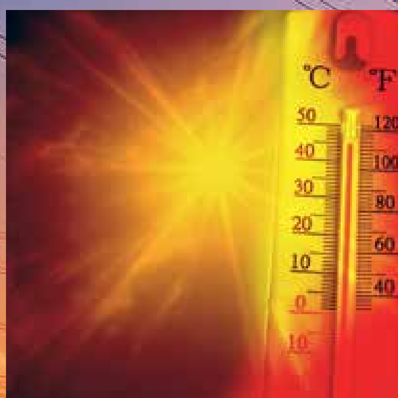
2025

A Strategic Guide for Key Stakeholders



Connecticut Grid Resilience Assessment

University of Connecticut and
University at Albany

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2025 GRACI Guide for Stakeholders

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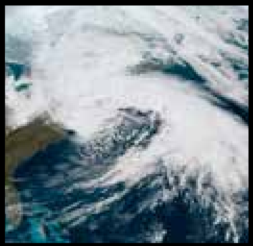
   

Introduction

This guide is based on a comprehensive synthesis of climate projections, outage data analysis, electric infrastructure impact and outage restoration modeling, customer surveys and social vulnerability metrics across **Connecticut (CT)**. Findings reveal that future risks from **extreme heat** and **high wind events** will be concentrated in already vulnerable areas, especially urban-suburban corridors, and communities with **aging infrastructure**, **low Distributed Energy Resources (DER) or Battery Energy Storage System (BESS)** resources, **and/or high social vulnerability**.

To support **data-driven planning** that **prioritizes** the **protection of populations most vulnerable to outage impacts**, we outline key conclusions and tailored recommendations, providing a practical roadmap for investment and resilience.

Key Takeaways

Climate-driven hazards, persistent outage clusters, and strong spatial variability on **electric infrastructure impacts,** underscore the need for **predictive, data-informed resilience planning** across the state, that could consider socially vulnerable populations. An analysis founded on **downscaled climate projections, impact and risk models for power outages, infrastructure reinforcement diagnostics, customer surveys and social vulnerability mapping,** reveals **compounding risks** that threaten **system performance and community well-being.** The following conclusions synthesize actionable insights across **climate stressors, outage behavior, infrastructure readiness,** and **community impacts,** forming the backbone for **targeted investment** and **policy guidance.**

4 STUDY RESULTS

Extreme Heat Stress is Rising in Urban Corridors

- Under **future climate scenarios** (CMIP5 RCP 4.5 and RCP 8.5; Taylor et al. 2012), urban areas along the I-95 and I-91 corridors, such as Hartford, Bridgeport, and New Haven, are projected to experience increases in the number of **heat waves** (3 or more consecutive days with temperatures exceeding 90°F; Fig 1) and number of days with exceeding **heat advisory** (heat index > 95°F) or **excessive heat warning** (heat index > 104°F) criteria (Tables 1 - 3).

- For example, for mid-century (2038 – 2057) projections, **New Haven** (Table 1) and **Bridgeport-Trumbell** (Table 2) could face up to **16 - 21 more days per year with heat index (HI) values above 95°F**, while **Hartford** (Table 3) may experience **up to 19 additional days,** stressing **energy demand,** due to **cooling needs.**

- These events **compound outage-related risks,** where power loss during a heatwave and coincident thunderstorms can lead to **critical public health threats,** especially for **elderly, low-income,** or **medically vulnerable residents.**

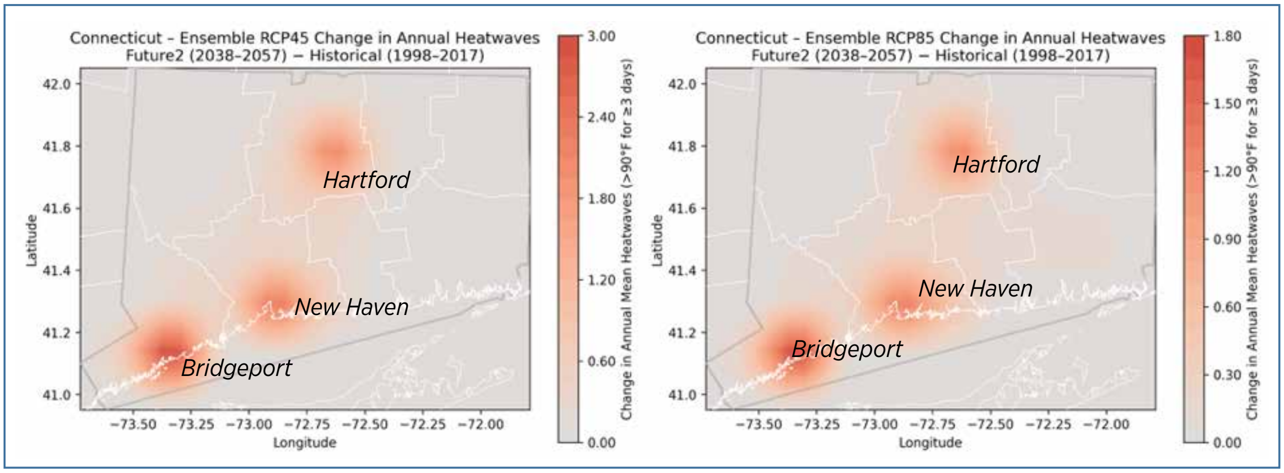


Figure 1. *State-wide mean change (baseline = 1998 – 2017) for the period 2038 – 2057 in annual number of heat waves (3 or more consecutive days maximum temperature is 90°F or higher) from ensemble mean of selected CMIP5 models (NCAR-CCSM, GFDL-CM3, and MIROC5) for RCP4.5 (left) and RCP8.5 (right). Source: New York State Energy Research and Development Authority (NYSERDA), 2022. Effects of Climate Change on Renewable Energy Production in New York State," NYSERDA Report. Prepared by the Atmospheric Sciences Research Center, University at Albany, State University of New York. nyserda.ny.gov/publications.*

Table 1. *Change in Mean Annual Number of Days with Heat Index > 95°F and 104°F for near-future (2018 – 2037) and mid-future (2038 – 2057) periods for New Haven, CT derived from CMIP5 models used in the NYSERDA (see Fig 1 caption)*

Model	Scenario	2018 - 2037 (95 | 104)	2038 - 2057 (95 | 104)
MIROC5	RCP45	0 | 0	3 | 0
MIROC5	RCP85	1 | 0	5 | 1
GFDL-CM3	RCP45	3 | 1	21 | 4
GFDL-CM3	RCP85	2 | 0	14 | 2
NCAR-CCSM4	RCP45	0 | 0	1 | 0
NCAR-CCSM4	RCP85	2 | 0	2 | 0
Mean		**1 | 0**	**8 | 1**

[1] Taylor, K., R. Stouffer, and G. Meehl, 2012: An Overview of CMIP5 and the Experiment Design, Bull. Am. Meteorol. Soc., 93(4), pp. 485–498.

Table 2. *Same as Table 1, except for Bridgeport-Trumbell, CT.*

Model	Scenario	2018 - 2037 (95 I 104)	2038 - 2057 (95 I 104)
MIROC5	RCP45	0 | 0	2 | 0
MIROC5	RCP85	0 | 0	4 | 0
GFDL-CM3	RCP45	2 | 0	16 | 3
GFDL-CM3	RCP85	1 | 0	10 | 0
NCAR-CCSM4	RCP45	0 | 0	0 | 0
NCAR-CCSM4	RCP85	2 | 0	2 | 0
Mean		**1 | 0**	**6 | 1**

Table 3. *Same as Table 1, except for Hartford, CT.*

Model	Scenario	2018 - 2037 (95 I 104)	2038 - 2057 (95 I 104)
MIROC5	RCP45	0 I 0	2 I 0
MIROC5	RCP85	0 I 0	5 I 1
GFDL-CM3	RCP45	2 I 0	19 I 3
GFDL-CM3	RCP85	1 I 0	12 I 1
NCAR-CCSM4	RCP45	0 I 0	1 I 0
NCAR-CCSM4	RCP85	2 I 1	2 I 1
Mean		**1 I 0**	**7 I 1**

Planning Implication: Integrate heatwave risk into outage prediction tools to strengthen energy reliability and prioritize grid hardening or battery storage deployment in areas where service disruptions during heat events could most severely impact public health and electric infrastructure reliability.

High-Wind Risks Are Intensifying, Particularly in Winter Months.

- Under the **SSP5-8.5** future climate scenario, **wind gusts** exceeding **60 MPH** and **100 MPH** are expected to become more frequent across **northern/central CT** (Fig 2).
- **Predictive modeling** shows potentially damaging wind hazards that coincide with areas with a history of **prolonged outages** and **slow recovery**, amplifying future outage risk.
- Especially in winter, these high wind events create a **compound hazard scenario** of **cold temperatures** and **power outages**, which can be highly impactful over **marginalized communities** (Figs 3 to 5).

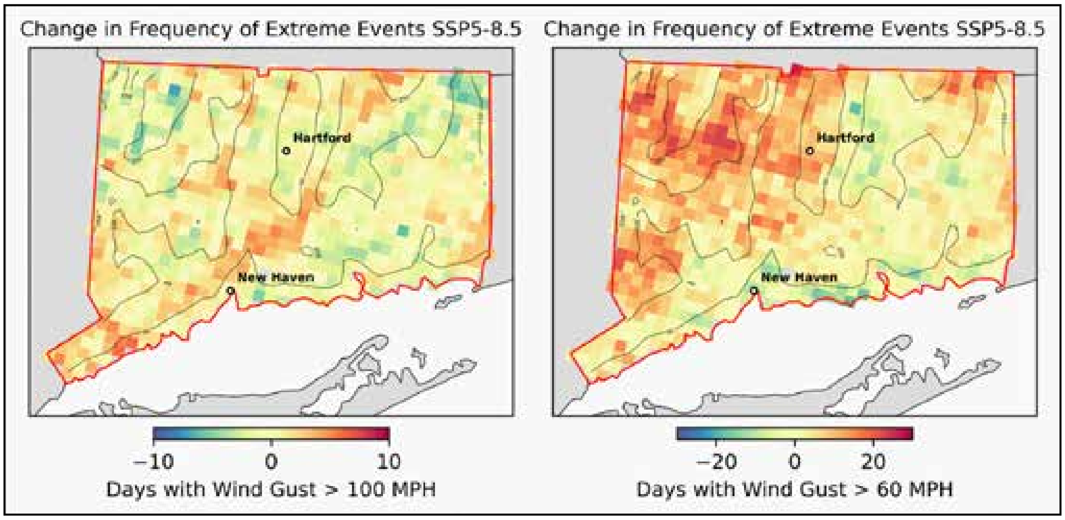


Figure 2. *Change in annual frequency of high-gust days between historical (2015–2019) and future (2055-2059) SSP5-8.5 simulations, CT.*

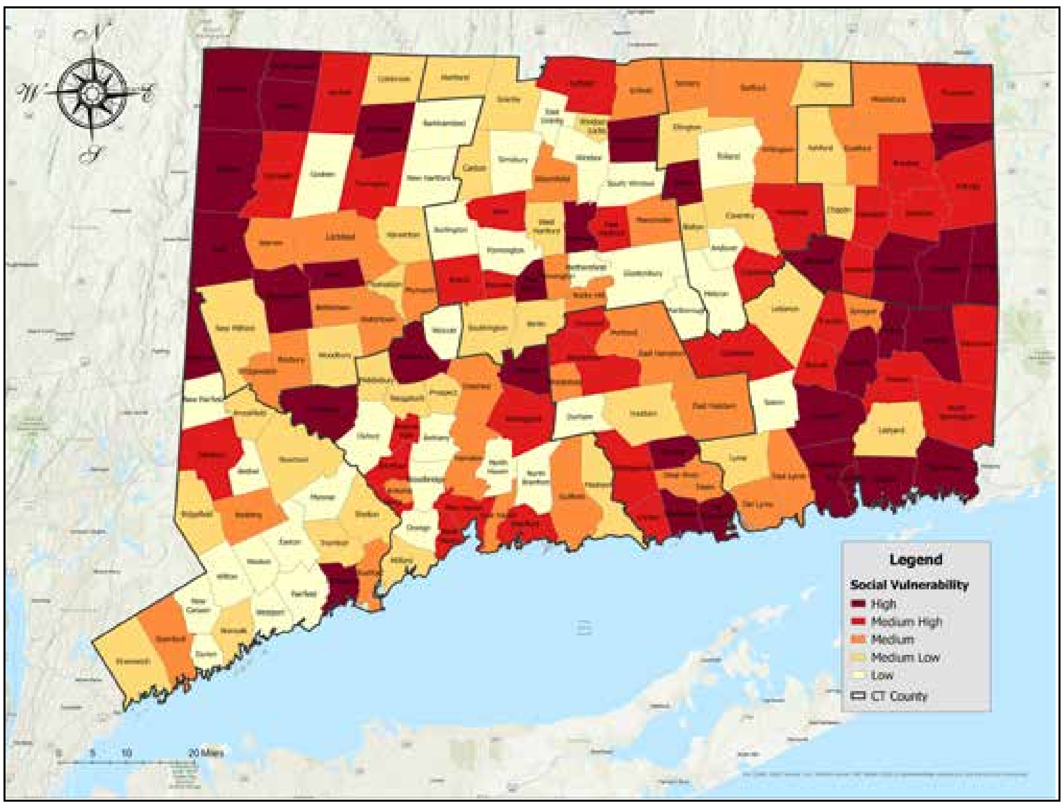


Figure 3. *Social Vulnerability to Environmental Hazards in Connecticut (2023). The Social Vulnerability Index (SoVI) was built from 34 variables in the 2023 American Community Survey 5-year estimates (U.S. Census Bureau), grouped into six pillars: Race/Ethnicity, Population Structure, Socioeconomic Status, Housing Structure, Access & Special Needs, and Employment Structure. SoVI can change over time due to the chosen input indicators, shifts in demographics, migration, housing, local economies, storm impacts, and ACS sampling error or boundary updates. In Connecticut, several high-income towns contain concentrated pockets of socioeconomically vulnerable residents. Mapping SoVI with outage frequency identifies communities where vulnerable populations face more frequent and longer interruptions, often along the coast or in wooded inland areas prone to wind events. Higher-income households may offset impacts with standby generators, while lower-income residents typically cannot and may be deprioritized when restoration triage favors larger load centers, which exacerbate hardship for those already at risk.*

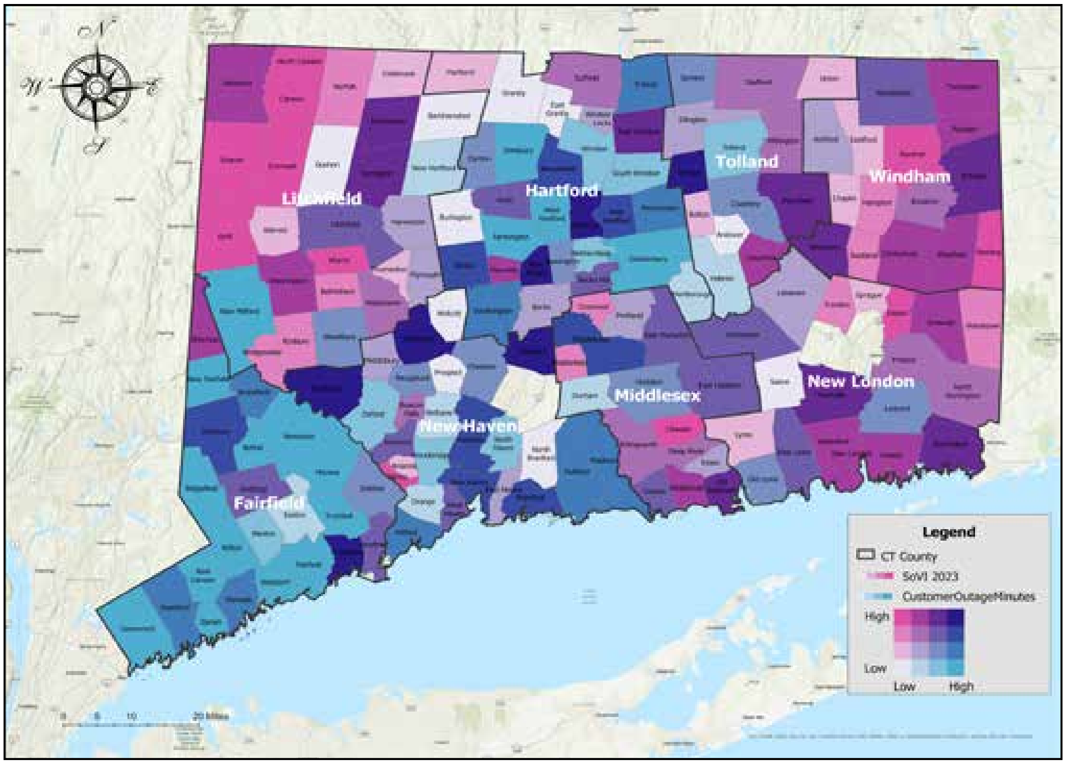


Figure 4. *Bivariate Spatial Analysis of SoVI and Customer Outage Minutes in CT (2005-2023).*

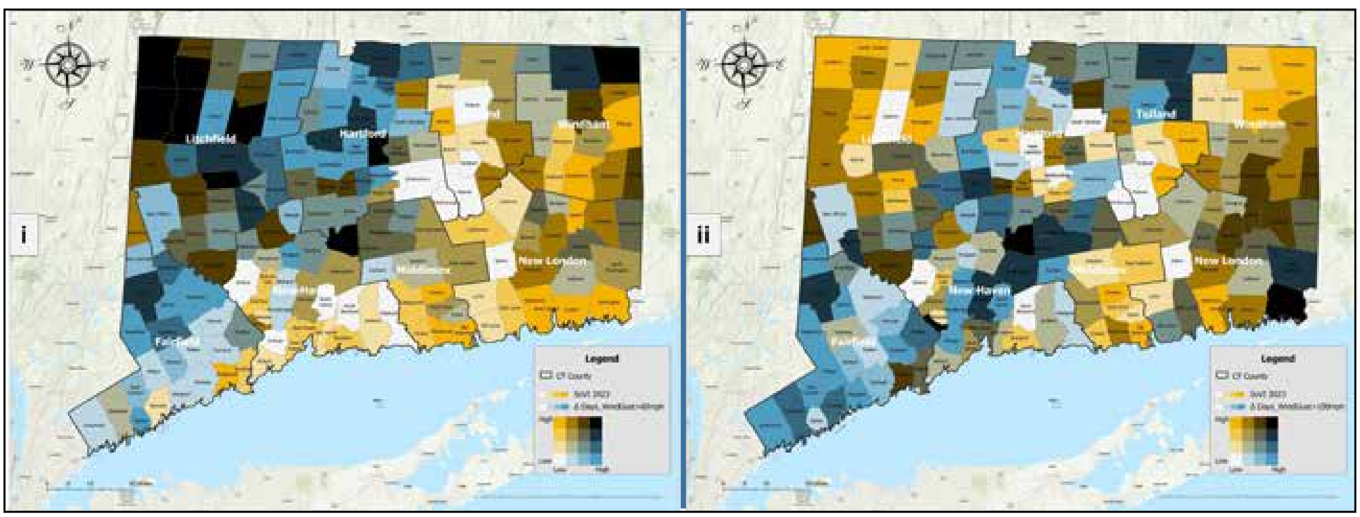


Figure 5. *SoVI and Projected Change in Days with Wind Gusts Exceeding (i) 60 mph and (ii)100 mph in CT under RCP 8.5.*

Planning Implication: Conduct comprehensive outage impact simulations across high-risk regions to guide cost-effective vegetation management and infrastructure hardening strategies that strengthen grid reliability and minimize service disruptions.

Historical Outage Trends and Future Climate Conditions Reinforce the Role of Vulnerability Clusters

- Risk analysis identifies historically persistent **power outage hotspots primarily in coastal CT towns** (Fig 6)

- Several municipalities in the region may face an **increased frequency of severe outage events**. For instance, in **New Haven**, events currently **expected to occur once every 50 years** may recur at **shorter intervals**, such as **every 45 years** (Fig 8)

- Certain areas with elevated outage risk coincide with **high Social Vulnerability Index (SoVI)** values (Figs 3 and 4), meaning that vulnerable residents often endure the **longest and most frequent outages**.

- This alignment suggests considering **social vulnerability** as a targeting criterion **in grid investment plans** (Figs 8 to 11), particularly when combined with **predictive outage clustering**.

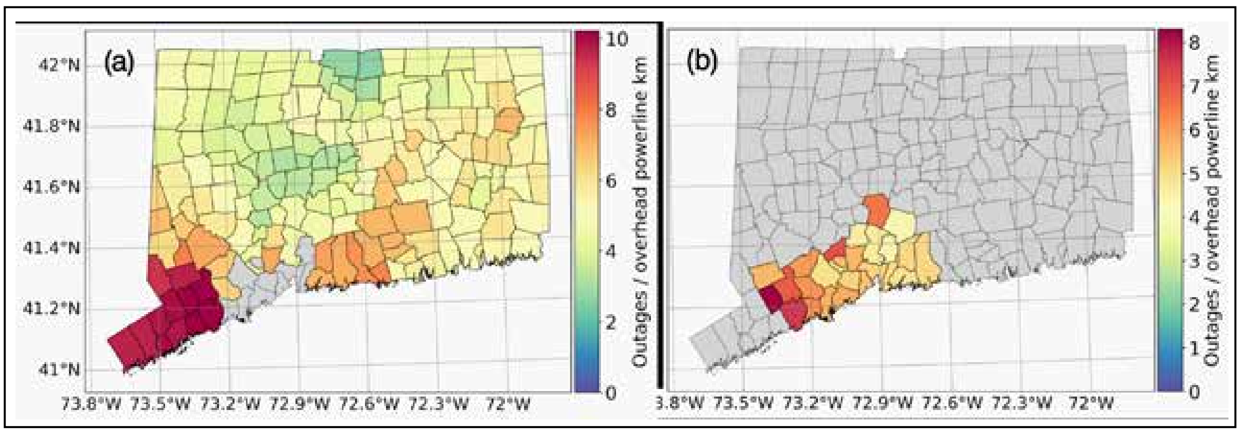


Figure 6. *Power outage totals across Connecticut associated with severe historical storms for the Eversource Energy* ***(a)*** *and United Illuminating* ***(b)*** *service territories, normalized by the length of overhead powerlines. Note that outage record lengths differ therefore a direct comparison should be avoided (see also Fig 7).*

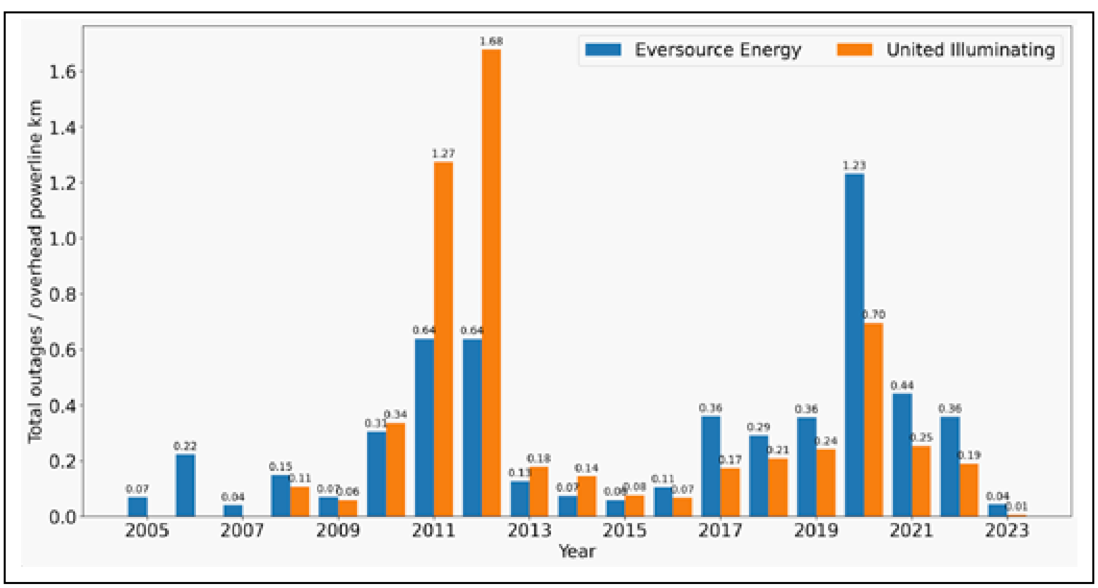


Figure 7. *Yearly power outage totals across the State of Connecticut associated with severe historical storms for the Eversource Energy and United Illuminating service territories, normalized by the total length of overhead powerlines. Note that values for the first and last year of record may not be representative of the entire calendar year.*

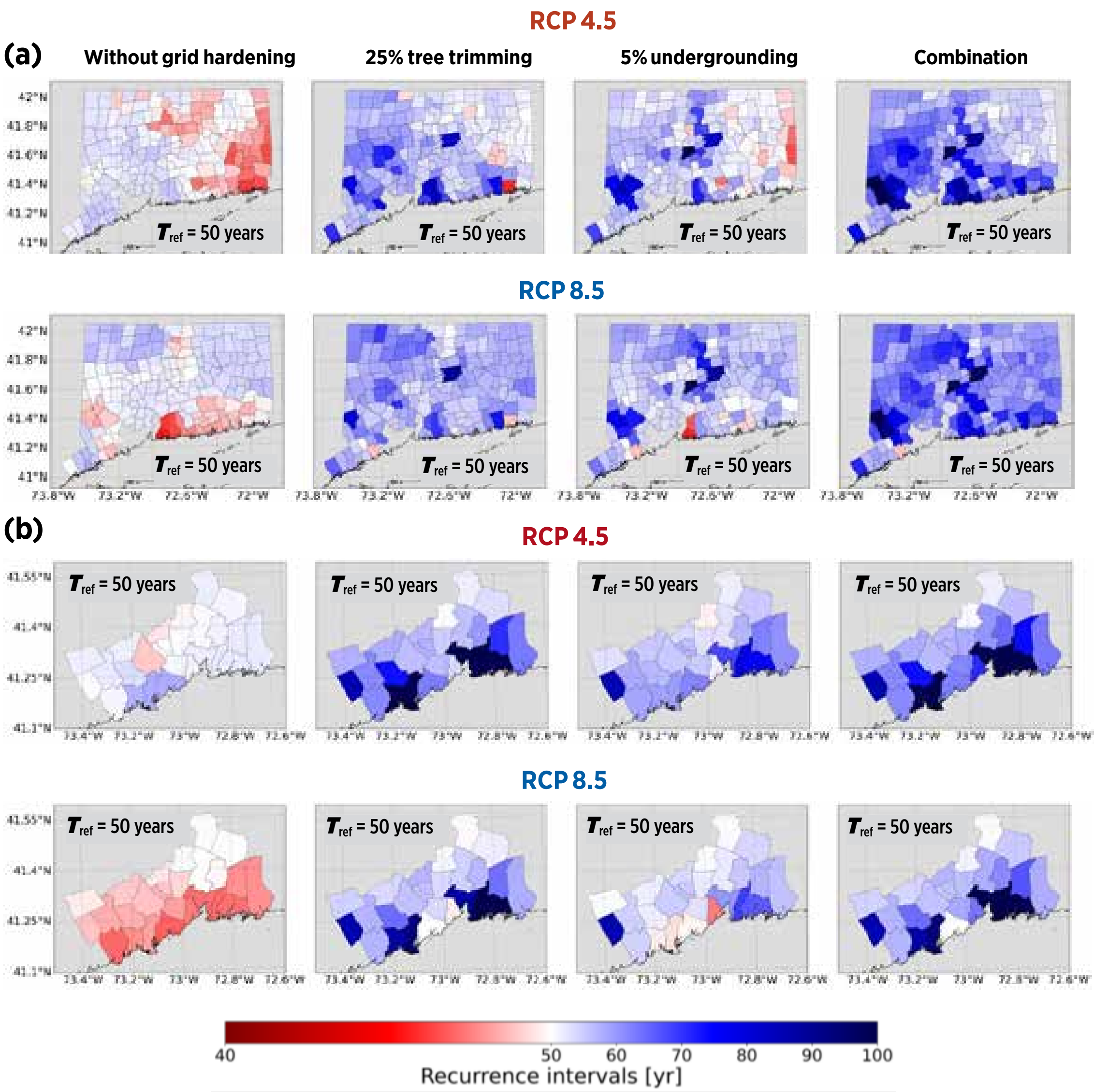


Figure 8. *Change in the recurrence interval of a power outage event with an estimated 50-year average return period, according to the moderate, and worst- case Representative Concentration Pathways, RCP4.5 and RCP8.5, respectively, for the Eversource Energy* ***(a)*** *and United Illuminating* ***(b)*** *service territories, covering the period from 2038 to 2057. Note that the scale of colors differs for better contrast.*

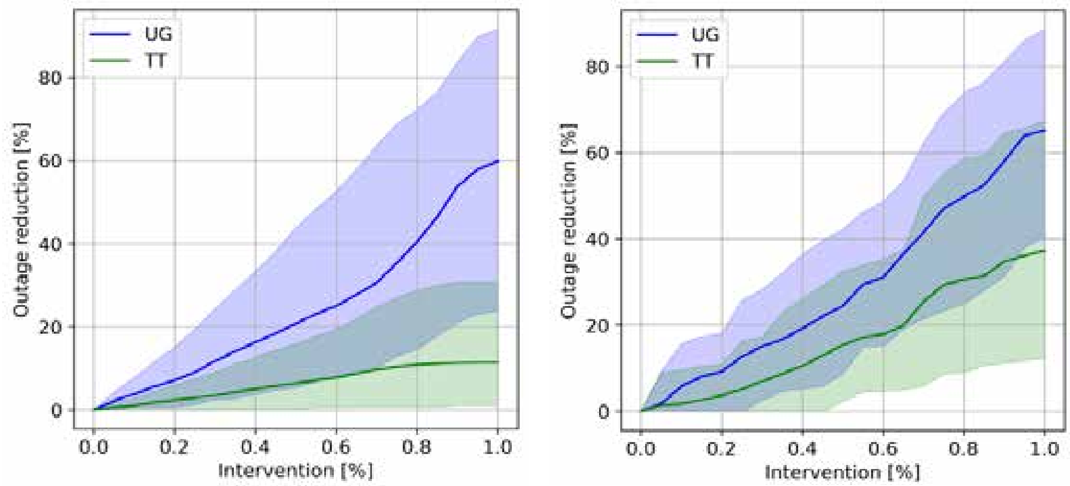


Figure 9. *Outage reduction percentages associated with varying levels of, overhead powerline, undergrounding, and tree trimming, simulated individually, considering severe historical storms. Results are shown for the service territories of* ***(a)*** *Eversource Energy and* ***(b)*** *United Illuminating in Connecticut. Shaded areas represent variability across different storms.*

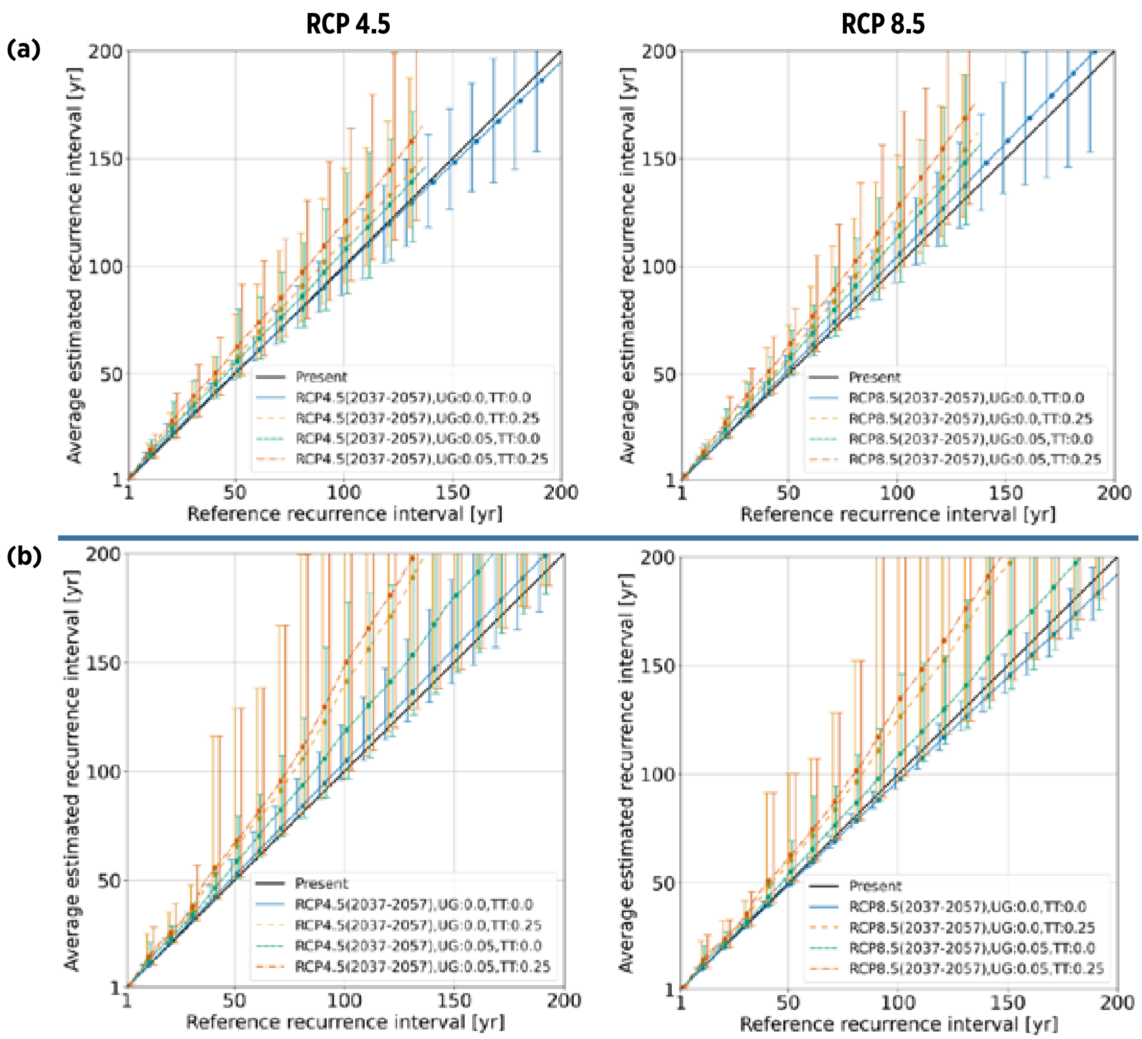


Figure 10. *Changes in the average recurrence interval estimates of power outages over the Eversource Energy* ***(a)*** *and United Illuminating* ***(b)*** *service territories in relation to severe storms, for the moderate, and worst- case Representative Concentration Pathways, RCP4.5 and RCP8.5, respectively, covering the period from 2038 to 2057, and application of undergrounding (UG) and tree trimming (TT) grid hardening strategies. Note that segments of lines that correspond to steep return period increase are masked out.*

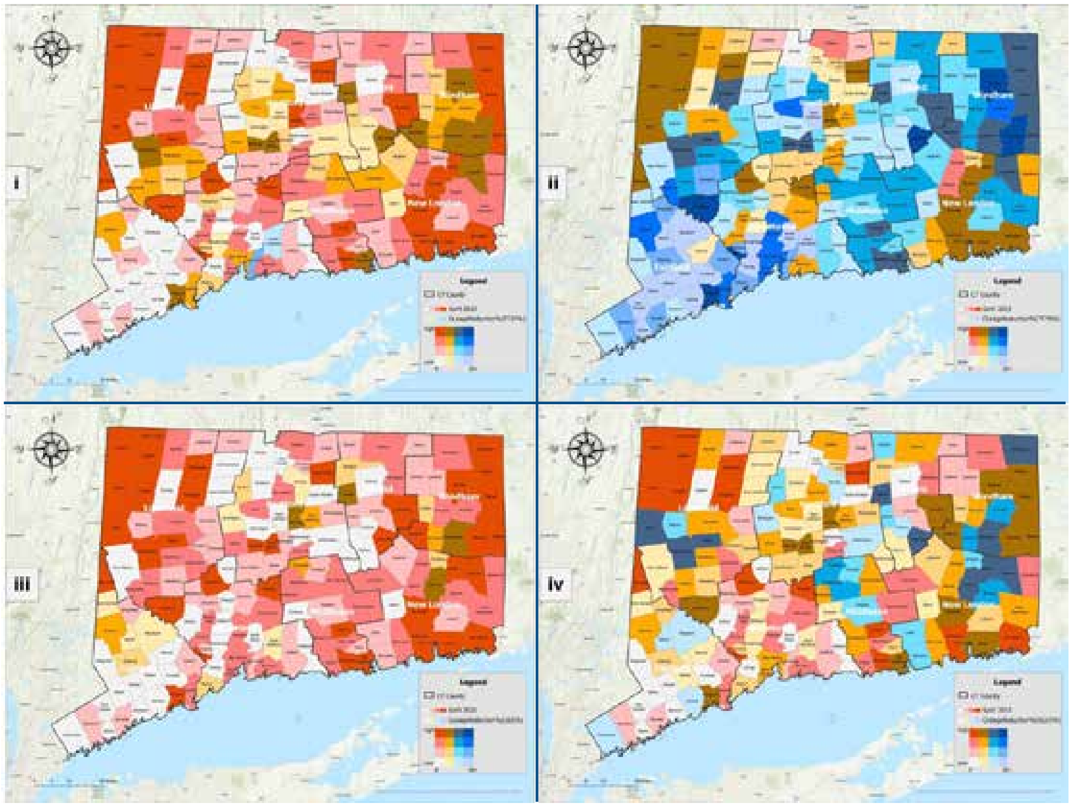


Figure 11. *SoVI and Resilience Enhancement Strategies: Tree-Trimming (i) 25%, (ii) 75% & Undergrounding (iii) 5%, (iv) 15% for Targeted Outage Reduction in CT.*

> **Planning Implication:** Prioritize resilience funding in regions with repeated outage exposure and electric infrastructure risk to maximize return on investment and ensure reliable service for vulnerable communities facing the highest disruption frequency.

Infrastructure Gaps Create Variable Circuit Resilience

- In circuits lacking **DER** or **BESS** systems, such as in **West Hartford, CT**, **voltage recovery** was shown, based on simulated restoration events, to be delayed by up to **4 minutes**, increasing the likelihood of cascading system failure (Figs 12 and 13).

- By contrast, **DER-rich** areas, such as **Wareham, MA**, show recovery in under **2 minutes** (Figs 12 and 13), illustrating the resilience benefits of **distributed energy resource investments**.

- These **comparative findings** suggest that **operational knowledge from DER-enabled circuits** in other regions can serve as valuable benchmarks to **inform infrastructure improvements and resilience planning** in Connecticut.

- Modeling shows that **targeted BESS** installation and **DER dispatch** coordination can cut **voltage instability** and **peak load surges**, particularly in **circuits with aging infrastructure exhibiting vulnerability to storms**.

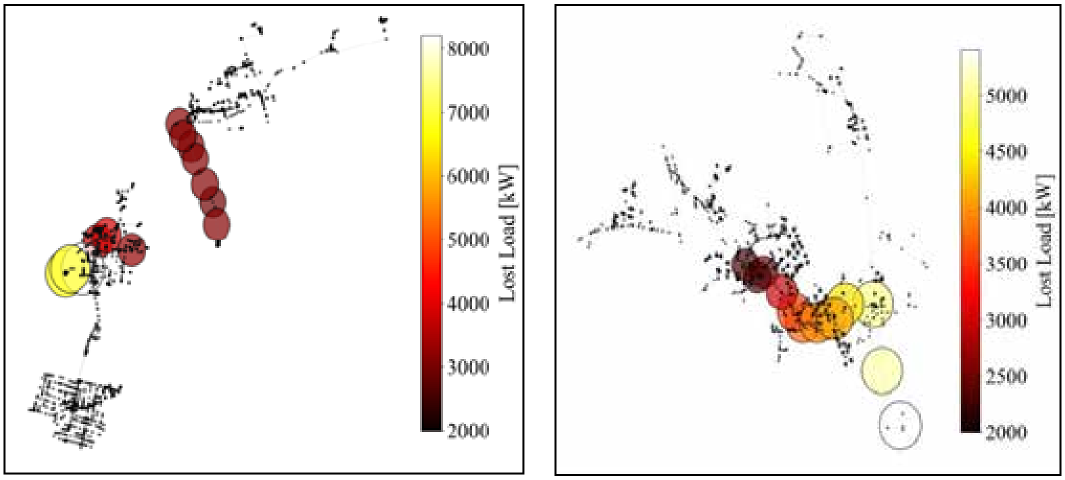


Figure 12. *Vulnerable zones for higher loss of loads during outages in West Hartford, CT,* ***(a)*** *and in Wareham, MA* ***(b)****.*

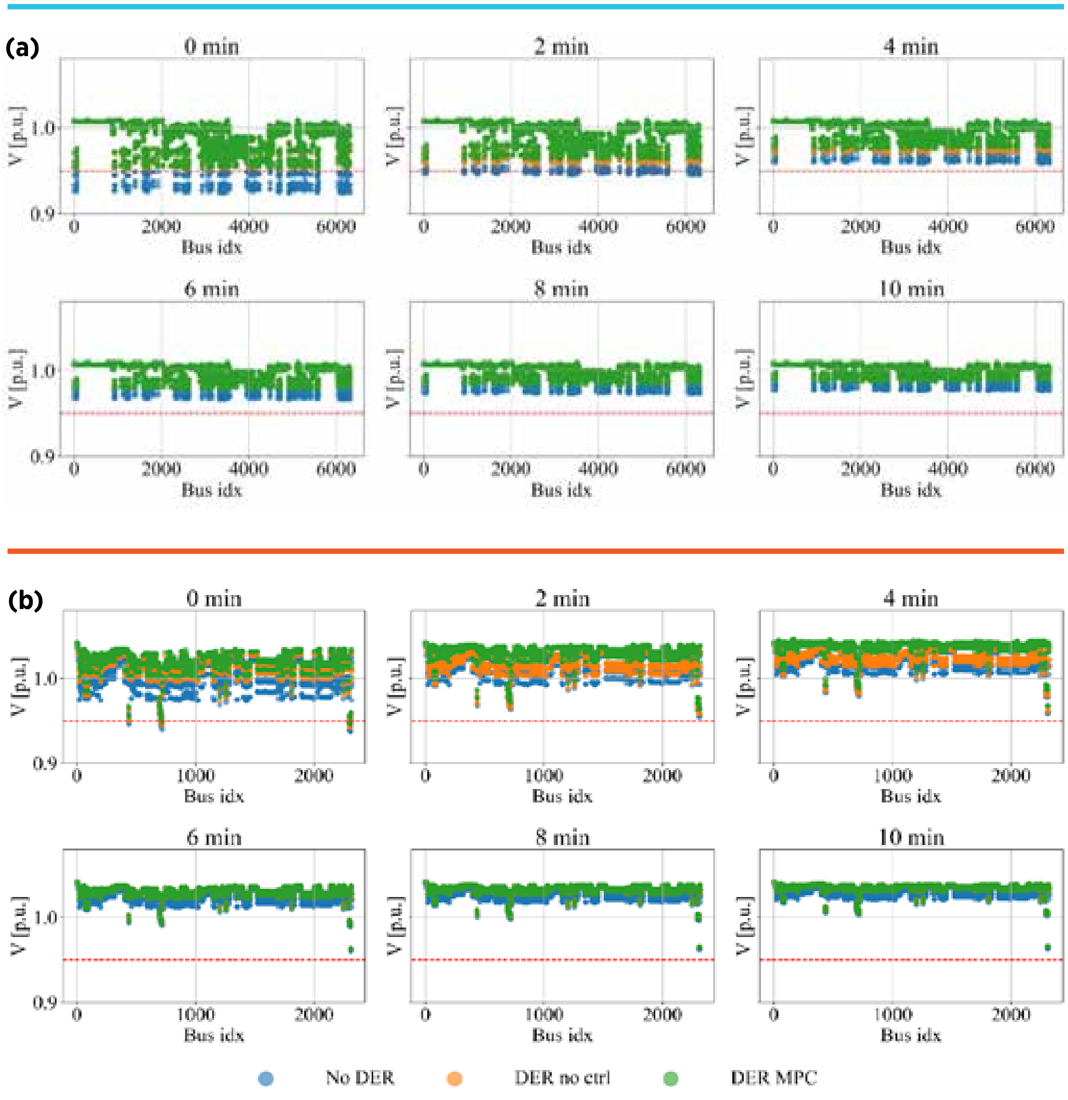


Figure 13. *Voltage recovery using DERs during a restoration action in West Hartford, CT, circuit* ***(a)*** *and in Wareham, MA, circuit* ***(b)****.*

Planning Implication: Prioritize DER and BESS deployment along backbone feeders in high-vulnerability, low-redundancy regions. Use simulation tools to identify "at-risk" feeder-customer pairs.

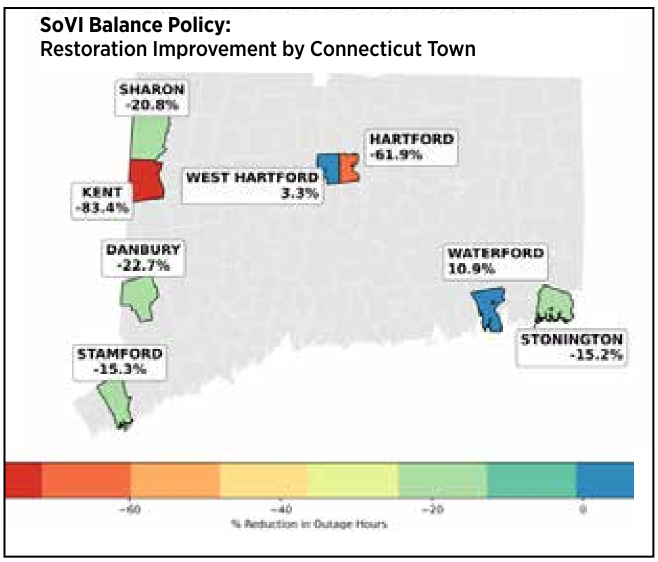
Vulnerability-Driven Restoration Shows Measurable Gains

- A targeted experiment, which assigned **evening-shift restoration crews** to vulnerable towns, achieved substantial outage reductions in major population centers: **62% in Hartford**, **23% in Danbury**, and **15% in Stamford**, with similar improvements across most high-vulnerability communities identified through SoVI (Fig 14a).

- Adjacent service areas exhibited **minimal impact**, demonstrating that targeted crew deployment improves overall system efficiency and delivers high-impact returns over vulnerable communities, **without** increasing operational burden (Fig 14b).

- As **grid hardening measures** evolve, they may **alter restoration dynamics** (Figs 15 and 16), warranting the evaluation of alternative protocols to optimize crew deployment strategies.

(a)



(b)

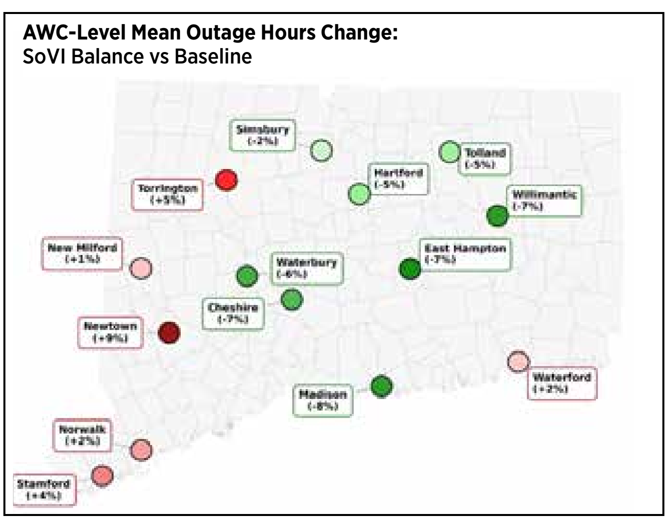


Figure 14. *Percentage change in mean customer outage duration through different crew allocation shown at town level **(a)** and Area Work Center (AWC) level **(b)**.*

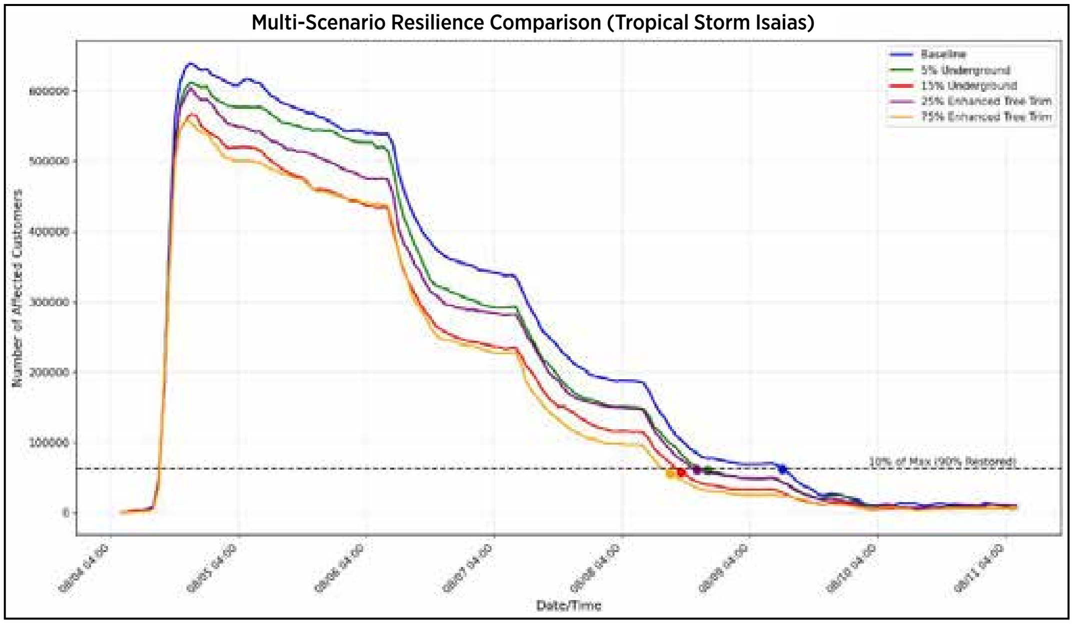


Figure 15. *Restoration of Tropical Storm Isaias under different resilience improvement scenarios. The dashed line indicates the 90% restoration threshold, representing the moment when just 10% of peak customers remained to be restored.*

Figure 16. *Change of restoration time by Area Work Center (AWC): the numbers represent the differences (in hours) for achieving 90% of customer outage restoration, with respect to the baseline scenario. Green circles indicate faster restoration, while orange/yellow circles show areas with minimal improvement or even slight delays.*

Planning Implication: Standardize data-driven crew deployment protocols across Area Work Centers (AWCs) to improve storm recovery efficiency, reduce outage duration, and prioritize service restoration in communities most at risk from repeated disruptions.

Customer Surveys Reveal Significant Heterogeneity in Residents' Willingness to Pay (WTP) to Reduce the Frequency and Duration of Power Outages

- Lower-income households (i.e., income less than $50,000) exhibit the highest annual WTP, highlighting their heightened vulnerability and limited coping capacity (Fig 17).
- High-income households (i.e., income larger than $200,000) also demonstrate relatively high WTP, potentially reflecting productivity concerns and stronger expectations for uninterrupted service.
- Middle-income groups show lower and statistically insignificant WTP, possibly due to existing preparedness measures and a balanced level of risk exposure.

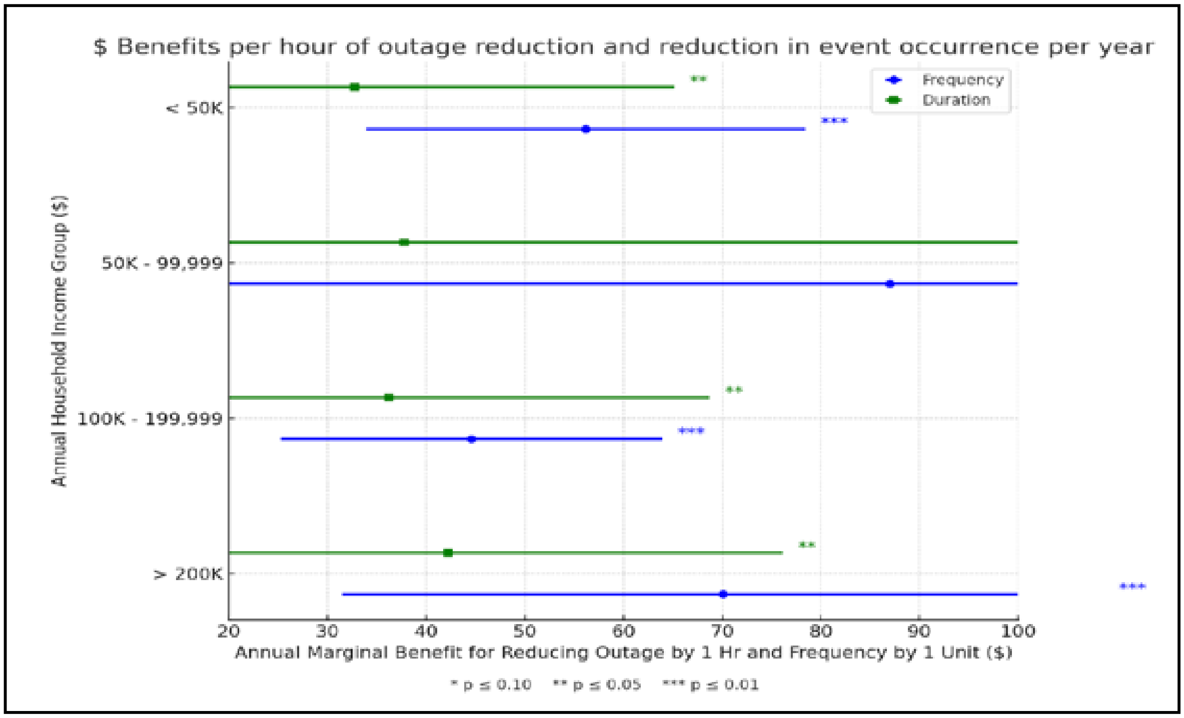


Figure 17. *Annual Marginal Willingness to Pay for Reducing Power Outage Frequency and Duration by Income Group: This figure shows the estimated annual marginal willingness to pay (MWTP) for reducing power outage frequency by one event per year (blue circles) and outage duration by one hour (green squares) across four household income groups. Error bars represent 95% confidence intervals. Statistical significance is indicated by asterisks: p ≤ 0.10 (*), p ≤ 0.05 (**), p ≤ 0.01 (***). Results are based on mixed logit model estimates and reflect heterogeneous preferences by income.*

Planning Implication: Tailor resilience investments to the needs and priorities of distinct demographic groups to support more targeted and equitable investment strategies for enhancing resilience and improving societal welfare.

RECOMMENDATIONS

Challenges & Priorities:

- **Extreme weather events under SSP5-8.5** include wind gusts that exceed historical thresholds by 10 MPH, as well as extended periods of **severe heatwaves**, which **amplify reliability challenges**
- **Outage modeling,** trained and validated based on historical data from 2005 to 2023, projects up to **3-fold increase in outage frequency** in southeastern and central CT under worst-case future climate scenarios.
- **Simulation of Hartford and West Hartford circuits** reveals **systemic vulnerabilities in backbone feeders**, including voltage instability exceeding 4 minutes during clustered outages without local DER or BESS support.
- **Recurrent outages** in Windham, New Haven, and coastal New London Counties correlate with areas facing **high infrastructure stress** and limited system redundancy.
- **Prolonged restoration timelines** in under-resourced communities reduce economic productivity and grid reliability.
- **Connecticut customer survey** asking about their trust in various institutions for making effective investments to reduce power outages showed that local and state governments are the most trusted entities, followed closely by nonprofit organizations and utility companies (see Fig. 18).
- **A substantial majority of survey respondents** also expressed agreement or strong agreement with the effectiveness of solar panels, microgrids, burying power lines, and trimming trees in ensuring power access during emergencies and reducing future outages.

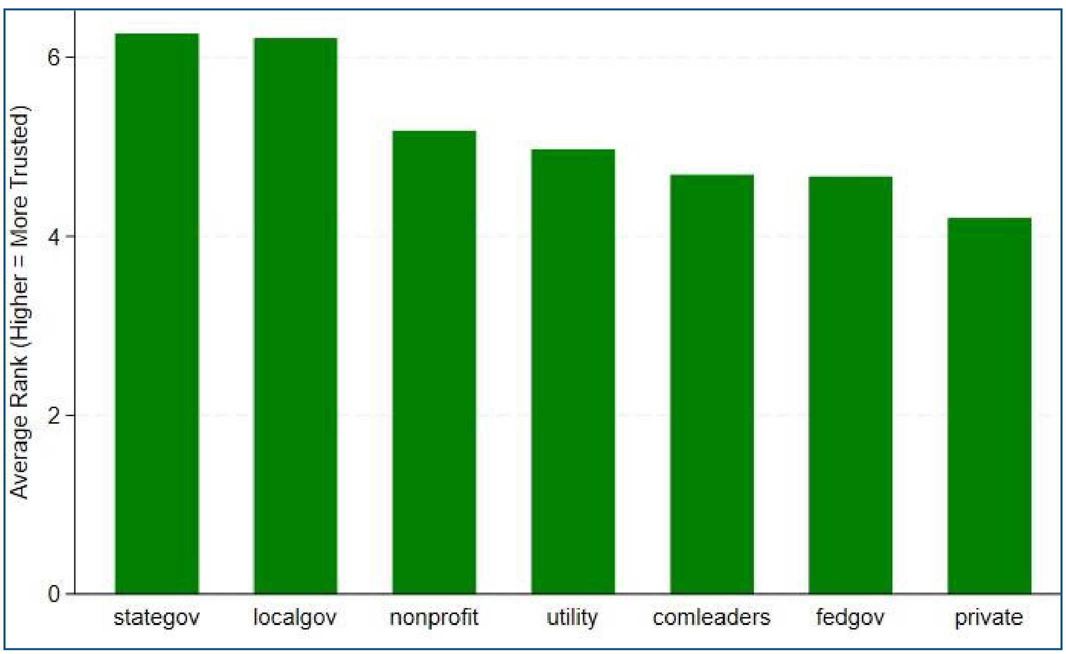


Figure 18. *Average Trust Rankings of Organizations for Leading Power Outage Reduction Efforts: This bar chart displays respondents' average trust rankings for various entities regarding who should take primary responsibility for investing in actions to reduce power outages in their community. Higher values indicate greater trust. State and local governments received the highest average rankings, followed by nonprofit organizations and utilities. Private companies and the federal government were ranked lower on average.*

Recommended Actions:

- **Build circuit-level dashboards** that combine weather, demand and outage risk, infrastructural fragility, and restoration times, to prioritize grid investments.
- **Fast-track BESS deployment** along backbone feeders in selected areas (e.g. Hartford) and integrate DER dispatch using Model Predictive Control (MPC) to enhance voltage stability.
- **Scale enhanced vegetation management** coverage to 75% in high-risk zones and initiate 15% **targeted powerline undergrounding** in areas with recurring outages and exposed infrastructure.
- **Advance community microgrids** where DER penetration already exists, optimizing islanding and VPP (define-Virtual Power Plants) potential and linking design to SCADA/ADMS upgrades.
- **Launch a Connecticut Resilience Roadmap (2025 – 2030)** aligned with PURA's grid modernization goals[1] and ratepayer value.

Recommended Strategies:

- The increase of **outage risk is spatially variable**, and **targeted modeling** is essential to efficiently guide resources to the highest-impact areas.
- **Combined grid-hardening measures**, when informed by **outage prediction models** and **operational data**, yield up to **2- to 3-fold reductions in event frequency and 30% in severity**.
- **Public sentiment favors investment** in resilience through proven measures, such as tree trimming, burying power lines, grid automation, and microgrids, to **enhance reliability and safeguard economic output**.

[1] Public Utilities Regulatory Authority (see also https://portal.ct.gov/pura)

INVESTMENT PRIORITIES FOR 2025 – 2030

1. **Further Develop Statewide Outage Forecasting Tools**
   Leverage available outage information, refined meteorological data, system fragility, and economic metrics, to continuously update regional outage risk assessments and operational storm preparedness. Support emergency response strategies to future compound hazards, including heatwaves, storm-outages, and floods, to ensure energy continuity, efficient resource deployment, and risk mitigation ahead of extreme weather events.

2. **Target Investments to Circuits under Highest Risk**
   Focus capital on circuits repeatedly flagged for outages, instabilities, or restoration delays, especially where public safety and economic activity are vulnerable. Use grid resilience simulation tools to evaluate the impact of investment on outages reduction.

3. **Deploy Adaptive Microgrids in High-Priority Areas**
   Identify grid-edge communities with existing DERs for rapid microgrid development, maximizing restoration capabilities and backup power access.

4. **Strategically Reallocate Restoration Crews during Outage Events**
   Use predicted storm impacts and restoration simulation tools to preposition crews in high-risk regions, maximizing response efficiency without increasing overall staffing.

5. **Integrate Outage Models into Utility and Public Grant Filings**
   Ensure all utility investment cases and municipal resilience plans cite quantitative modeling results to justify spending and assess benefits.

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