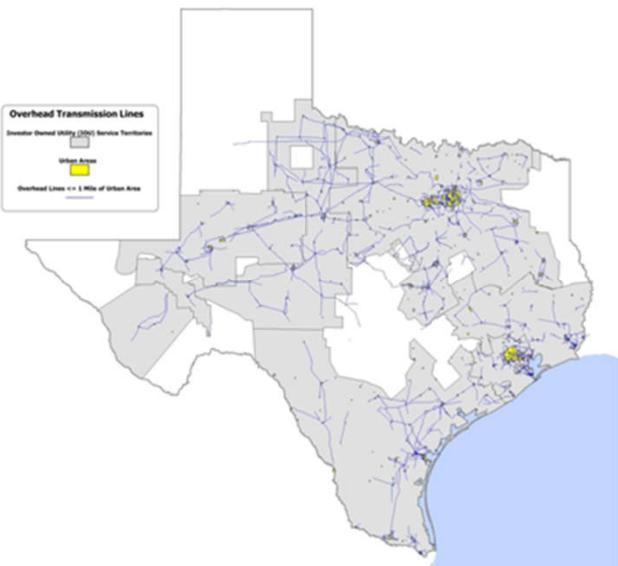
Estimated benefits (1)

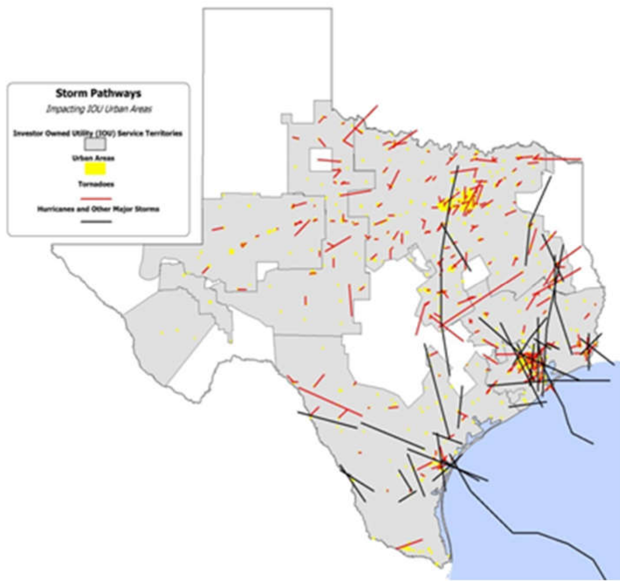




Estimated benefits (2)

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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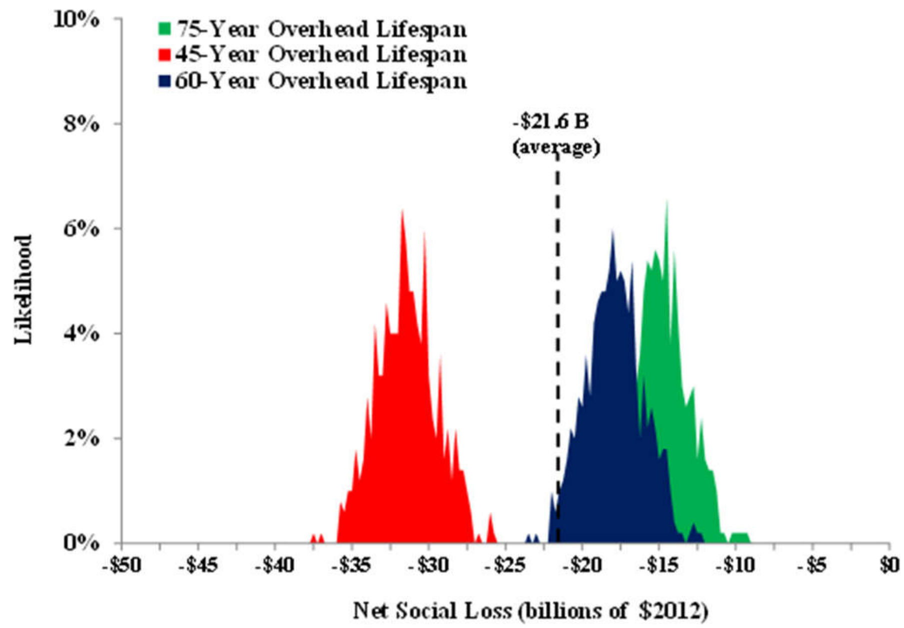
Valuation results

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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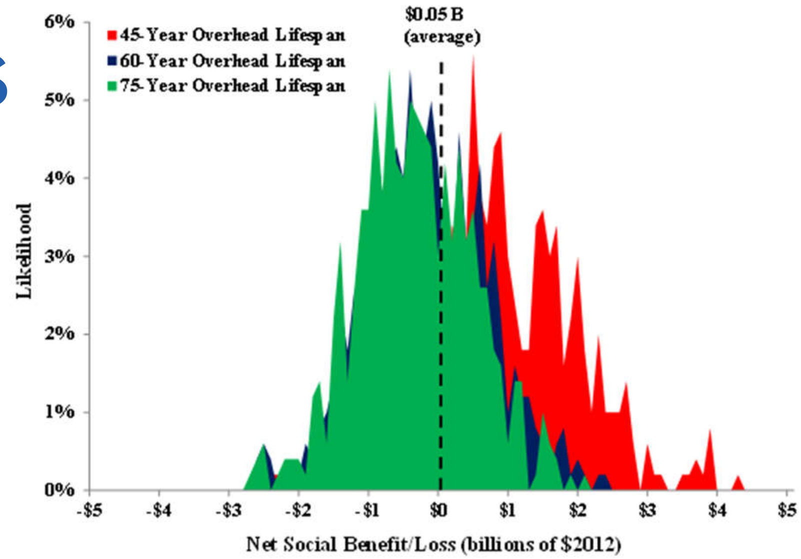
Possibility of net benefits

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 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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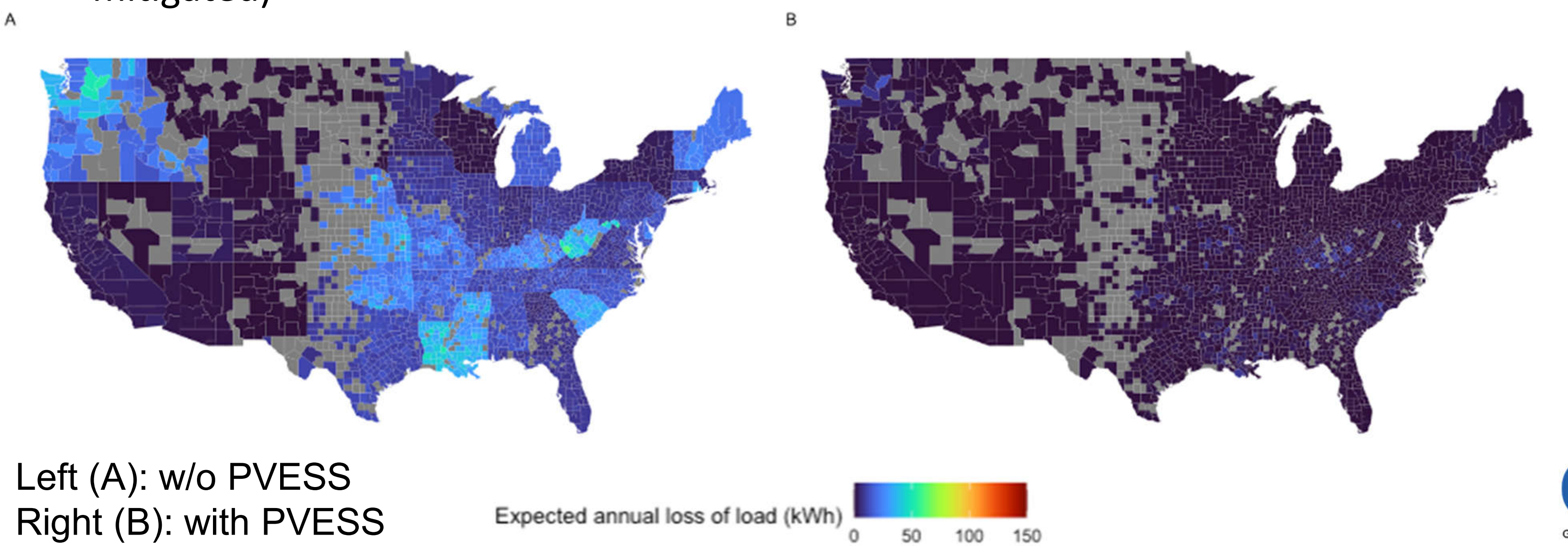
PVESS mitigates customer interruptions

- 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

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

$where\ d = resilience\ event\ duration\ interval\ (ranging\ from\ 1\ day\ to\ 10\ days),$

$m = month,$

$VOLL_{FIPS} = VOLL\ estimate\ assigned\ to\ each\ FIPS\ region\ belonging\ to\ each\ state$

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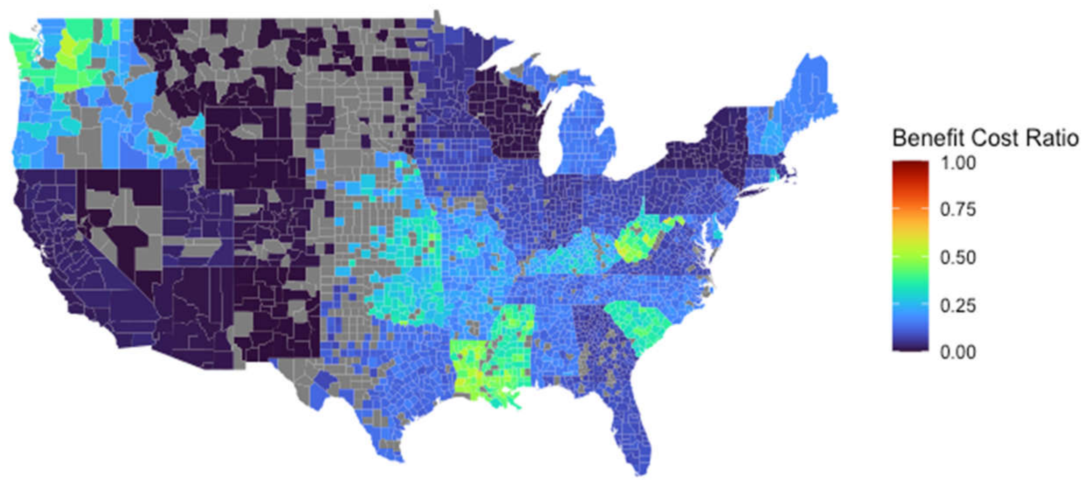
Distribution of benefit-cost ratios

- 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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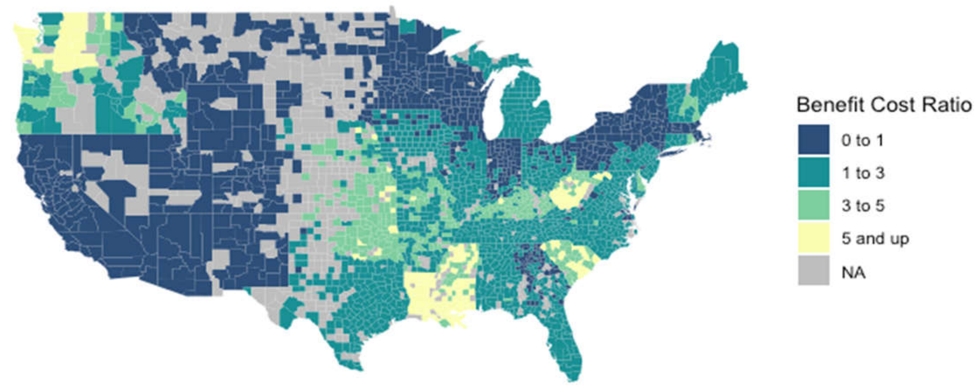
Importance of scenario/sensitivity analyses

- 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**

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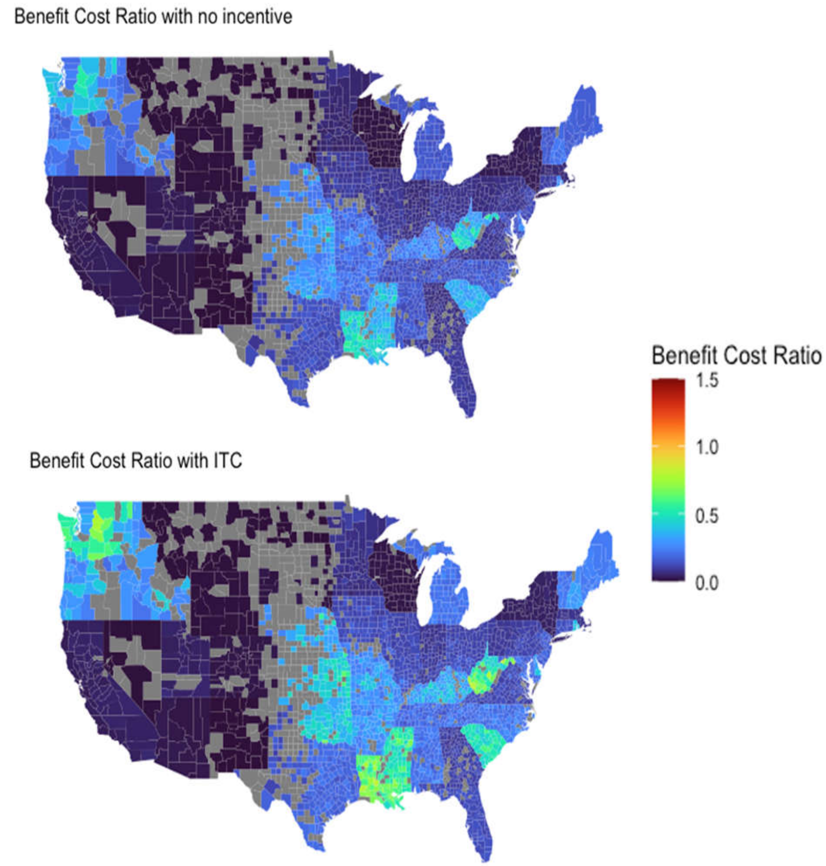
Impact of federal incentives

- **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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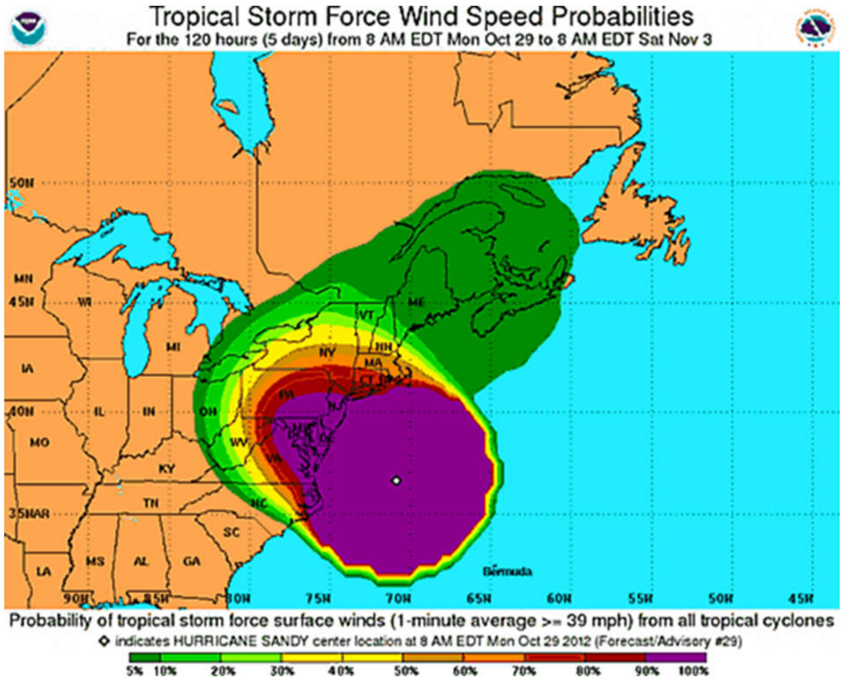
Example #3: Prioritizing a resilience strategy

- 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.](#)



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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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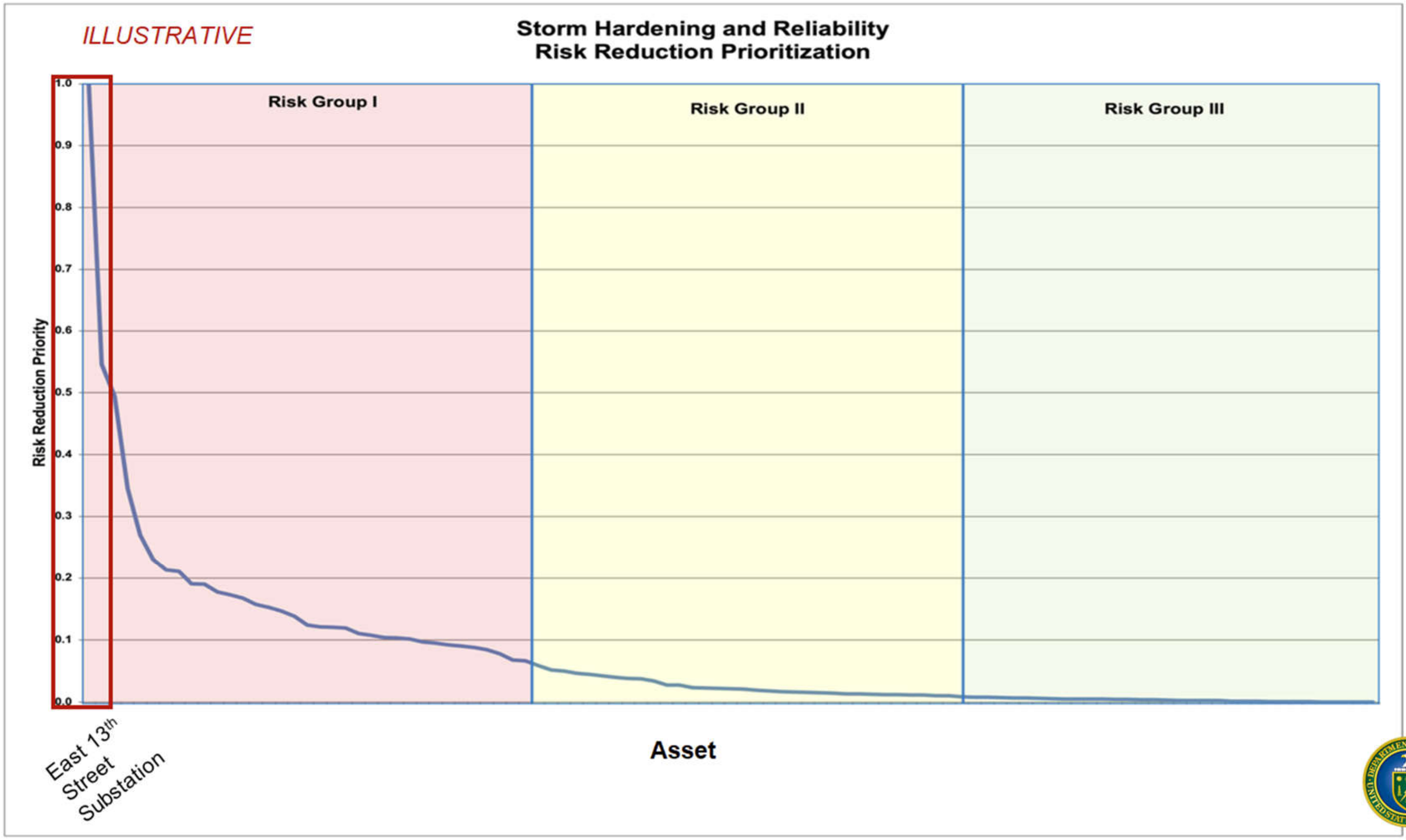
Project prioritization and valuation (1)

- 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

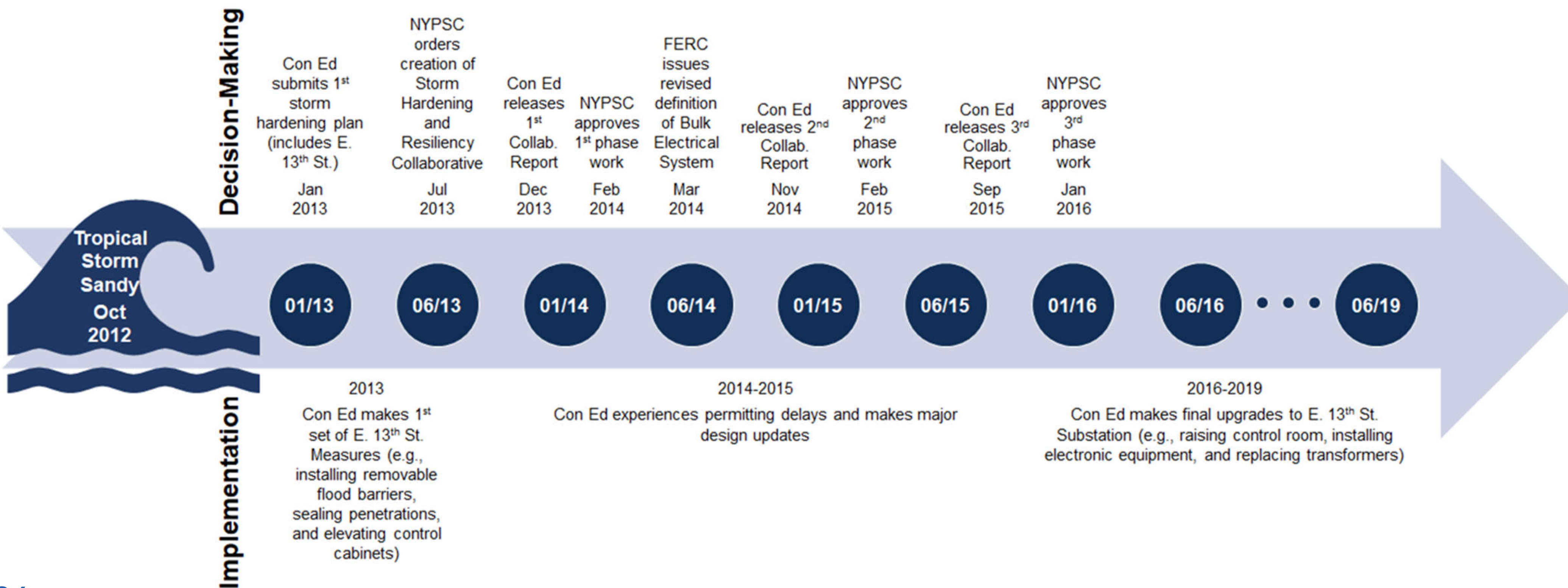
Models	Key Inputs
Risk Assessment and Prioritization Model	● Location-based flood probabilities provided by proprietary New York City inundation models ● Wind damage probabilities derived from historical wind gust frequency distributions ● Costs of storm hardening measures ● Estimated power interruption 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)



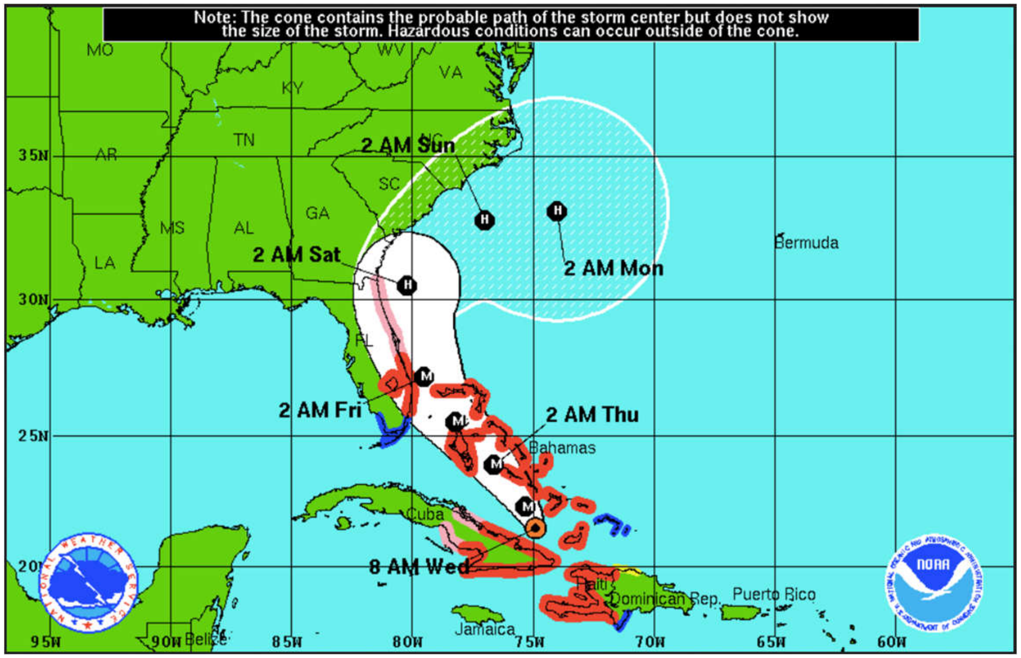
Source: ConEd (2013)

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."



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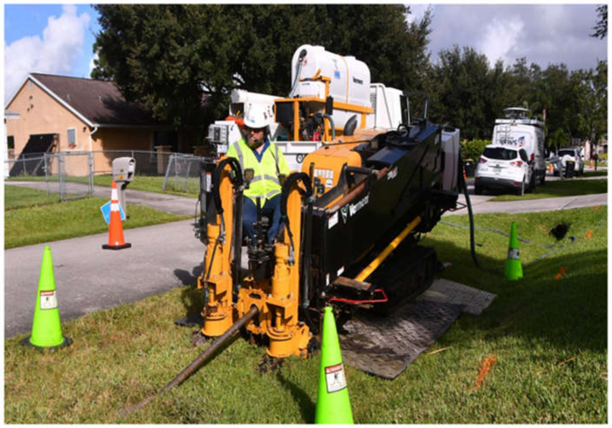
Regulatory and utility processes

- 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

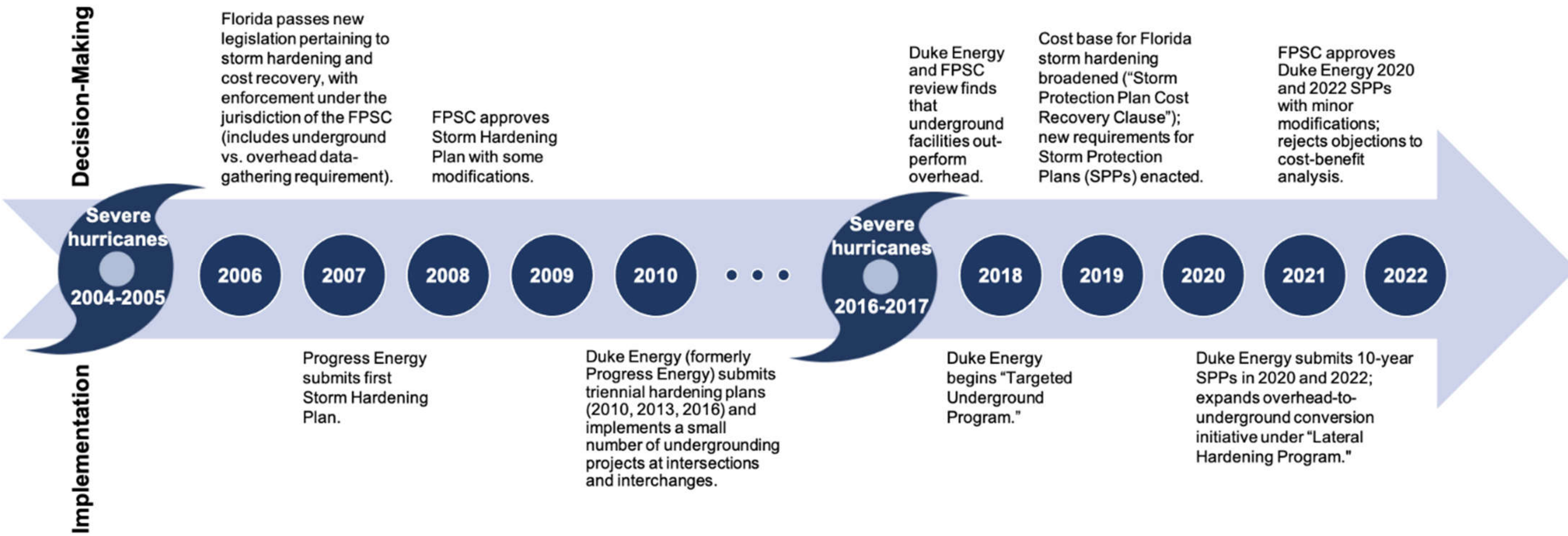
Benefit-cost modeling

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



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?

Contact

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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GDO GRID DEPLOYMENT OFFICE

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

Presented by Nichole Hanus, Berkeley Lab

Resilience Training for States – Western Region

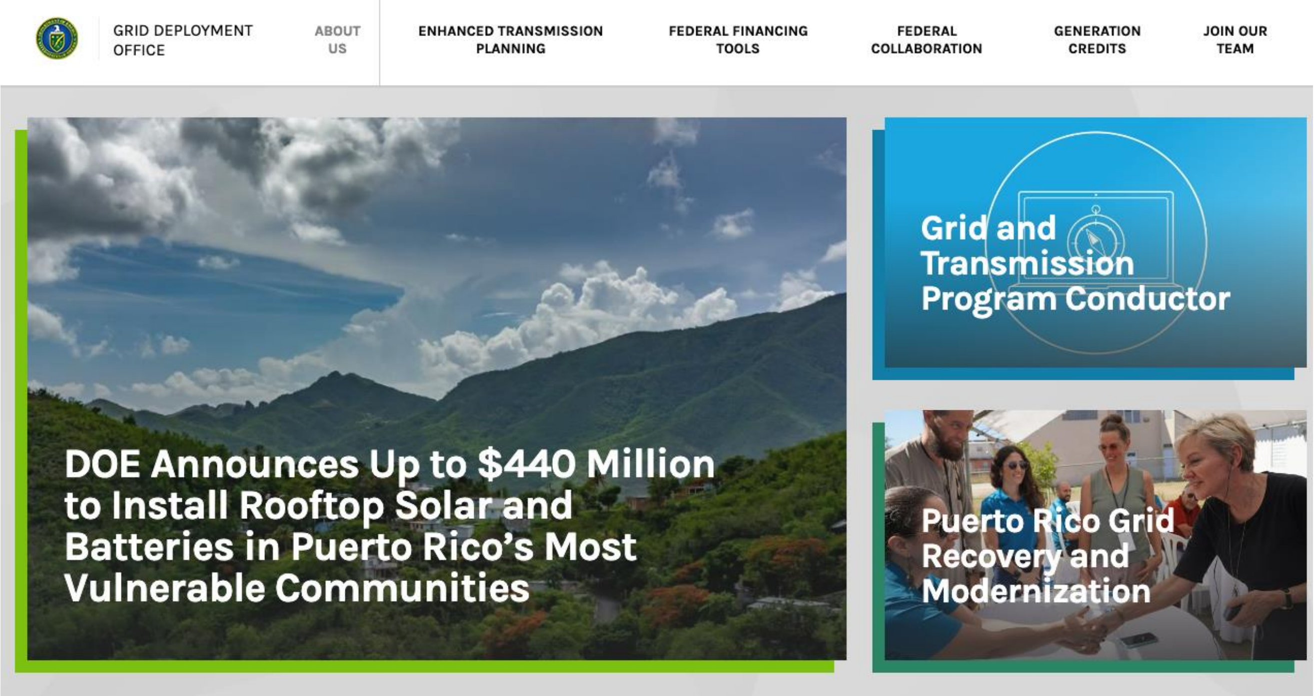
January 25, 2024

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

[8] Source: EPRI

2. Pole Investments

3. Wire Investments

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

[8] Source: EPRI

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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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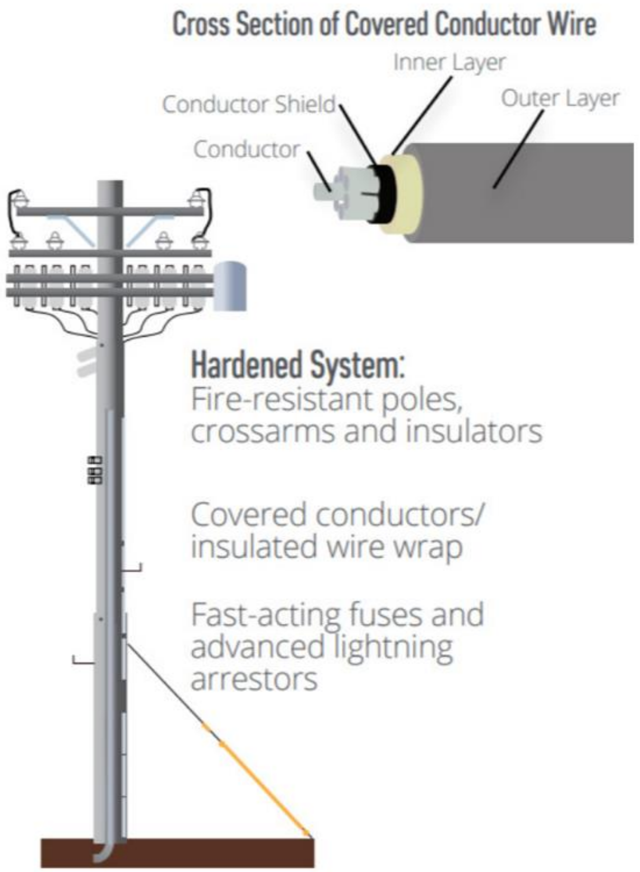
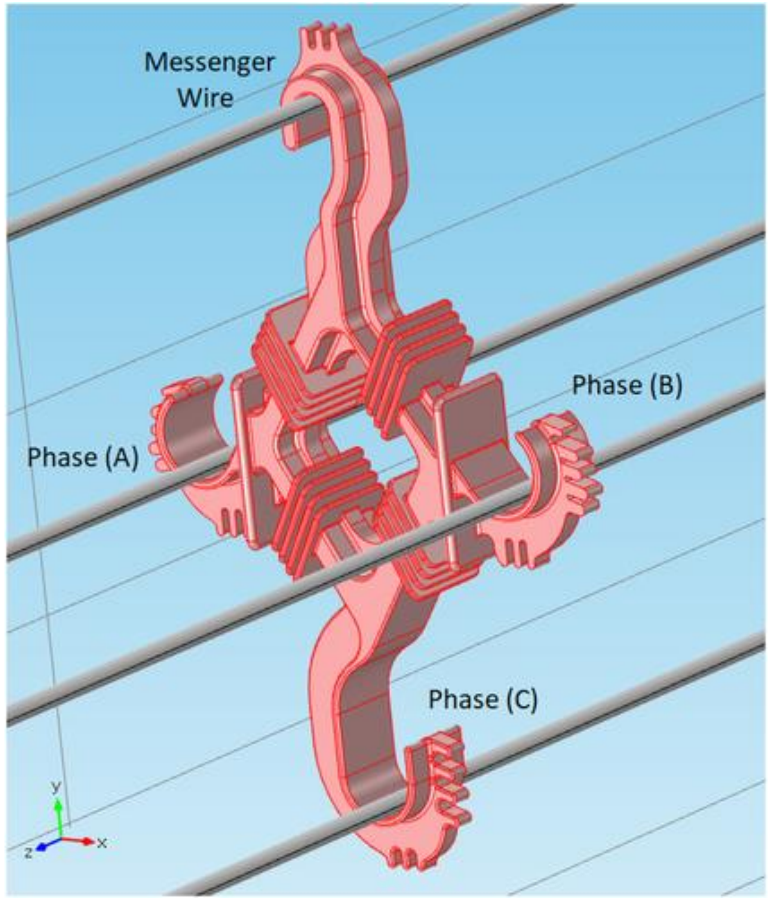
3. Utility Wire Investments

- 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

- 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: $1-6M / 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]

[8] Source: EPRI

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

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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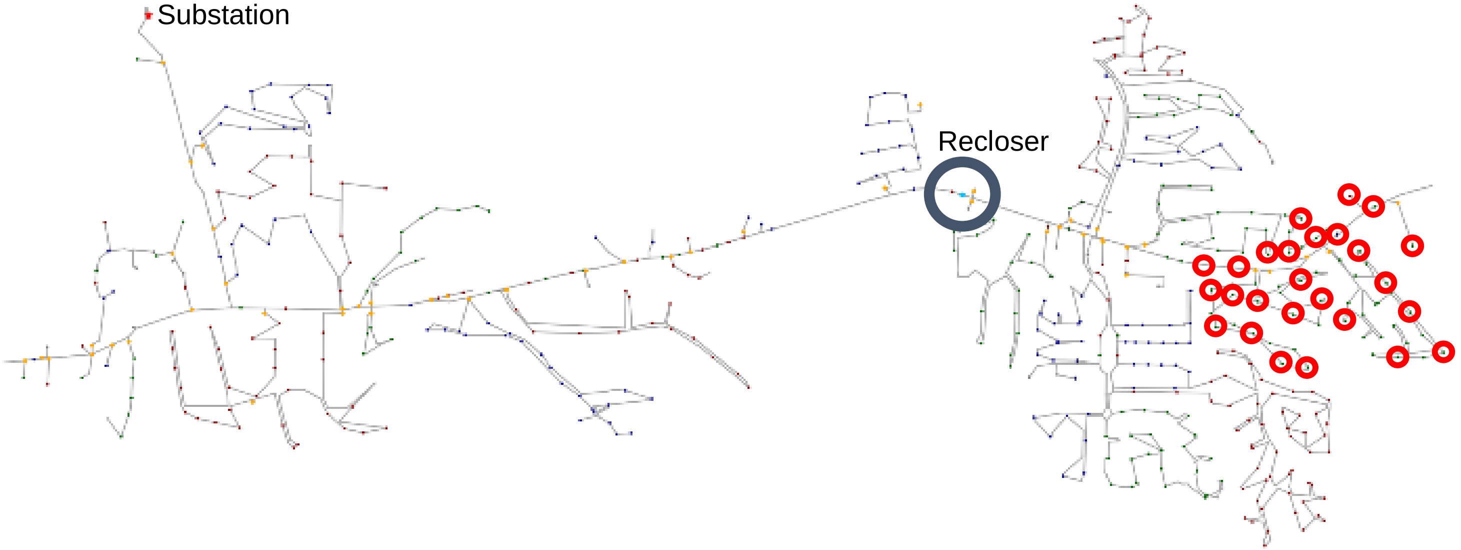
Grid Modernization Technologies

- **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

[8] Source: EPRI



Cost Ranges:

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

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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

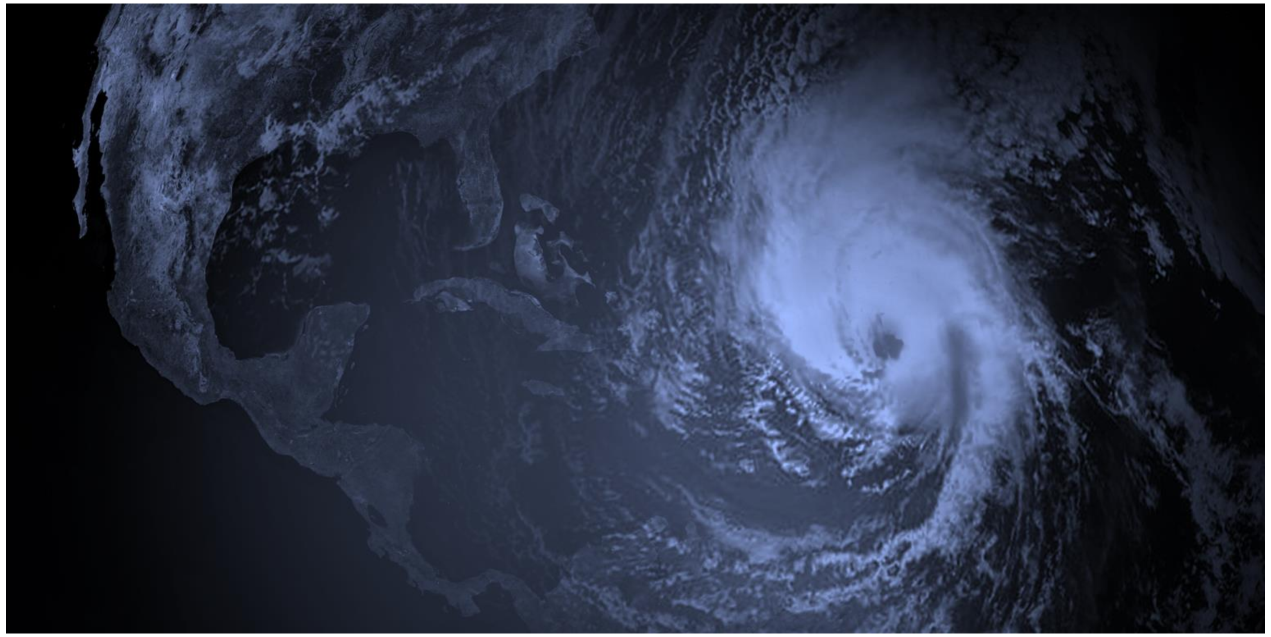
(Rule 25-6.030, F.A.C.)

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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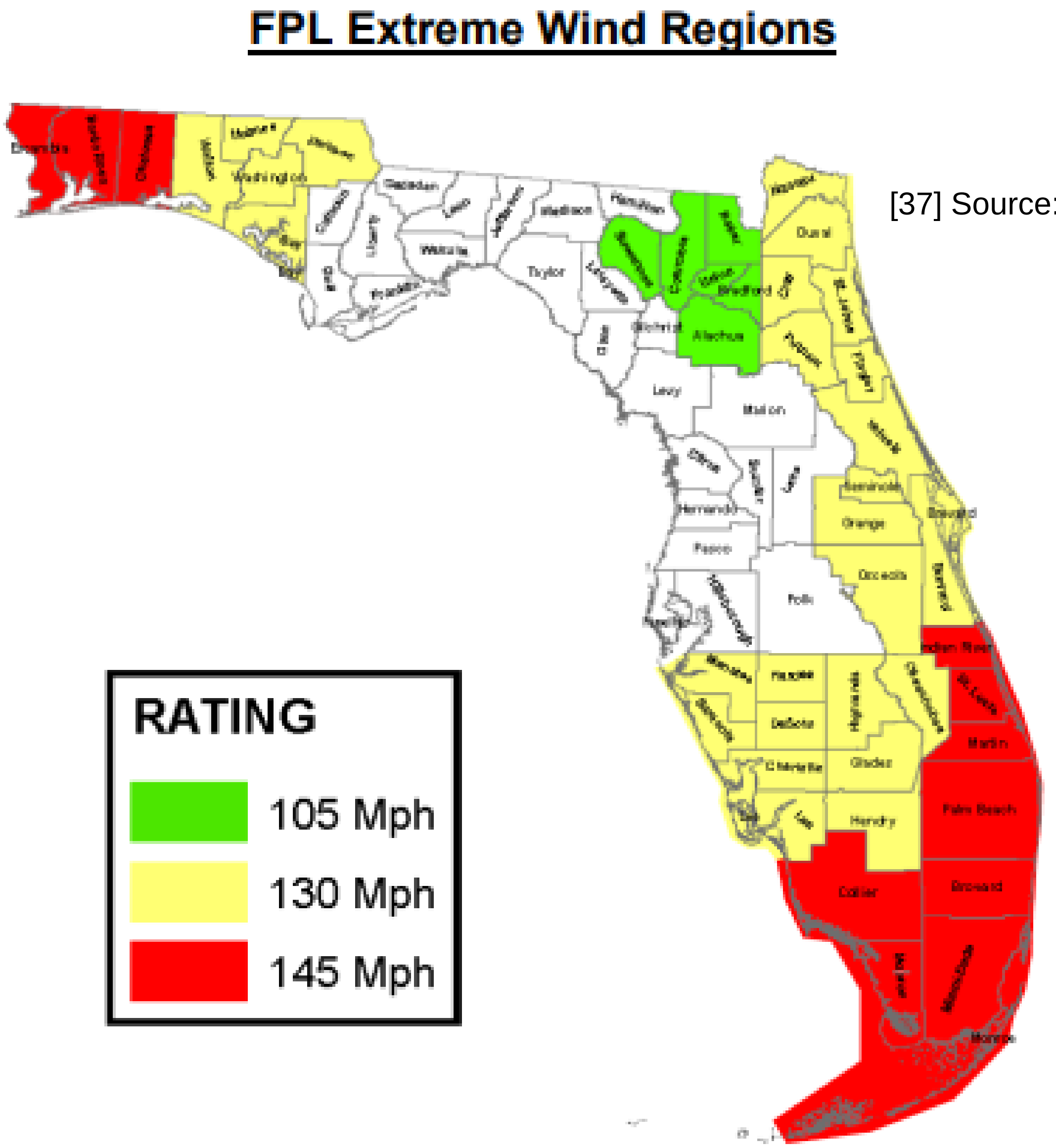
Distribution Feeder and Lateral Hardening Programs

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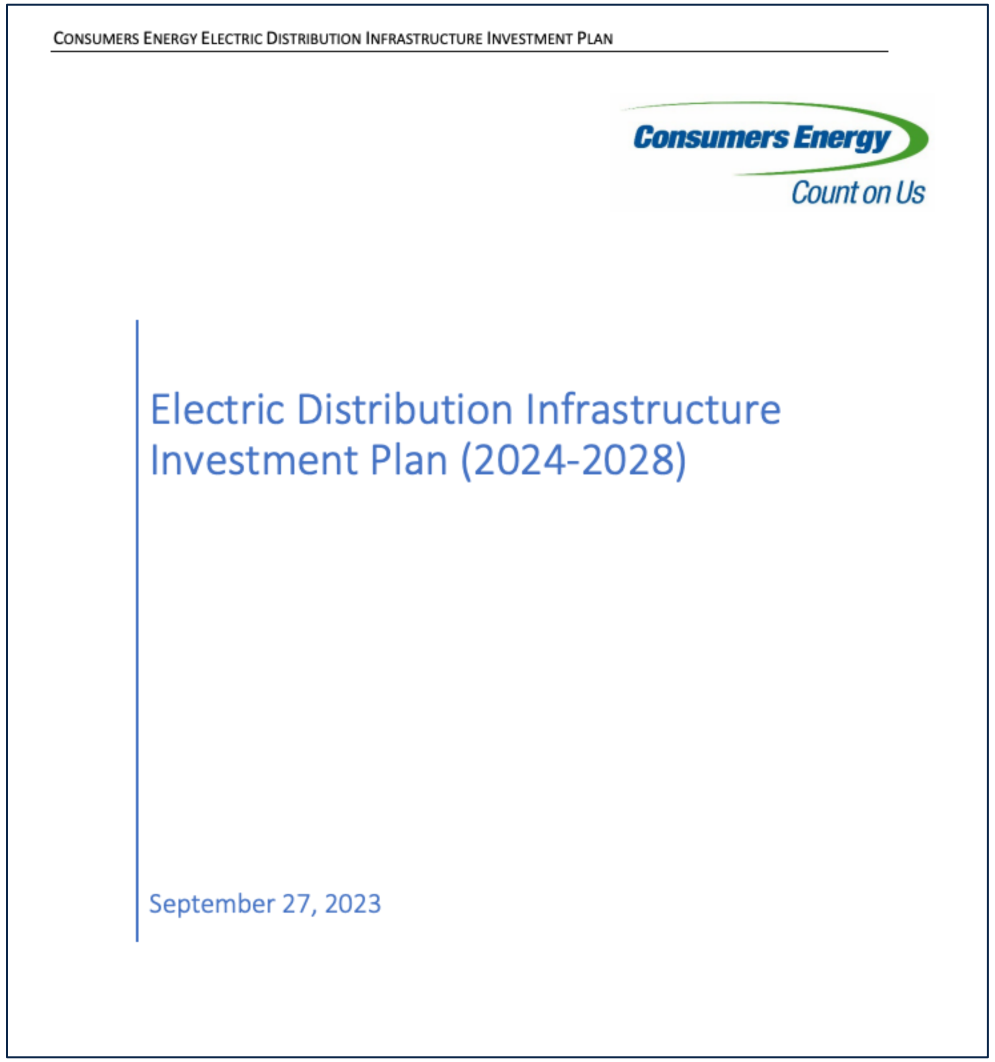
Consumer Energy's Electric Distribution Infrastructure Investment Plan (EDIIP) [38]

- 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

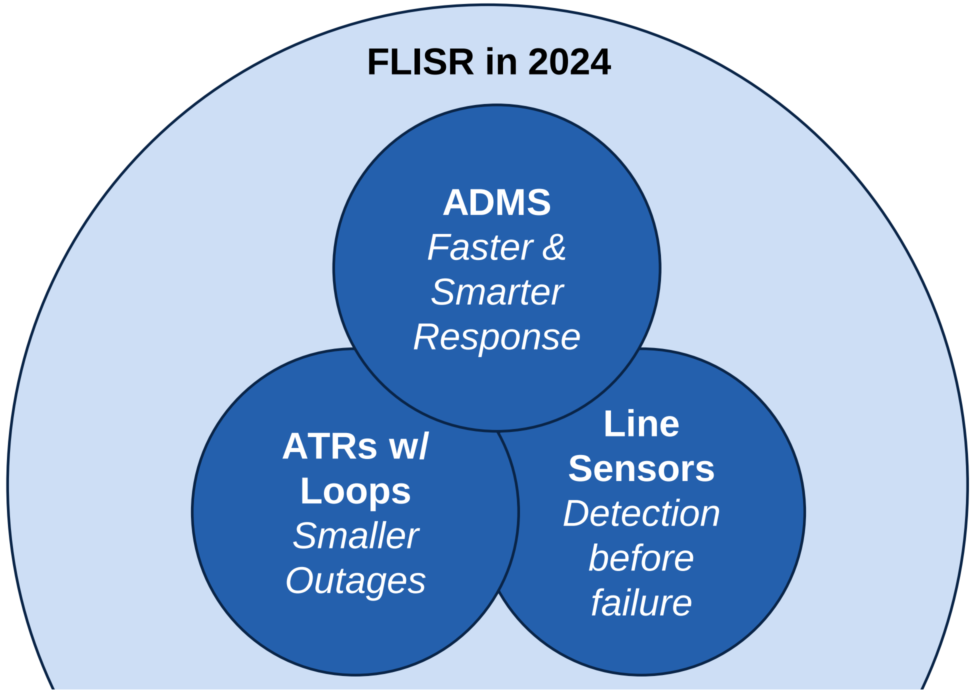
Automatic Transfer Reclosers (ATRs) w/ Loops

- 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



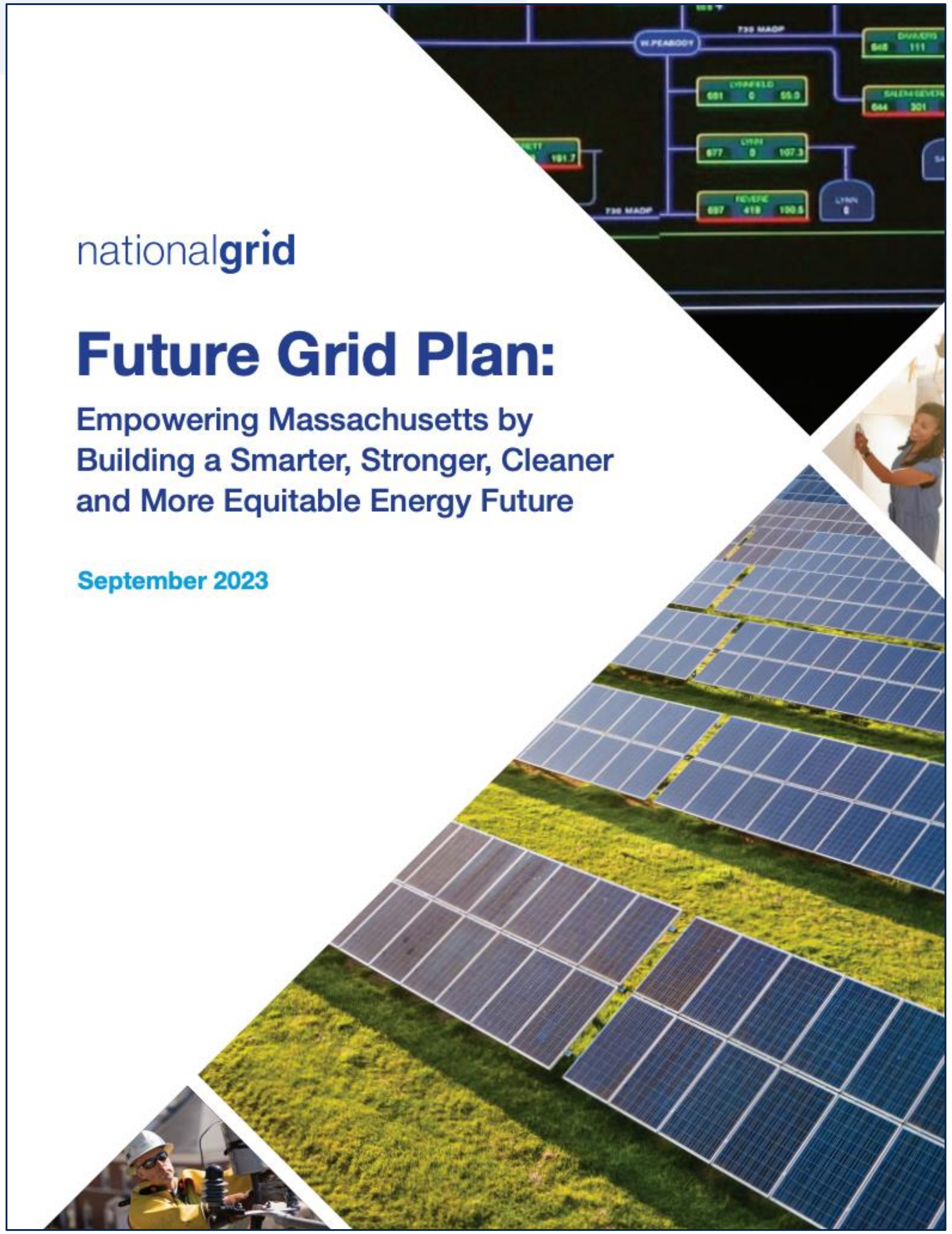
[38] Adapted from: Consumers Energy

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	$0	$1,600k	$0	4 minutes
DMS complete FLISR and SOM				
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**

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



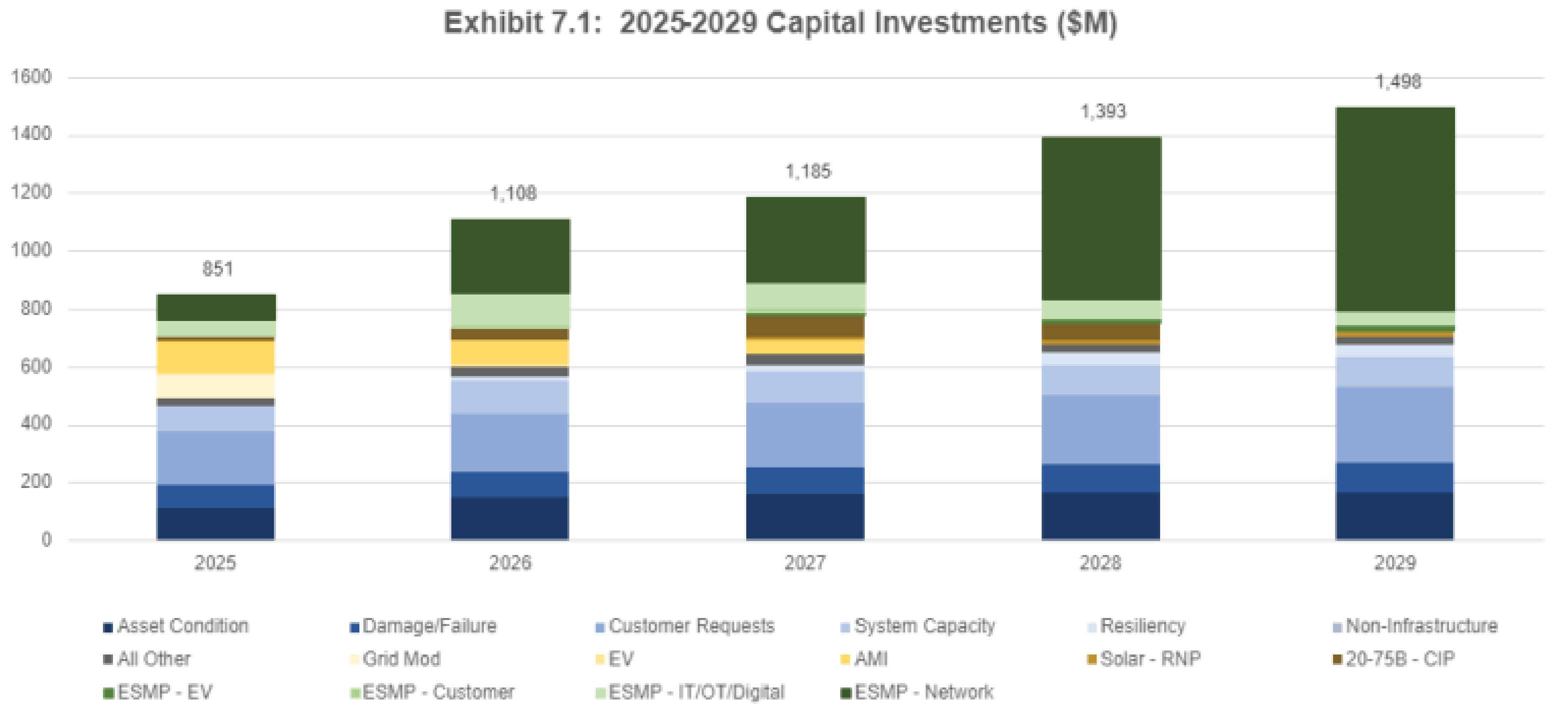
National Grid's Grid Mod Strategies

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



Questions to Ask

- What are the biggest threats (natural or human caused) to grid resilience that your state faces today?
- What resilience investment attributes are most important (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?
- If you have multiple resilience investments in mind, how would you prioritize them and stage their implementation for optimal performance?

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BERKELEY LAB

What Should Grid Resilience Plans Include?

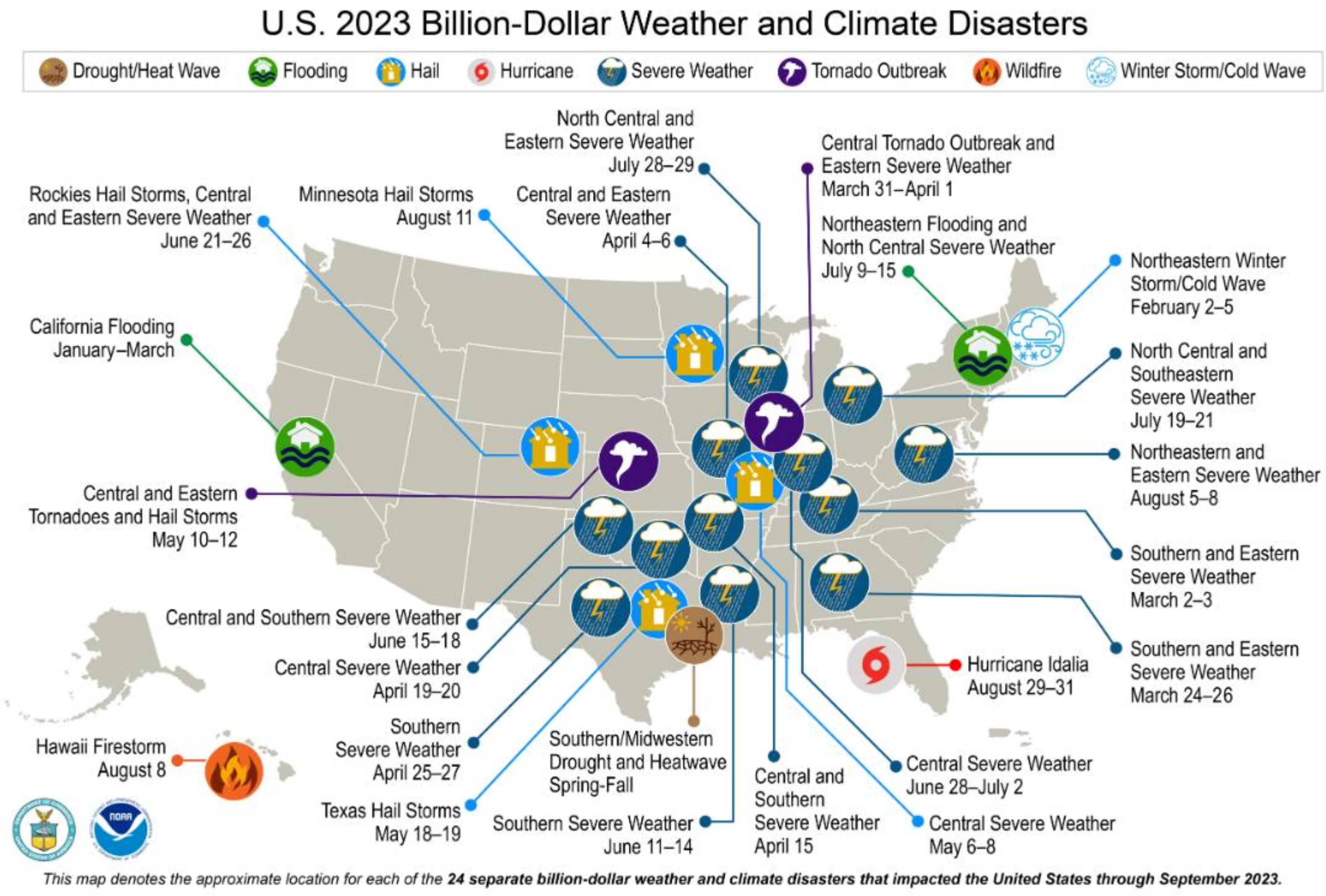
Planning Requirements, Emerging Best Practices, and Template

Presented by Josh Schellenberg, Berkeley Lab Affiliate

Resilience Training for States – Western Region

January 25, 2024

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



- **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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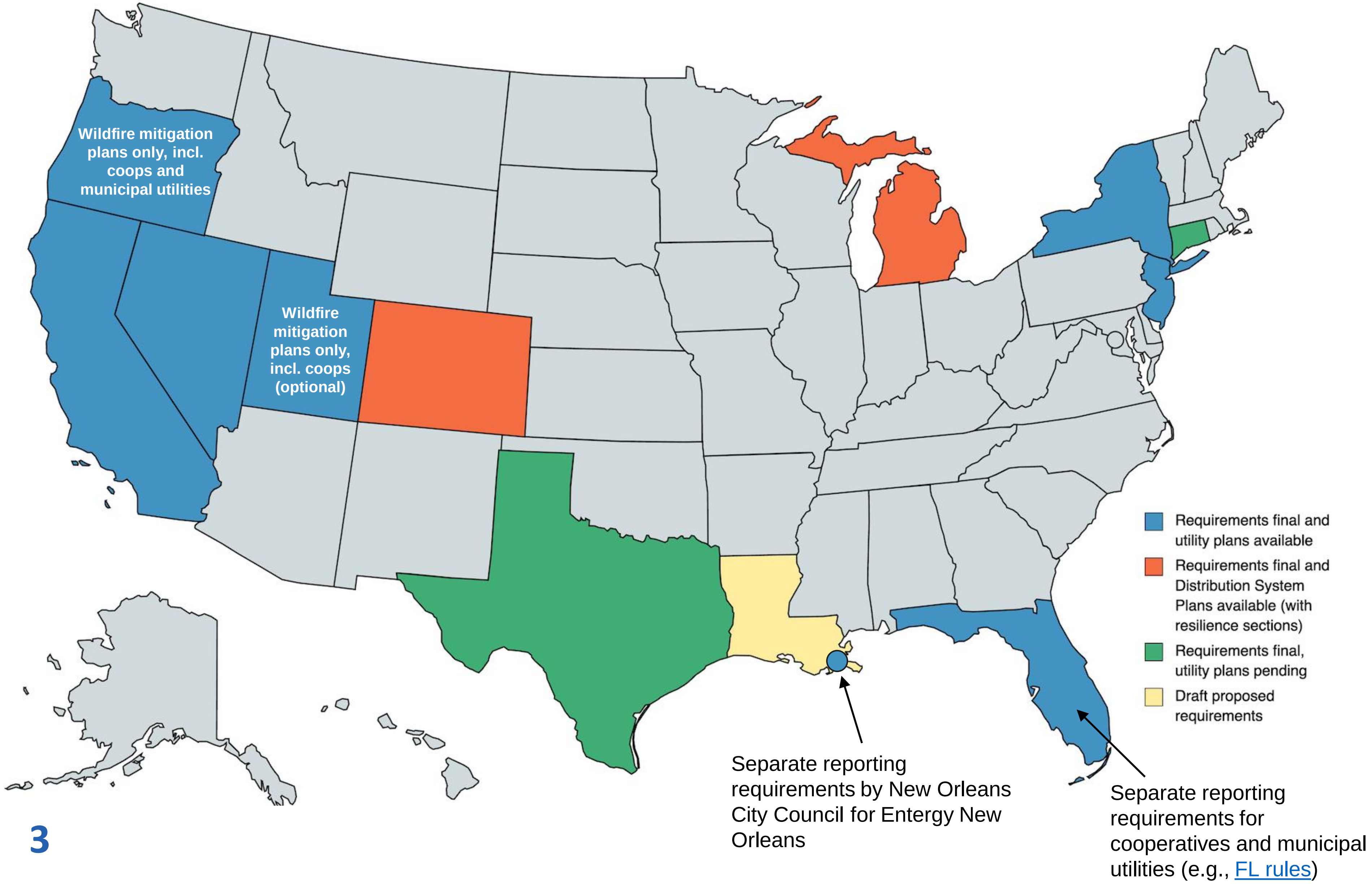
States are responding with resilience planning requirements for regulated utilities



- 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 establish best practices, which serve as guidance to states that have not created resilience plan requirements and regulatory processes.

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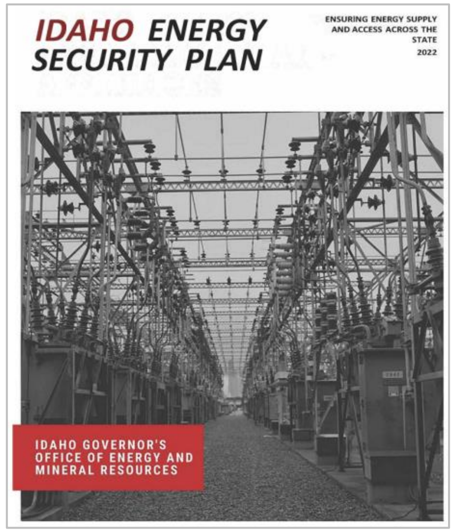
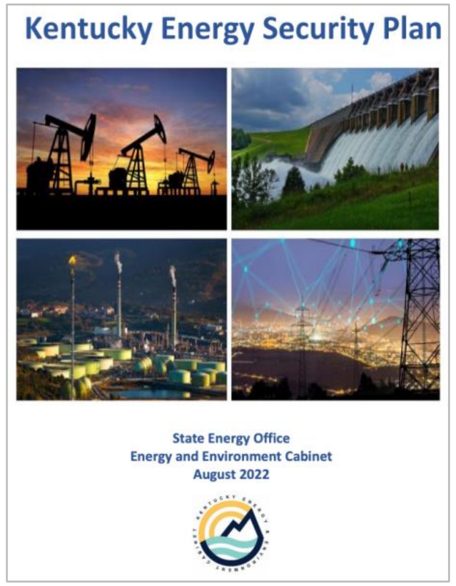
States are also developing Energy Security Plans

- 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

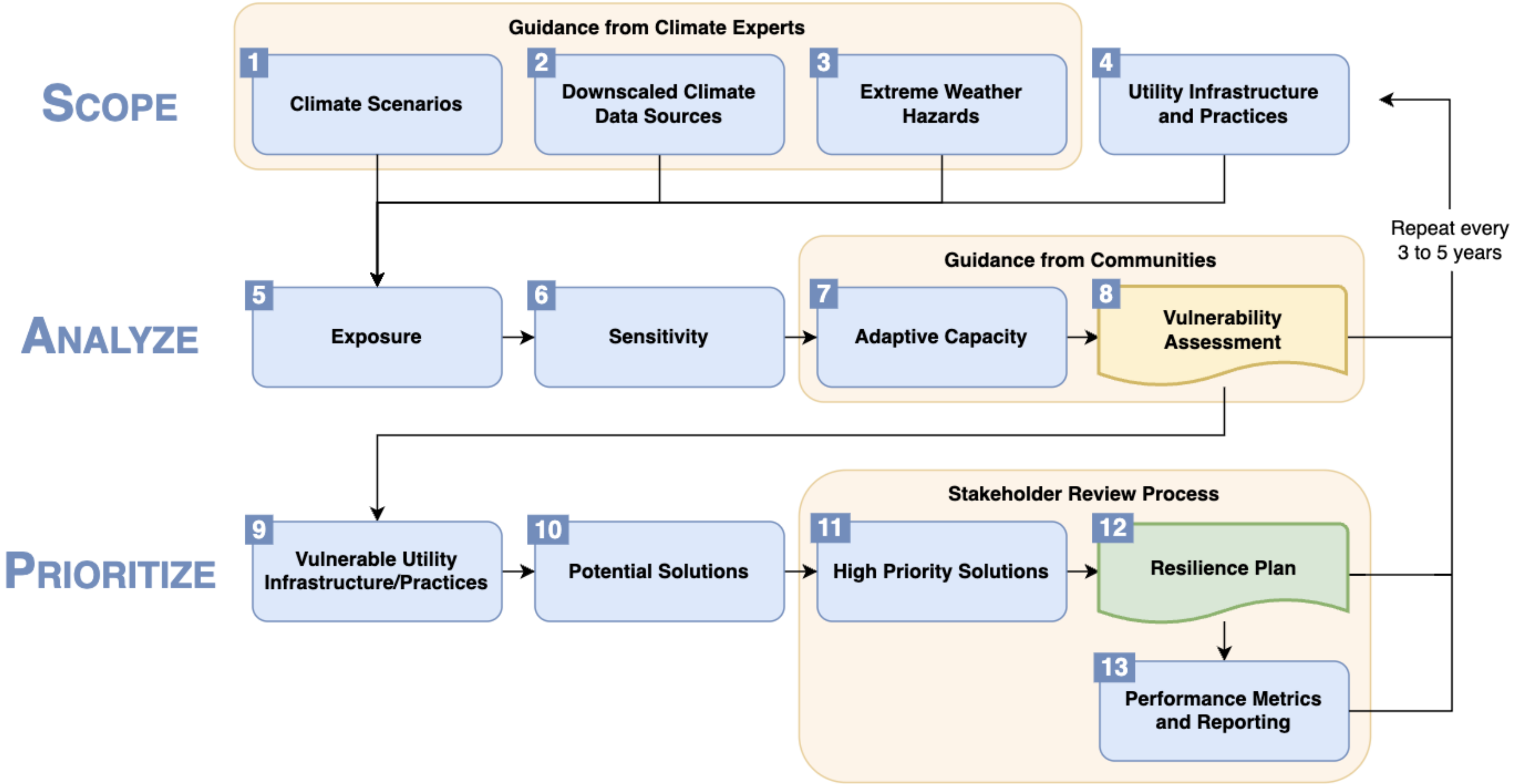
Resilience Plan Template

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

Page 1 of 5

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)

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Resilience Planning Requirements and Emerging Best Practices

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*

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

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

Resilience planning requirements

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	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 low frequency, high impact event that poses a material risk to the safe and reliable operation of an electric utility's T&D systems, including *cyber/physical security threats*	3 years (voluntary)	3 years (minimum)

* Per HB 2555 (2023) for Texas requirements

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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

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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

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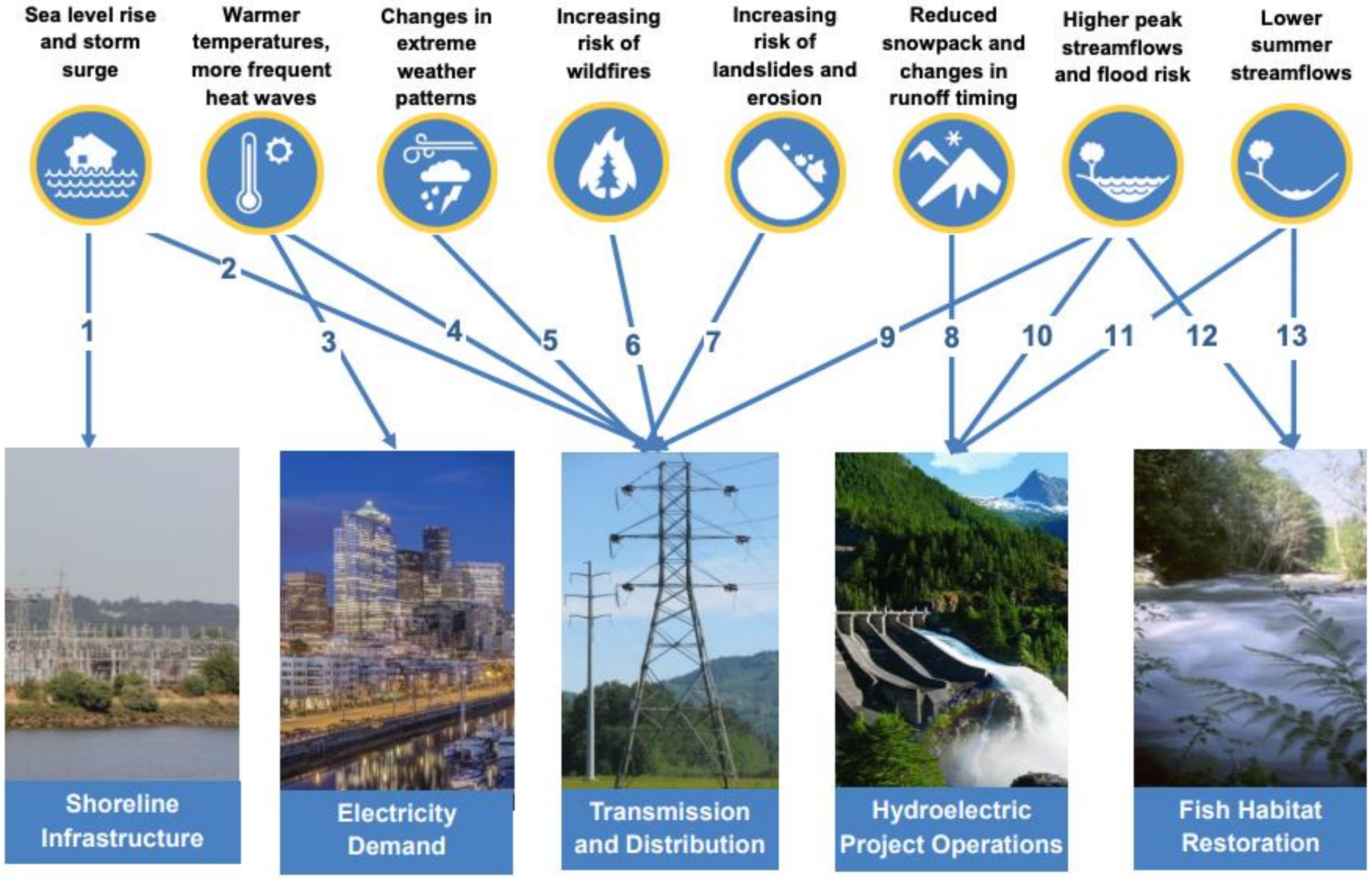
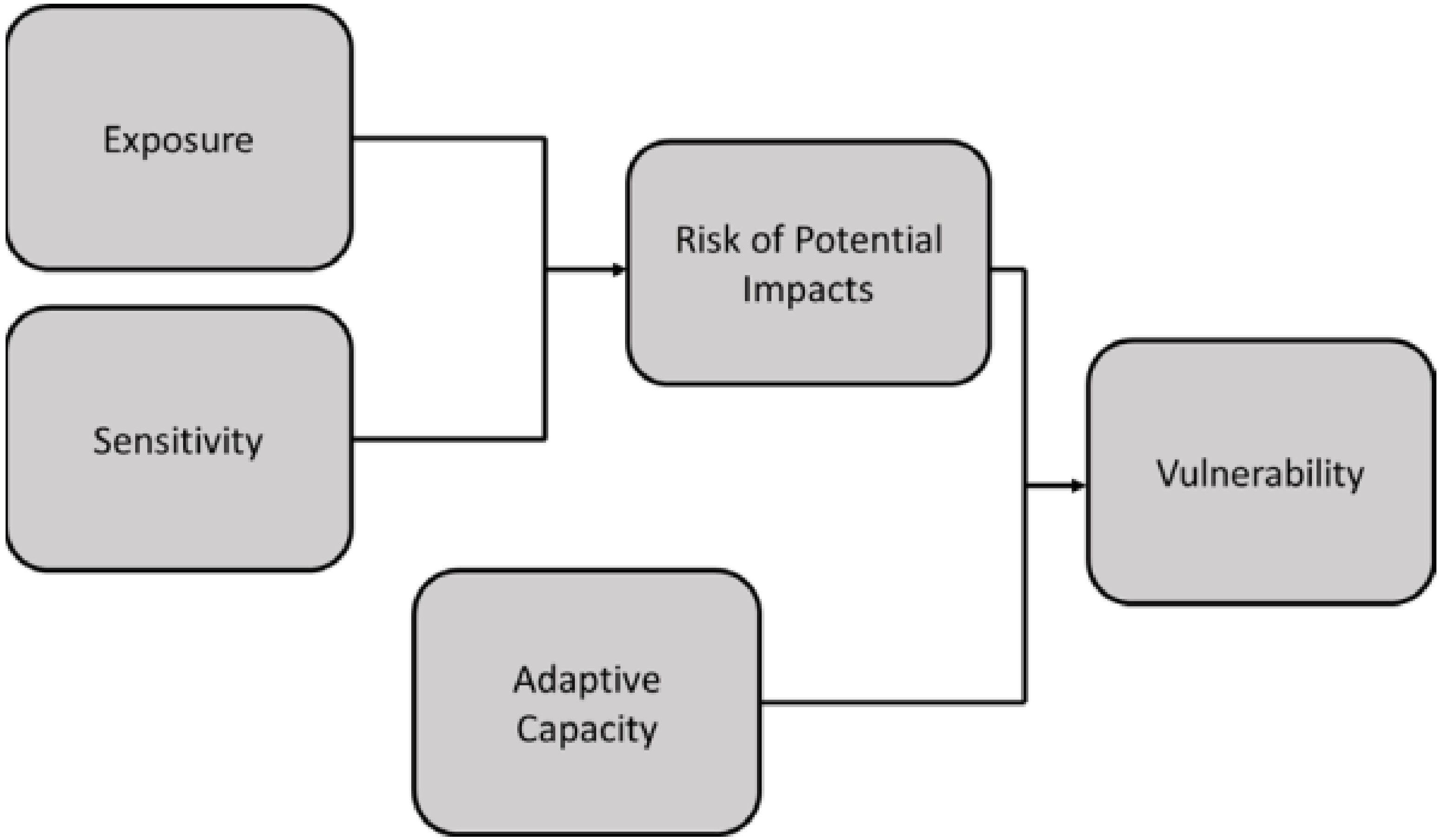
Example Utility Plans and Best Practices

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



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."

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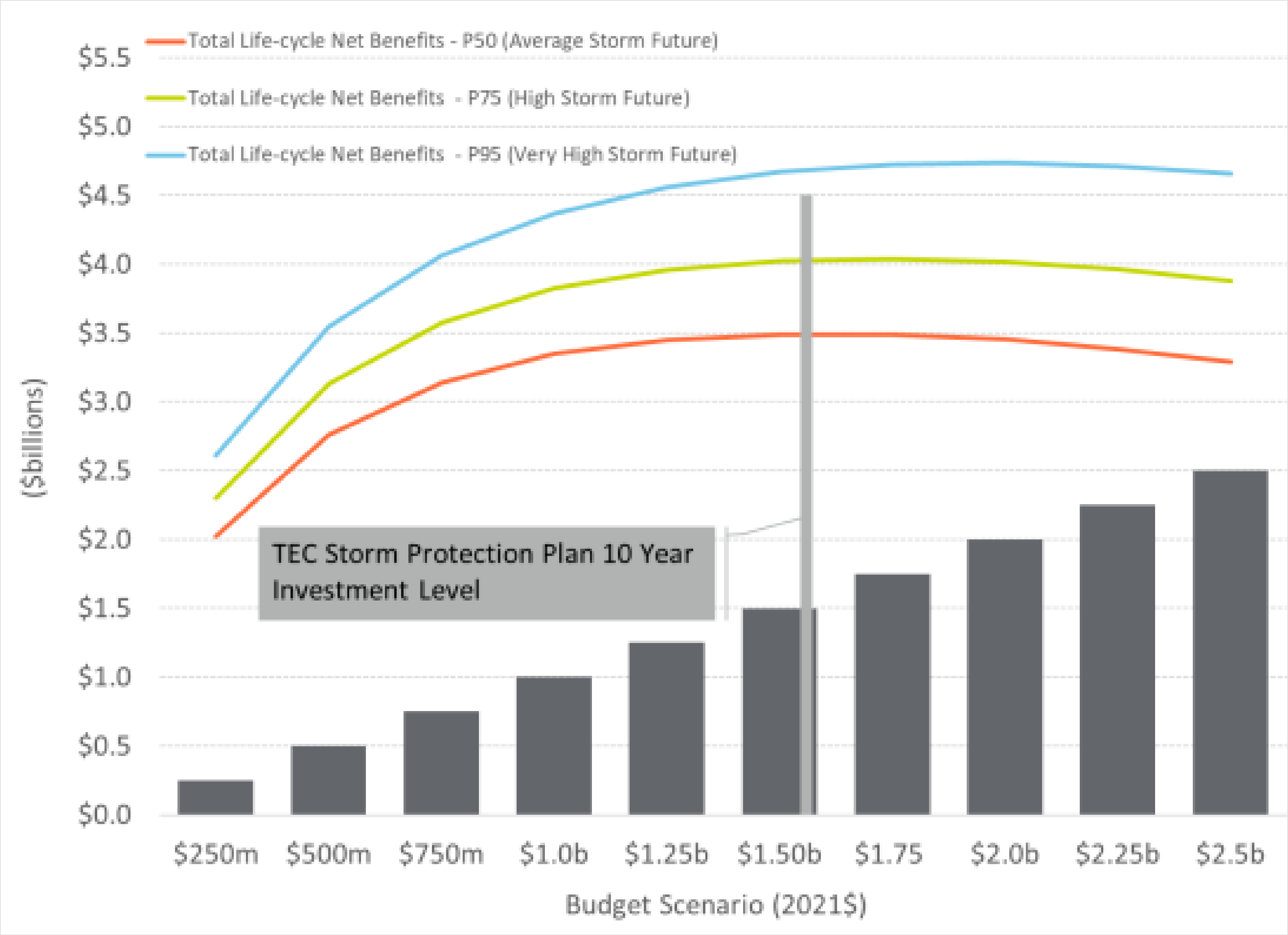
Tampa Electric Storm Protection Plan (2022)



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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

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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?

Contact

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STATE CRITERIA FOR EVALUATING RESILIENCE PROJECTS

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

Resilience Training for States – Western Region

January 25, 2024

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

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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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Types of Evaluation Criteria

- Quantitative
- Qualitative

Potential Evaluation Criteria

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

Potential Evaluation Criteria

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

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%)

Things to Consider

- Mechanics of the criteria
  - Number of criteria
  - Availability of data
  - Scoring rubric
  - Scoring weights

Things to Consider

- Review process
  - Who’s involved?
  - How do you evaluate consistently?
  - Timeframe for review

Things to Consider

- 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

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

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?

Contact

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