Leveraging Cross-Sector Investments for Peak Demand Reduction and Energy System Resilience in the Era of Deep Decarbonization

Presented by:
Jill Moraski, PhD

Presented to:
Massachusetts Office of Energy Transformation

August 7, 2025

Image source: AP News

1. **RAIL SECTOR:** RAIL-BASED MOBILE ENERGY STORAGE
2. **BUILDINGS SECTOR:** PASSIVE SURVIVABILITY INVESTMENTS

nature energy

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Leveraging rail-based mobile energy storage to increase grid reliability in the face of climate uncertainty

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Jill W. Moraski[1,2], Natalie D. Popovich[2] & Amol A. Phadke[2]

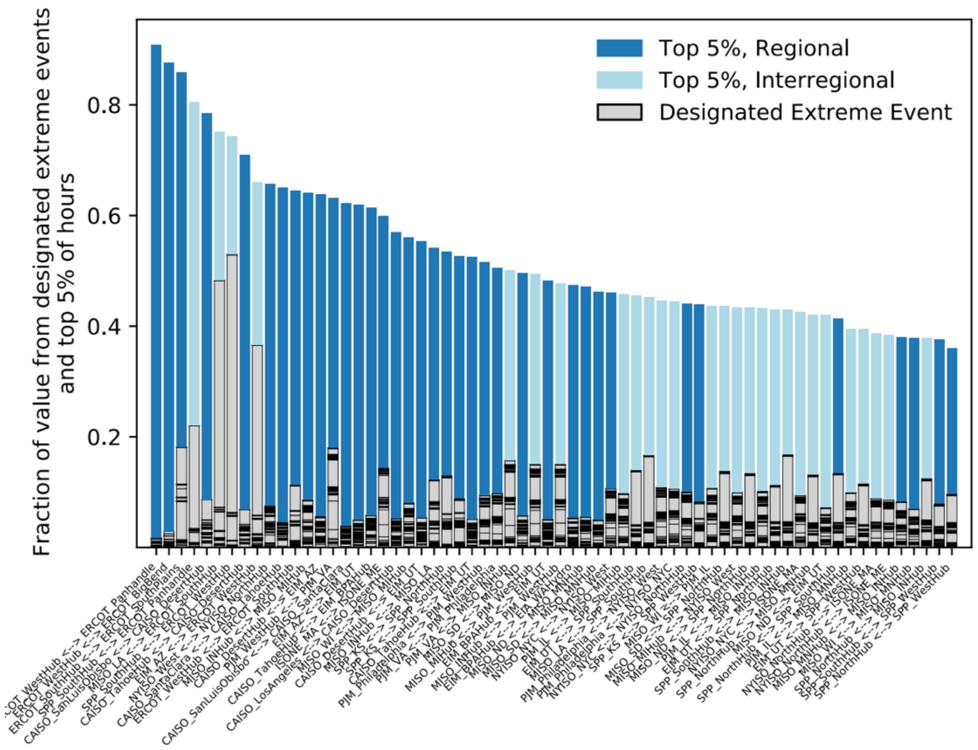
SOLUTION 1: RAIL-BASED MOBILE ENERGY STORAGE

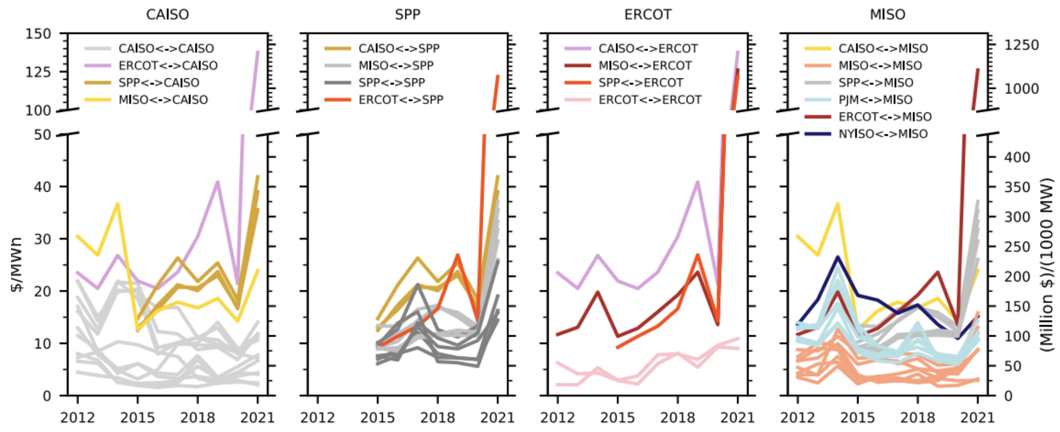
Is it feasible for rail-based mobile energy storage (MES) to serve as spatially flexible, low fixed-cost resource for meeting infrequent peak demand conditions?

Economic motivation: Transmission lines are a baseload solution to peak-y issues

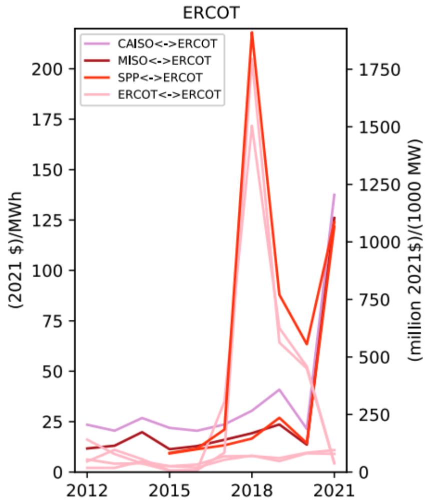
Millstein et al. (2022)

- 50% of transmission congestion value comes from top 5% of hours (~25% of value in top 1% of hours)
- Extreme conditions play an outsized role in the value of transmission
- Valuable transmission links vary by year





[Millstein et al (2022)](#)



ERCOT Panhandle and Big Bend Links

Technical motivation: Existing infrastructure and proven technology

Mobile batteries alleviate locational uncertainty

Source: Union Pacific

Union Pacific Railroad - $100 million investment in 20 battery electric locomotives

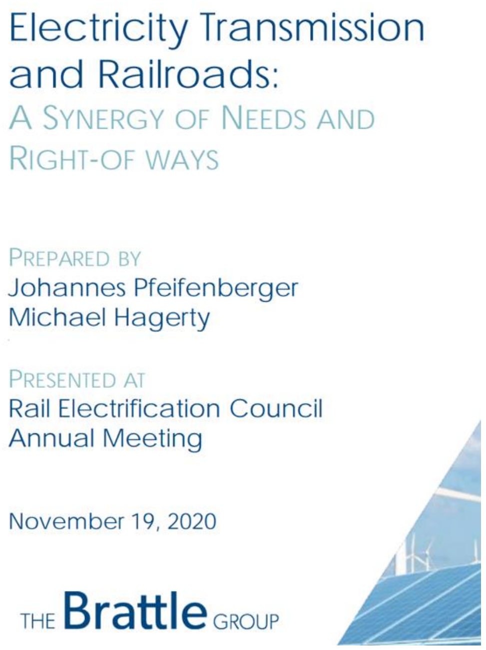
Source: Wartsila, European Commission, Green Car Congress, 2022

Maersk - 600 kWh container ship battery for hybrid operation;
Current Direct – European Commission-funded swappable container waterborne transport battery

Popovich et al (2021) – Technoeconomic feasibility of freight locomotive battery electrification
Kersey et al (2022) – Technoeconomic feasibility of container ship battery electrification

Rail corridors relieve transmission siting issues

- 140,000 miles of rail in the contiguous United States
- Several entities have pointed out the synergies between transmission expansion needs and rail rights-of-way *Brattle (2020), DOE (2021), DOE(2022)*


Electricity Transmission and Railroads:
A Synergy of Needs and Right-of Ways

Prepared by
Johannes Pfeifenberger
Michael Hagerty

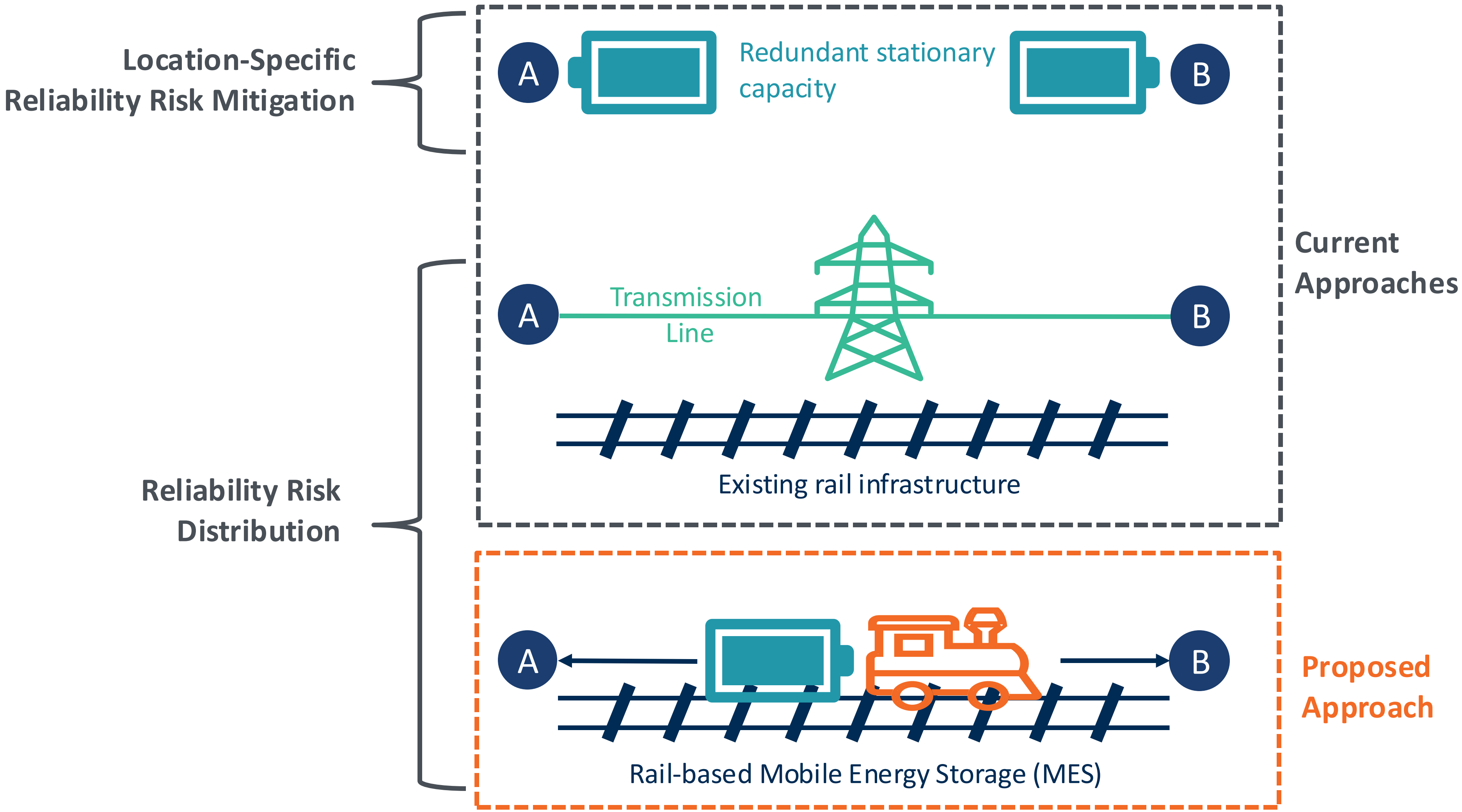
Presented at
Rail Electrification Council Annual Meeting

November 19, 2020

The Brattle Group

"While being historically and operationally different…the interaction of freight railroads and the grid represents a major opportunity -- often a missed opportunity -- to anticipate greater electrification of our economy and greater utilization of brownfields rights-of-way to site energy delivery facilities…"
– former FERC Chair James Hoecker (RM20-10-000)

Conceptual idea: Rail-based Mobile Energy Storage (MES)



Assessing Rail Sector Feasibility

It is possible to move large amounts of mobile energy storage over the rail network without disrupting freight schedules?

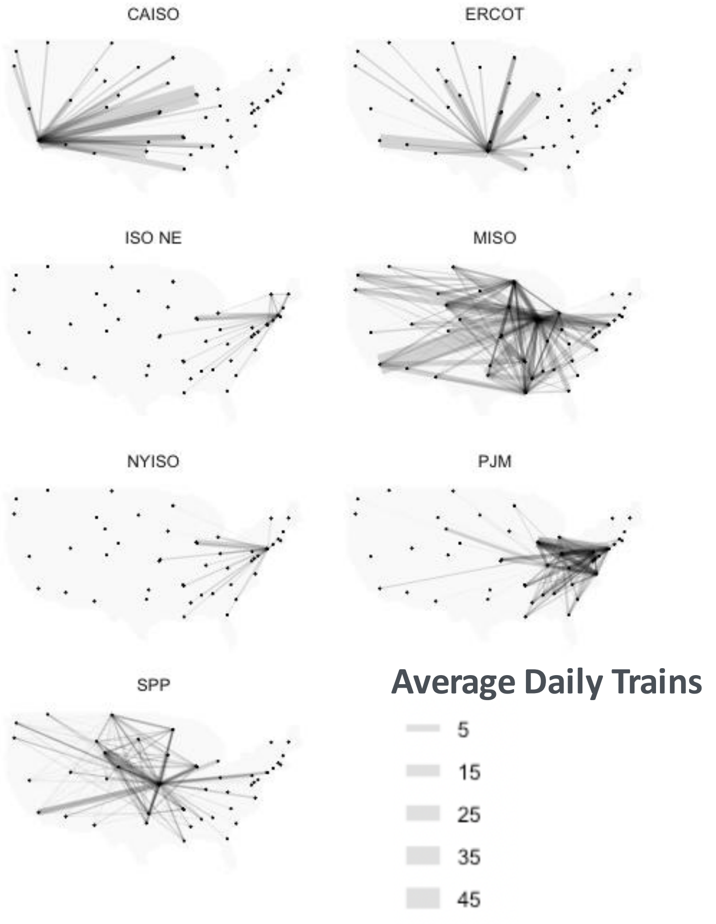
Data

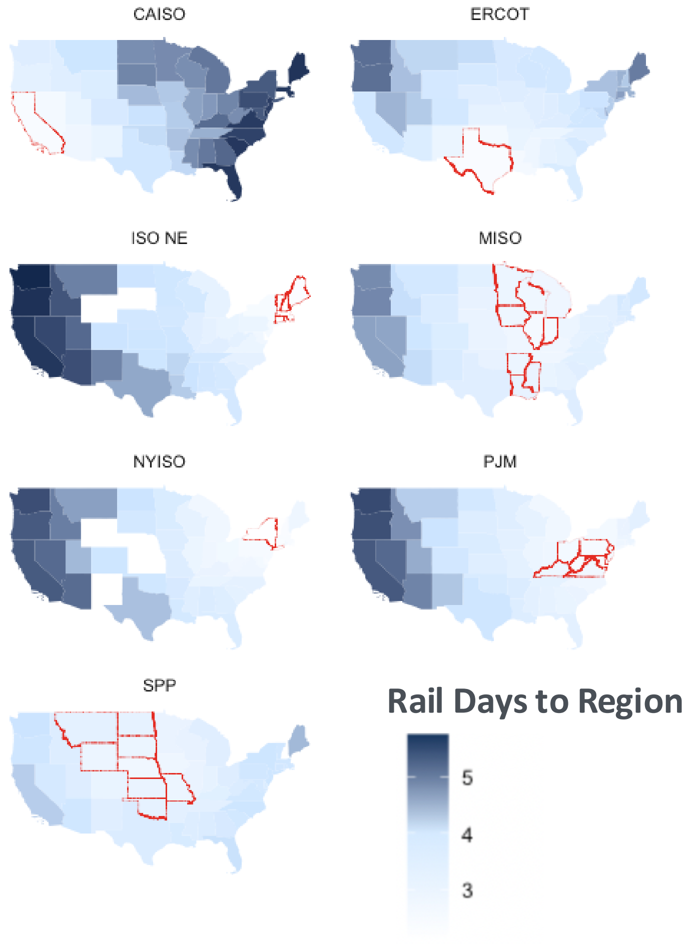
2019 Waybill Sample (Surface Transportation Board)

Rail network geospatial data (ABB Velocity Suite)

Methods

Network graph analysis





Assessing Rail Sector Feasibility

It is possible to move large amounts of mobile energy storage over the rail network without disrupting freight schedules?

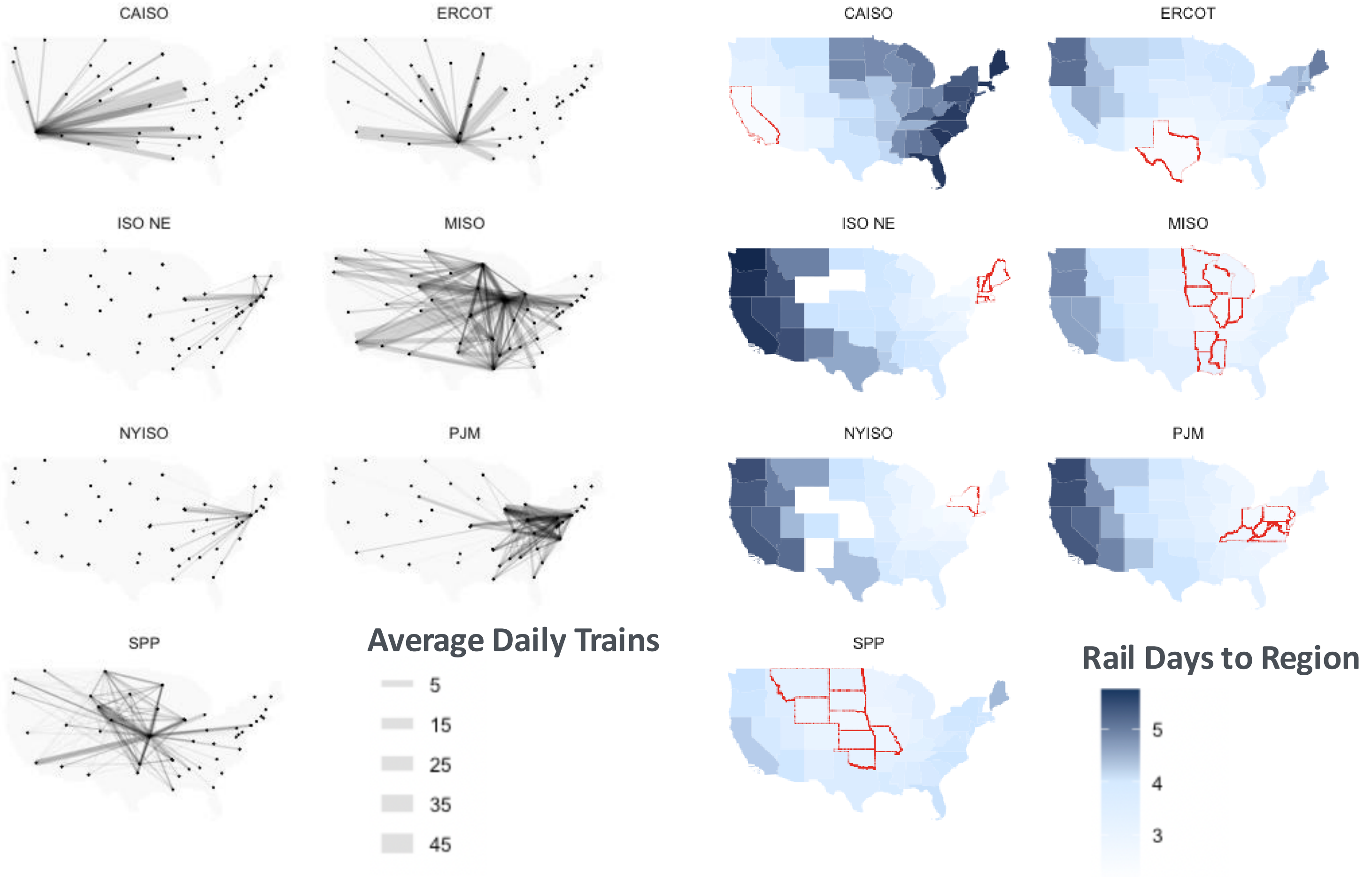
Findings

Most major grid operating regions have between one and 50 daily train shipments traveling to them from each state

It would take 1-6 days to move a train between two regions of the power sector, inclusive of scheduling time

Conclusions

It is possible to move large amounts of mobile energy storage over the rail network without disrupting freight schedules



Assessing Power Sector Feasibility

Are peak events predictable and sufficiently spaced in time to be effectively served by rail-based MES?

Data

2010 – 2021 Locational Marginal Price (ISO price zones only)

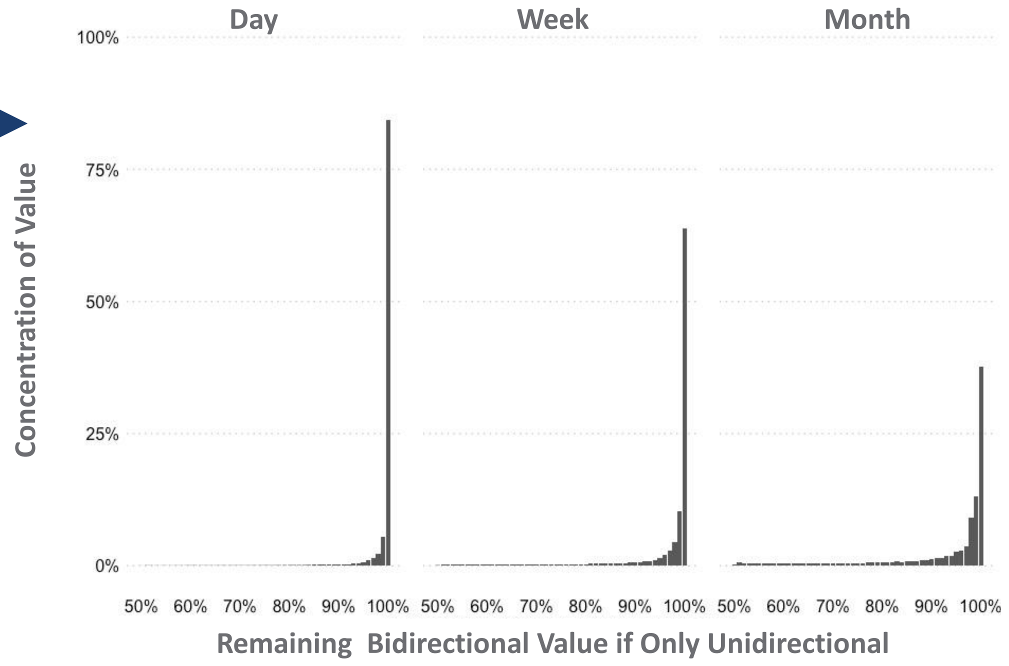
2010-2021 Gross Load Forecast (ABB Velocity Suite)

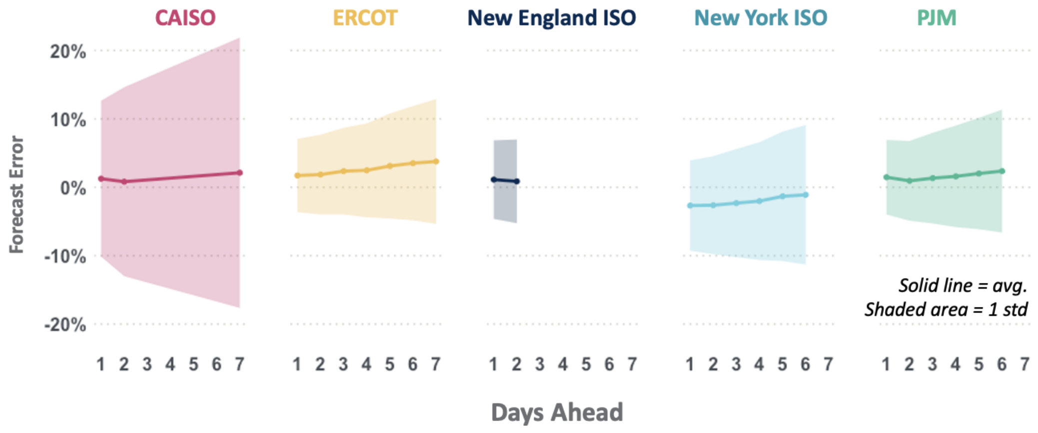
Event analysis reports (CAISO, ERCOT)

Methods

Statistical analysis of price correlation, forecast error

Temporal analysis of tx value





Assessing Power Sector Feasibility

Findings

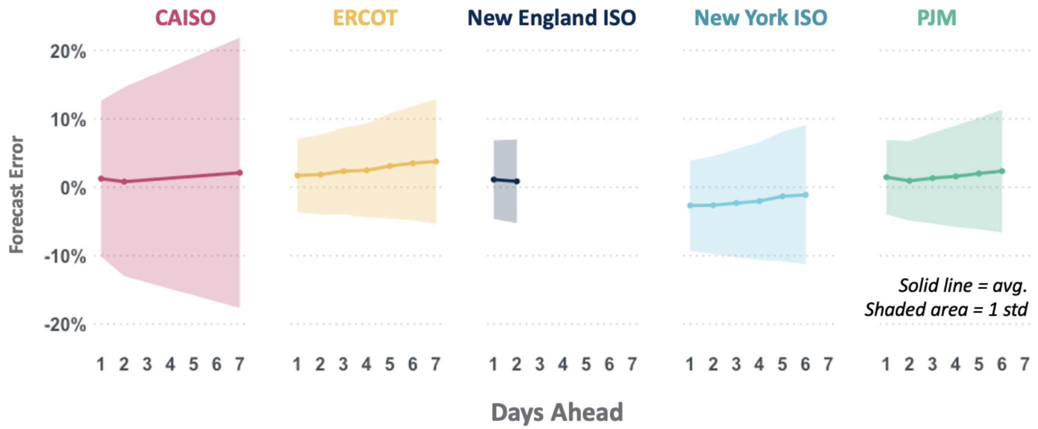
Peak demand periods can be predicted up to 7 days in advance with relative certainty - within 5% of actual load on average

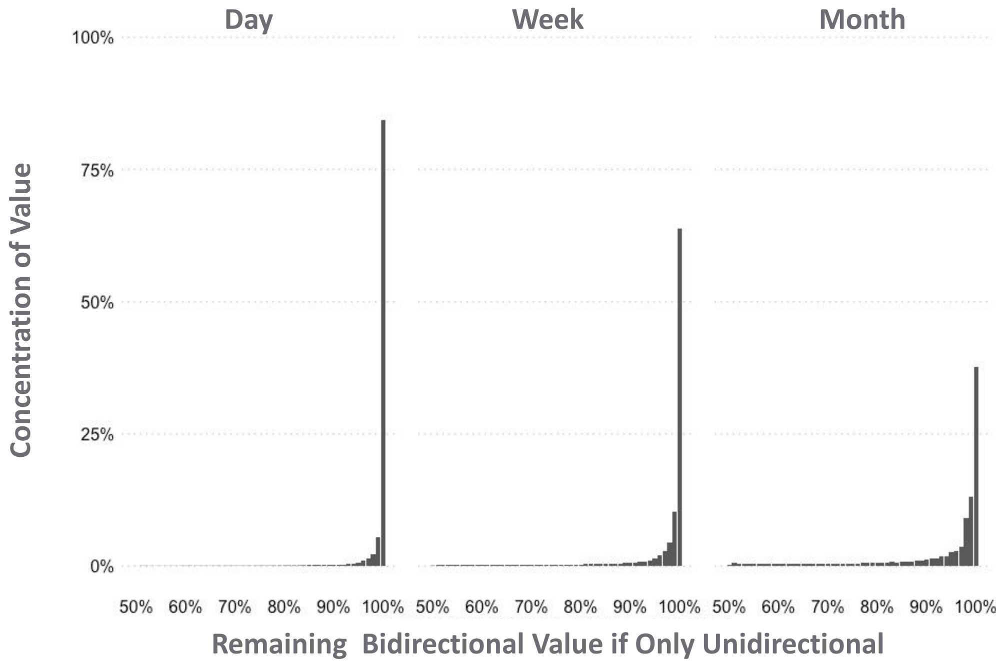
85% of bidirectional transmission arbitrage opportunity can be captured by unidirectional arbitrage on the day surrounding a peak event

Conclusions

Additional capacity needs in most operating regions can be predicted enough in advance for transmitting stored electricity over the rail network.

There is sufficient temporal separation in peak events such that the same capacity can be used in multiple locations





SOLUTION 1: RAIL-BASED MOBILE ENERGY STORAGE

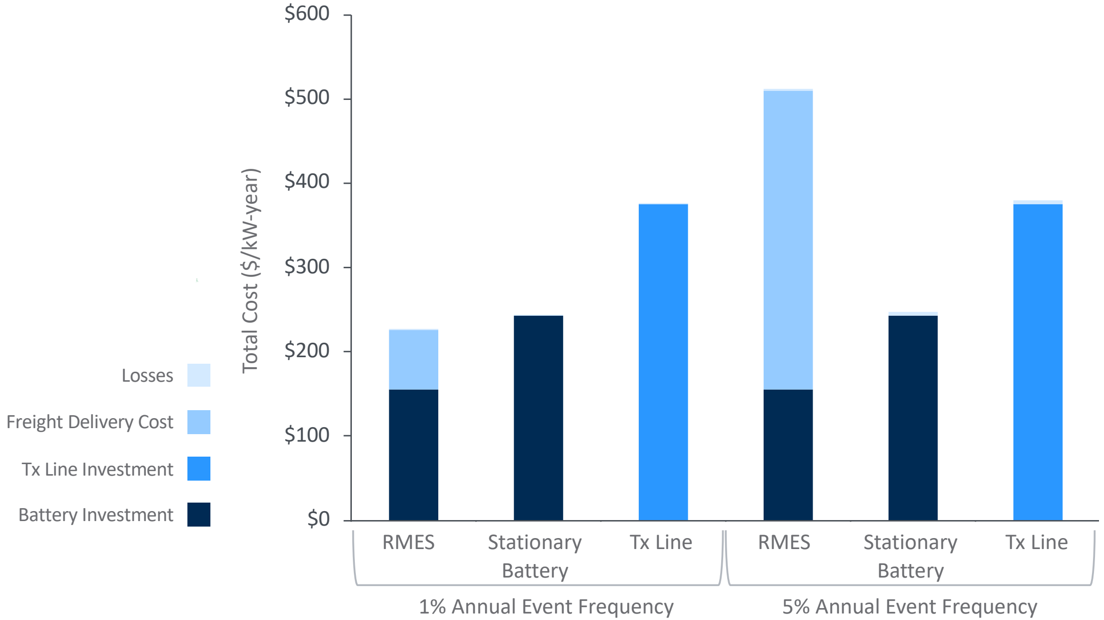
Cost-effectiveness of MES

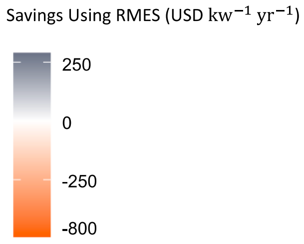
Findings

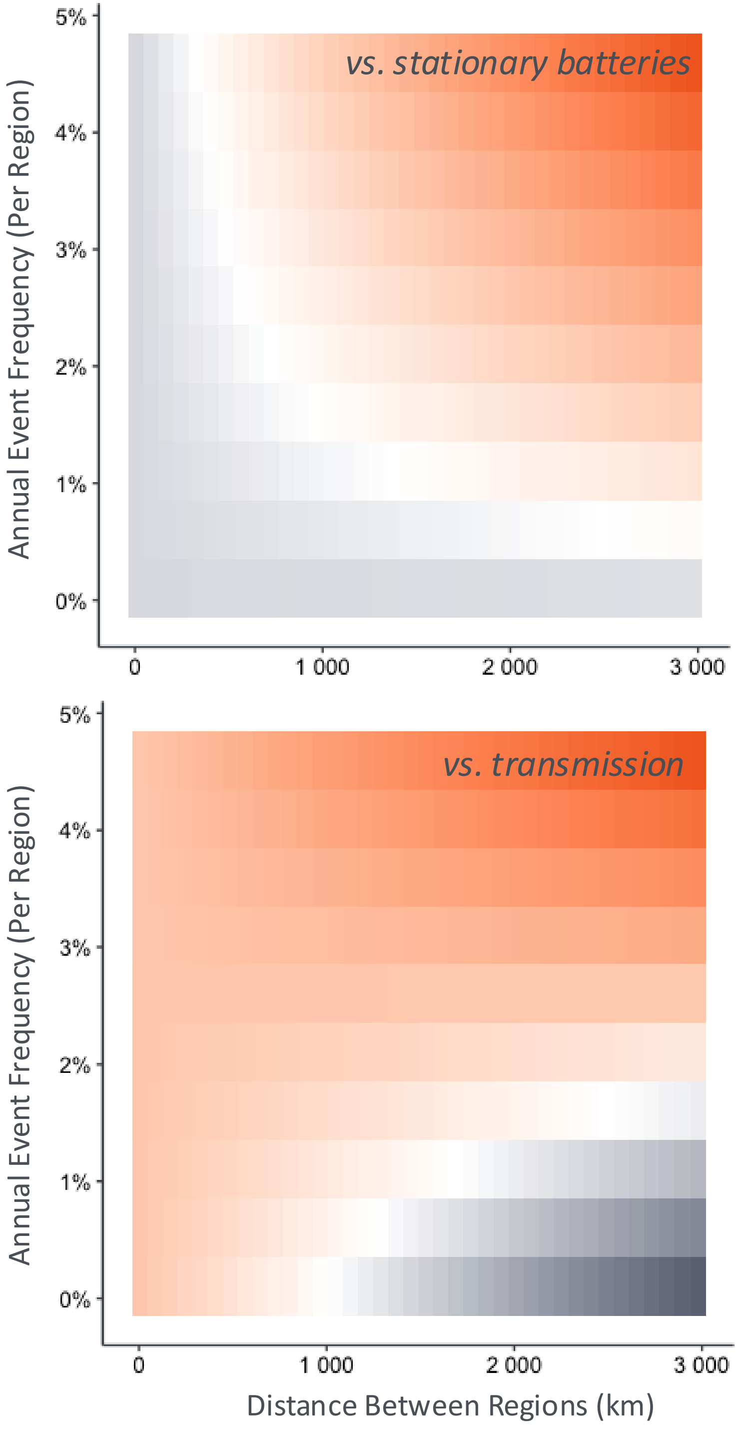
The economics of MES are highly dependent on distance between operating regions and how frequently it is needed to serve demand.

When operating regions are closer together (e.g., within 400 km), MES may be more cost-effective than stationary capacity investments for addressing high-impact, low-frequency events, especially if their occurrence is at or below 1% annually in each region.

For very rare events (0.1% annual event frequency), MES is valuable compared to stationary batteries regardless of the distance between regions. When operating regions are farther apart, RMES may be more cost-effective than new transmission to address low-frequency peak demand events.







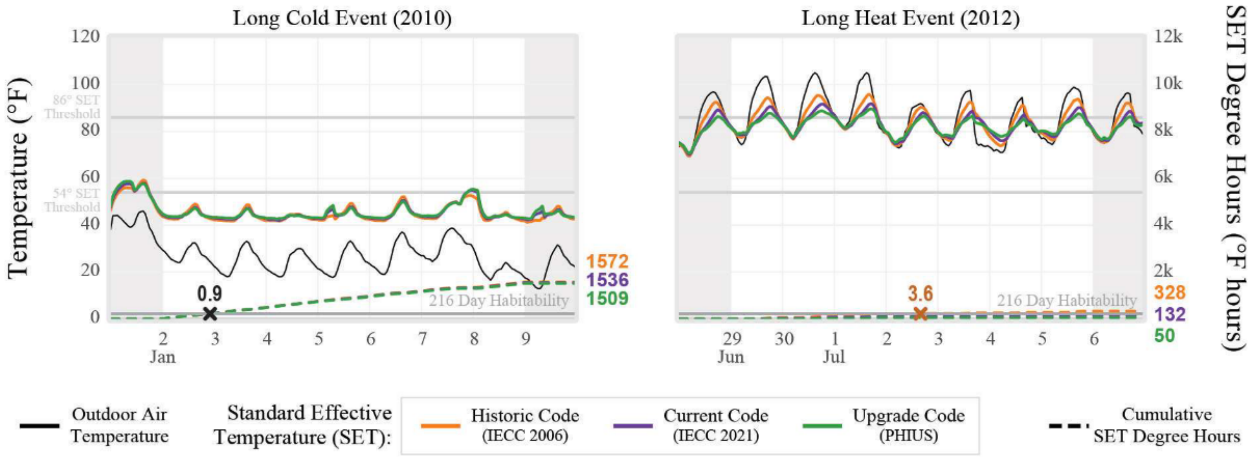
SOLUTION 2: PASSIVE SURVIVABILITY INVESTMENTS

Can energy system resilience investments at the building level help the bulk power system meet peak demand amid deep decarbonization?

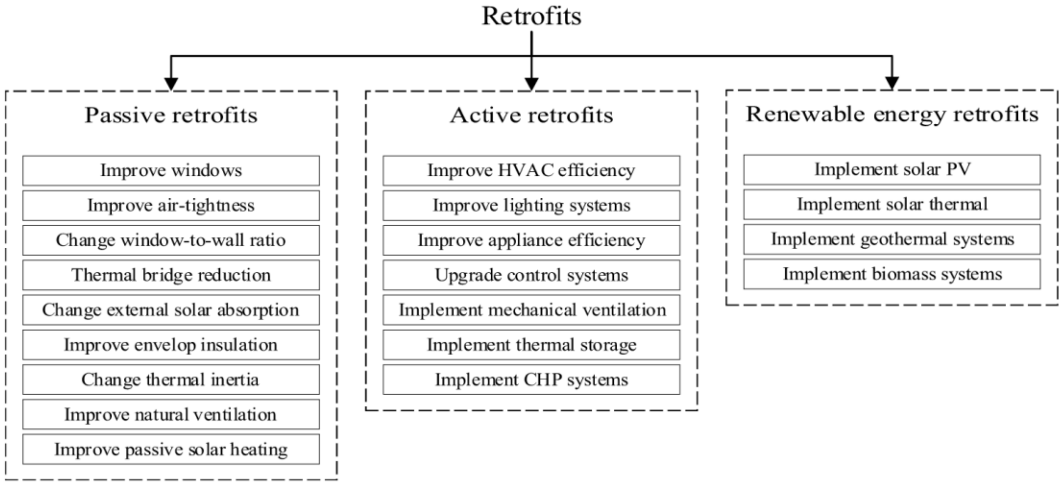
Quantifying the Power System Benefits of Building Upgrades for Passive Survivability in a Changing Climate

Jill Moraski (University of California, Berkeley)
Haochi Wu (University of Michigan, Ann Arbor)
Michael Craig (University of Michigan, Ann Arbor)
Duncan Callaway (University of California, Berkeley)

Motivation: Building-level resilience to power supply disruptions



Franconi et al. (2023)

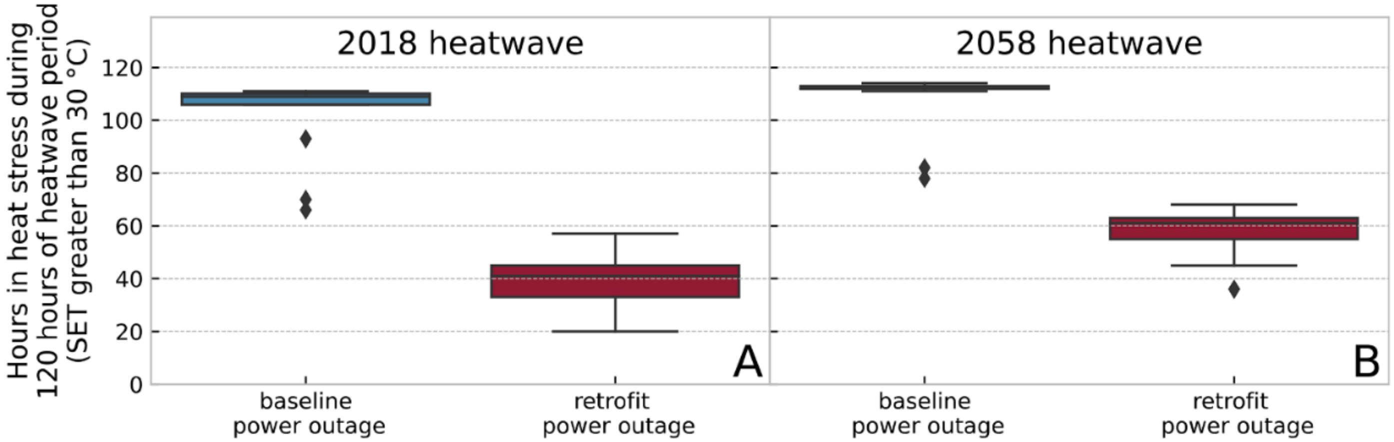


Liyanage et al. (2024)

Passive Survivability

Maintaining safe indoor conditions during temperature-driven power supply disruptions

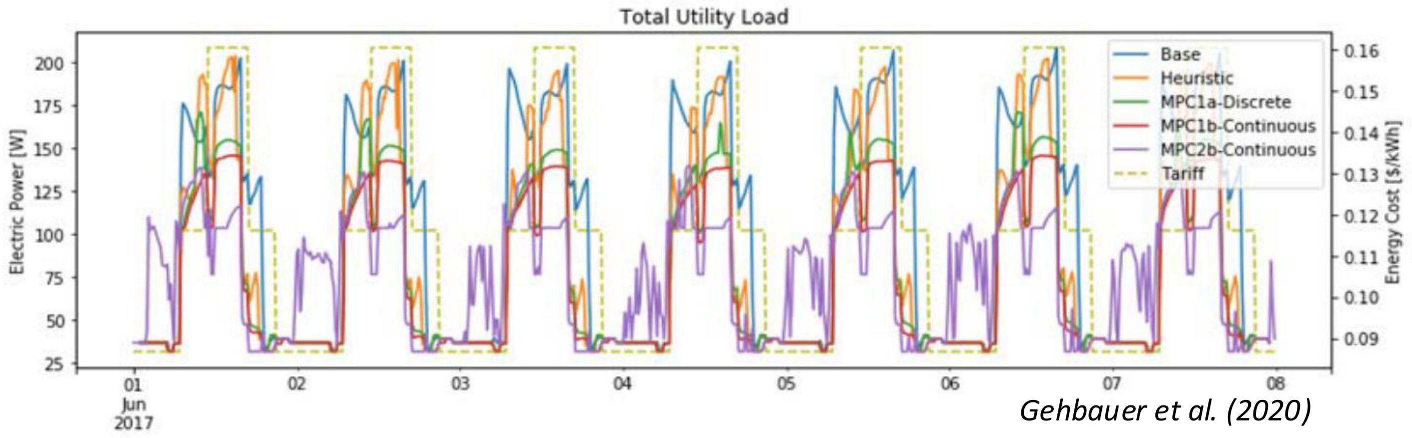
- Energy-efficient building envelopes (Franconi et al., 2023; Sun et al., 2021)
- Dynamic building technologies, e.g., sun shading and passive ventilation (Ji et al., 2023; O' Donovan et al., 2021)



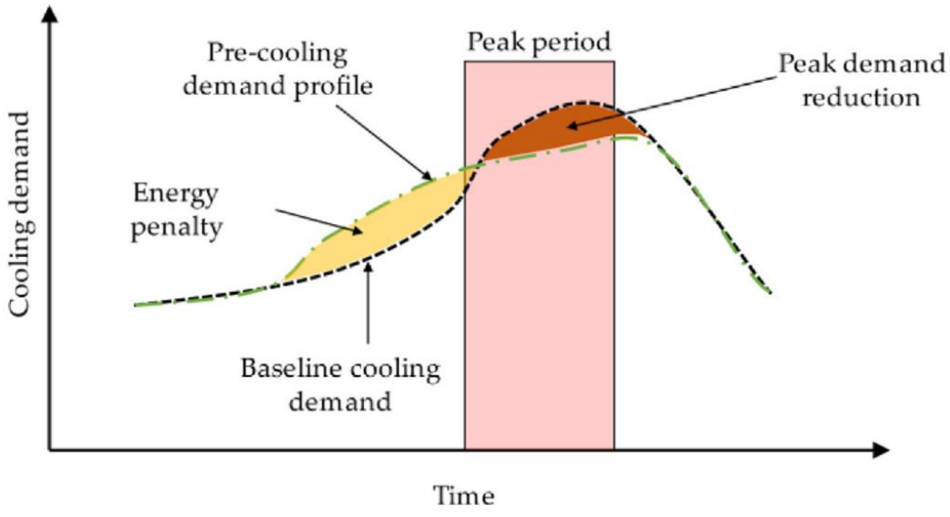
Lee et al. (2024)

Motivation: Grid benefits from building-level resilience measures

Load modification



Gehbauer et al. (2020)



Naderi et al. (2022)

Demand Response

Peak demand reduction

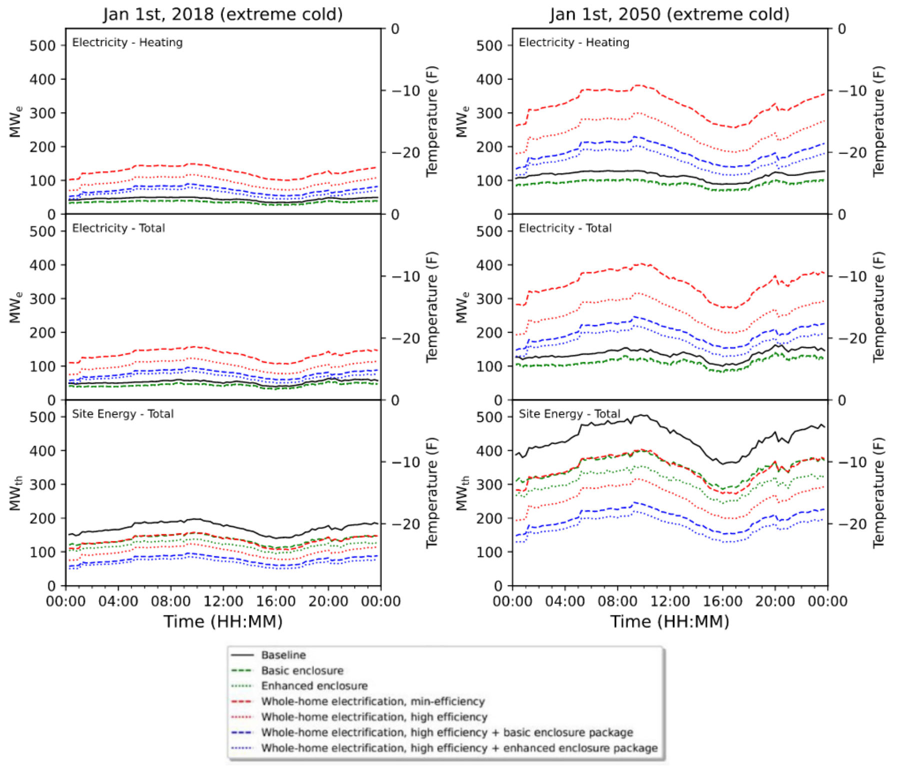
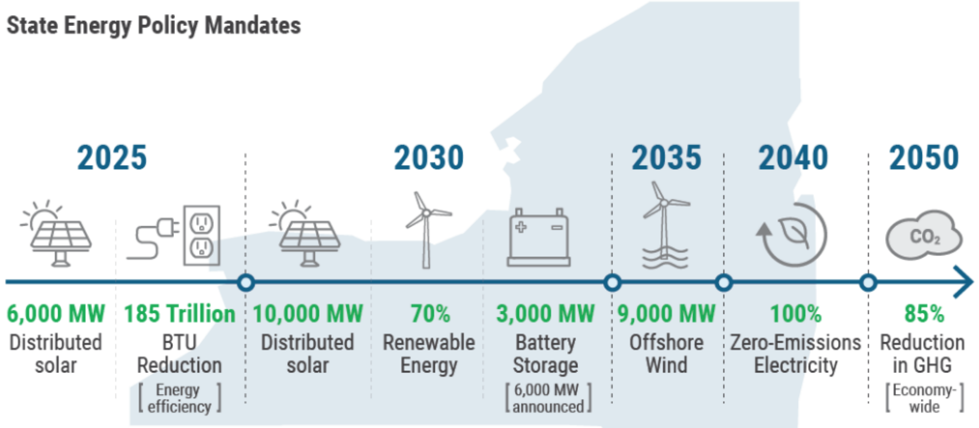


Figure 3. 2018 and 2050 electricity demand residential load shapes for the Pierre, SD microarea by efficiency and/or electrification package for all residences, extreme winter day.

Maxim & Grubert (2023)

Study Region: New York State

Aggressive Decarbonization Targets



Climate Leadership and Community Protection Act (State)

- Economy-wide GHG reductions
- Clean energy mandates

Local Law 97 (NYC)

- GHG emissions reductions in 25,000 + sq. ft. buildings

Vulnerability to Extreme Heat

Summer Extreme Weather Statewide System Margins (MW)

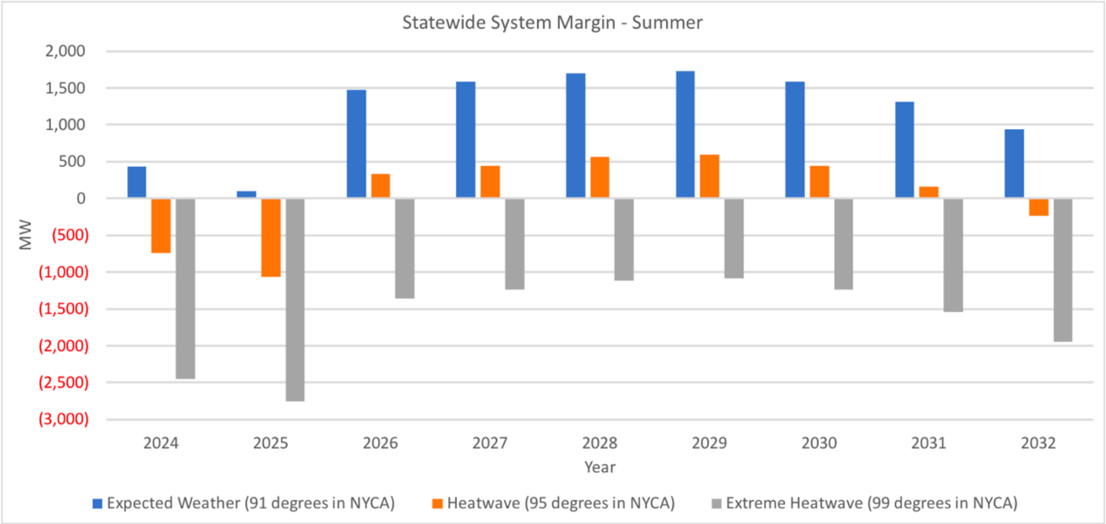
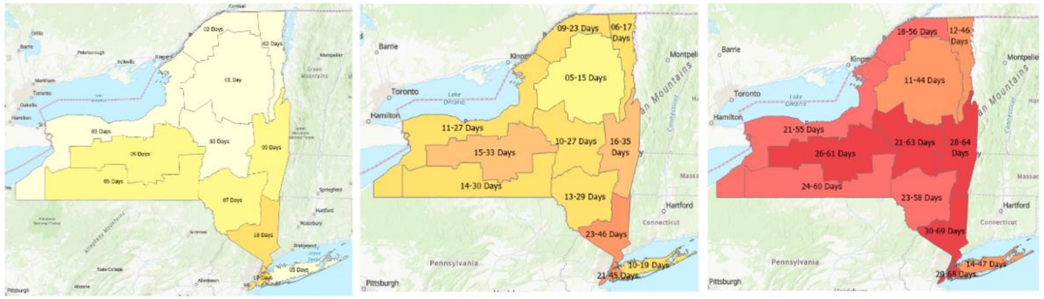


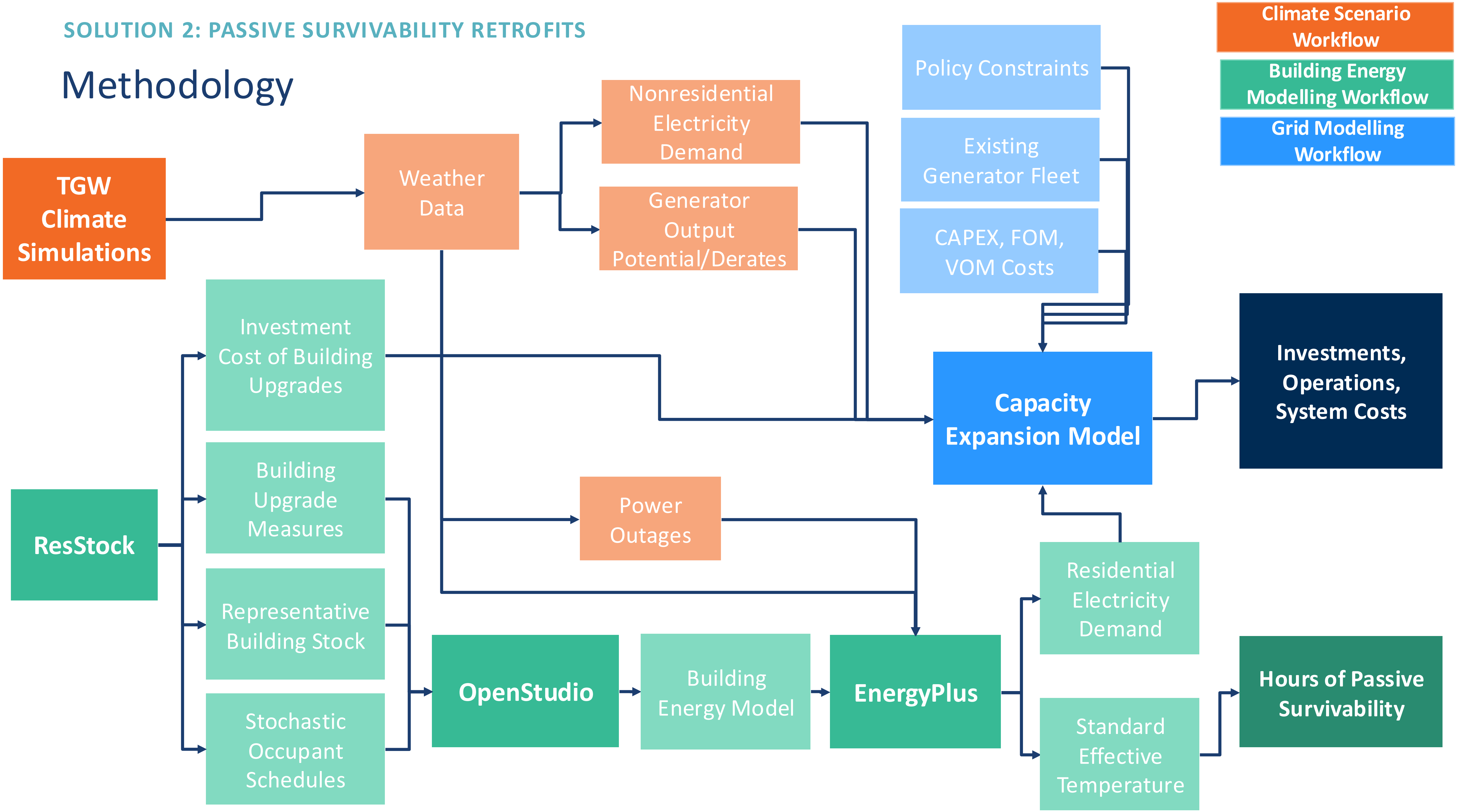
Figure 1. Projected increases in days above 90°F by 2050 and 2080 in New York State compared to the baseline



Sources: NYISO 2023-2032 Comprehensive Reliability Plan, NYC Accelerator LL 97 Retrofit Guide, NY State Extreme Heat Action Plan

SOLUTION 2: PASSIVE SURVIVABILITY RETROFITS

Methodology



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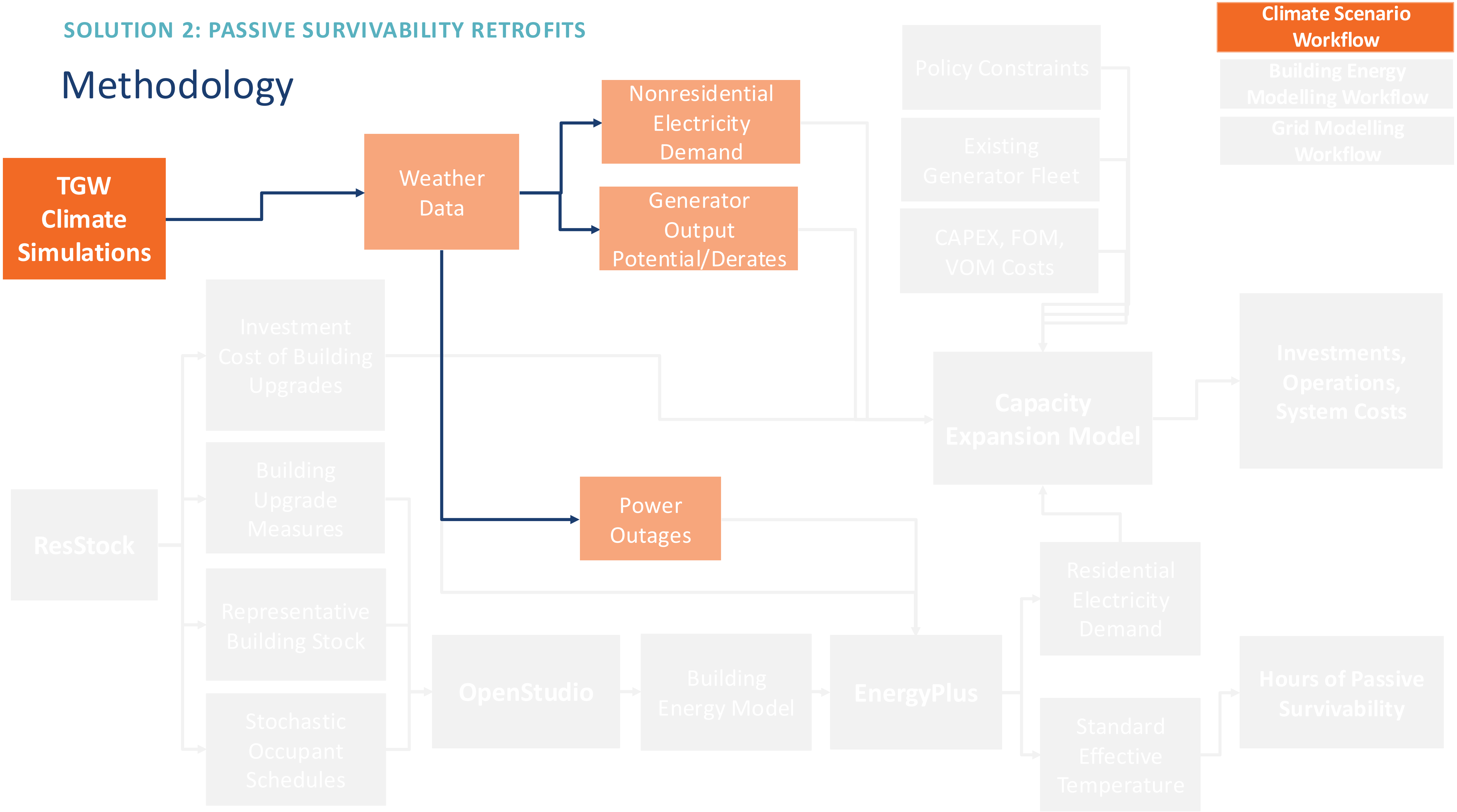

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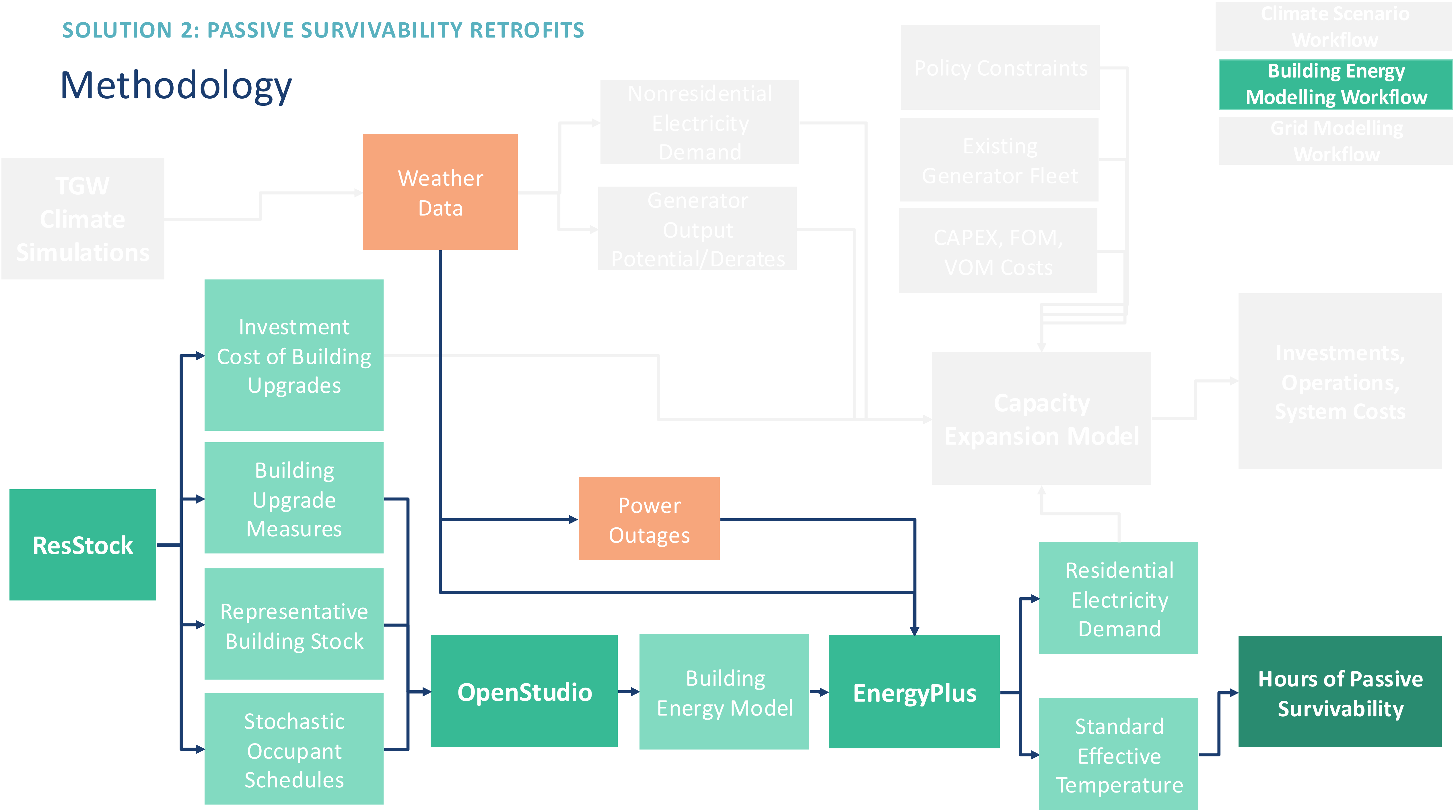

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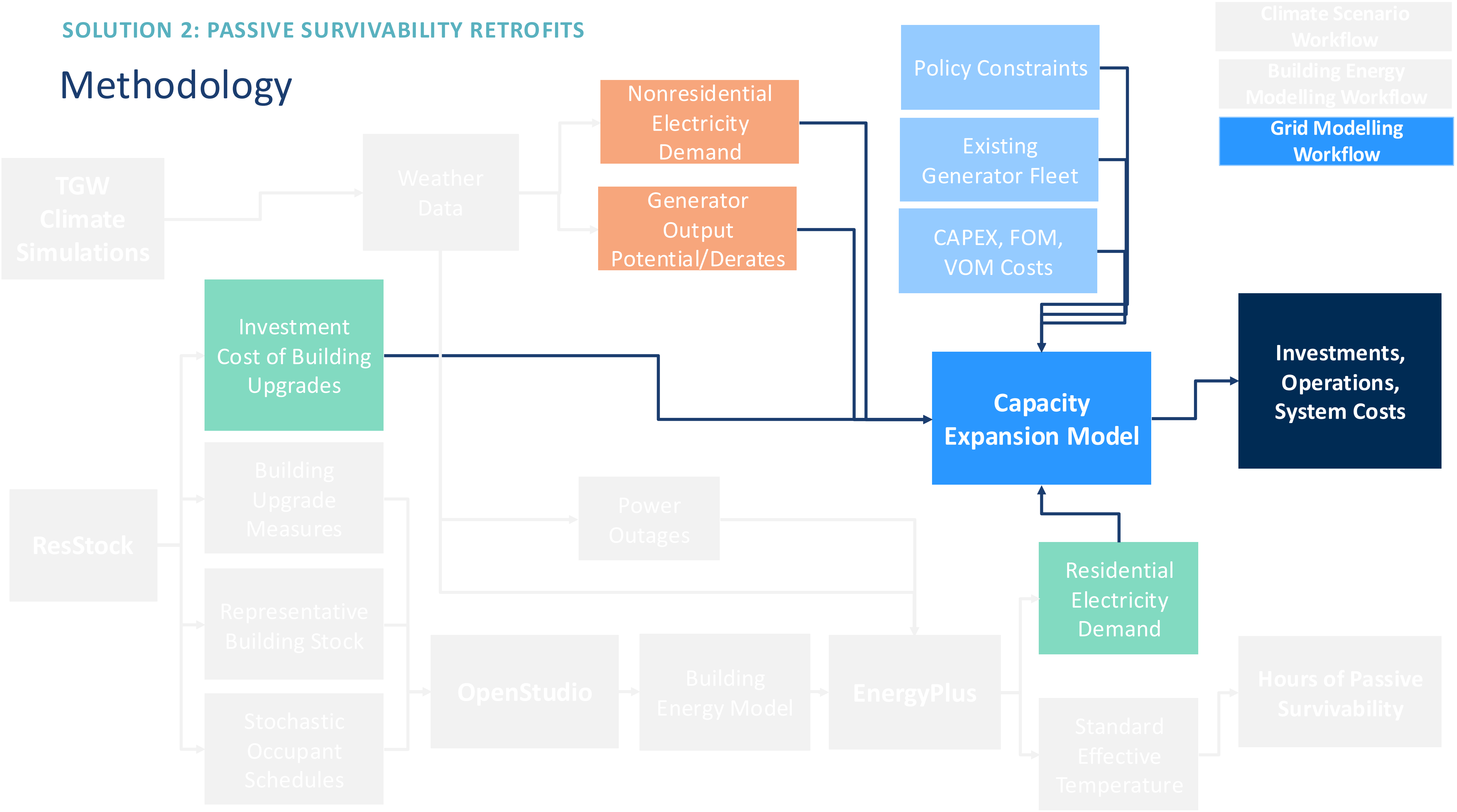
Methodology

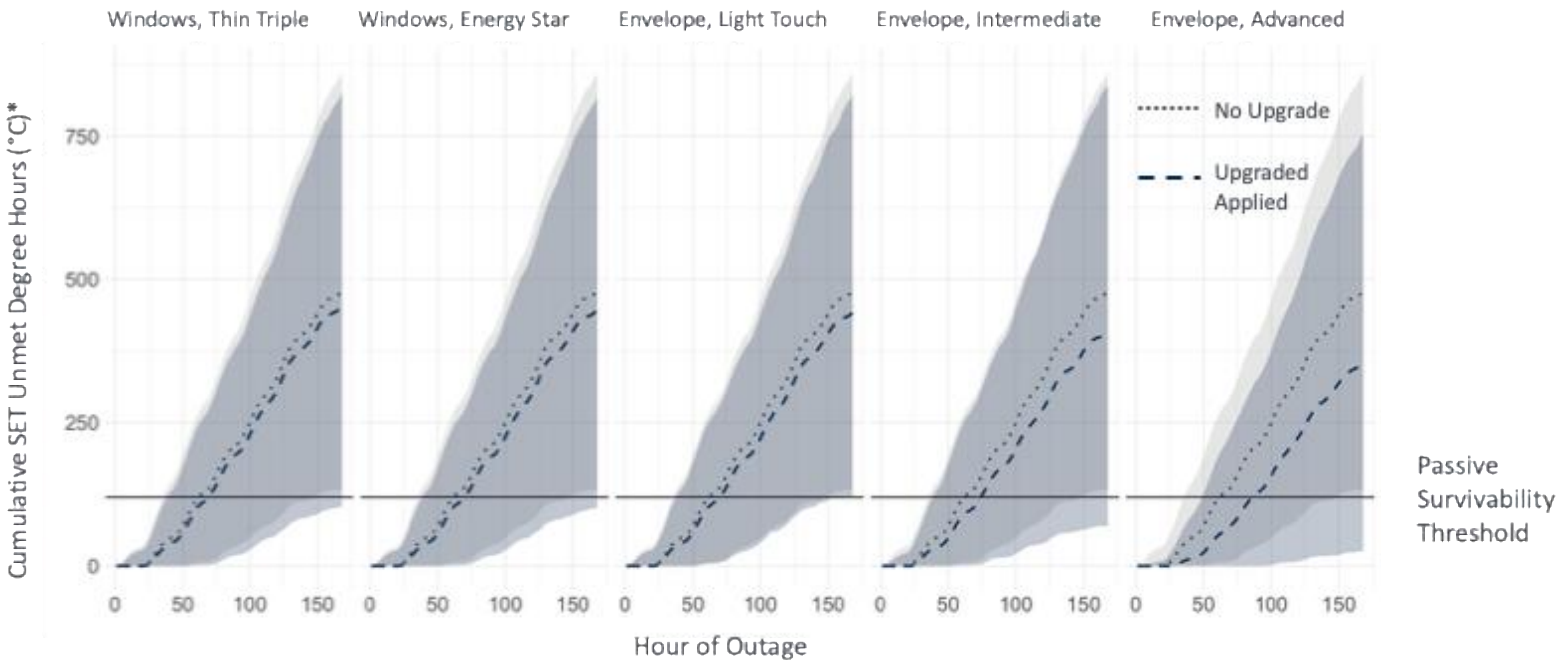


Passive Survivability: Cumulative Unmet Degree Hours

Findings

Upgrades extend the number of hours before the median building crosses the passive survivability threshold by between 1 hour (Light Touch Envelope) and 19 hours (Advanced Envelope).

While the Light Touch Envelope has the smallest impact on passively survivable hours, it reduces the final cumulative SET UDH by 35°C-hours compared to the No Upgrade scenario—more than both windows upgrades.



** Lines reflect median value. Shading reflects 95% confidence interval*

Changes in Electricity Demand

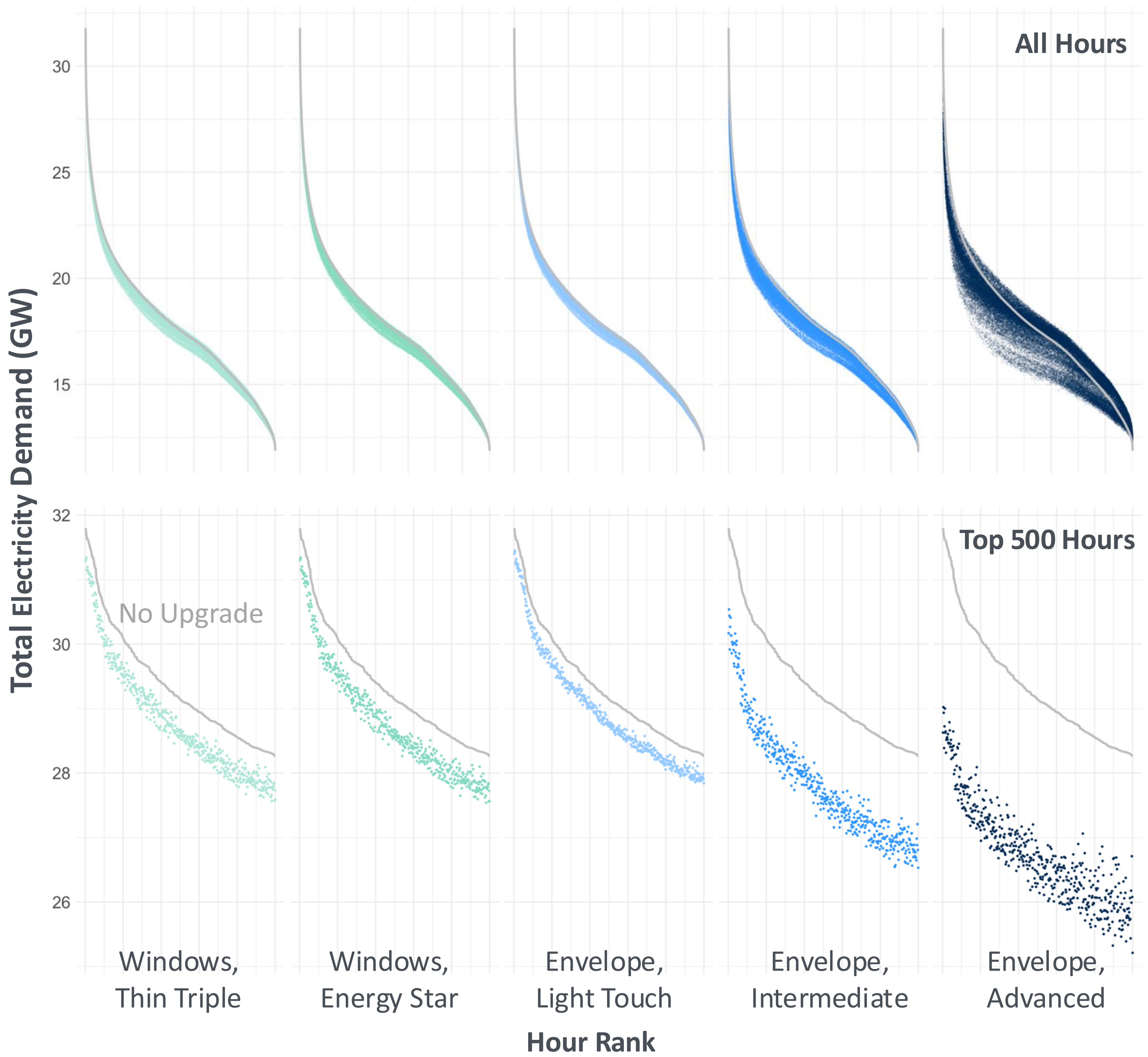
Findings

Building upgrades reduce peak demand by between 300 MW (Light Touch Envelope) and 2.7 GW (Advanced Envelope).

While all upgrades reduce electricity demand during high-load hours, their effects across the full load curve vary.

Example: Advanced Envelope upgrades

- Reduce peak demand the most
- Increase consumption during some off-peak periods—particularly in the evenings and shoulder seasons.



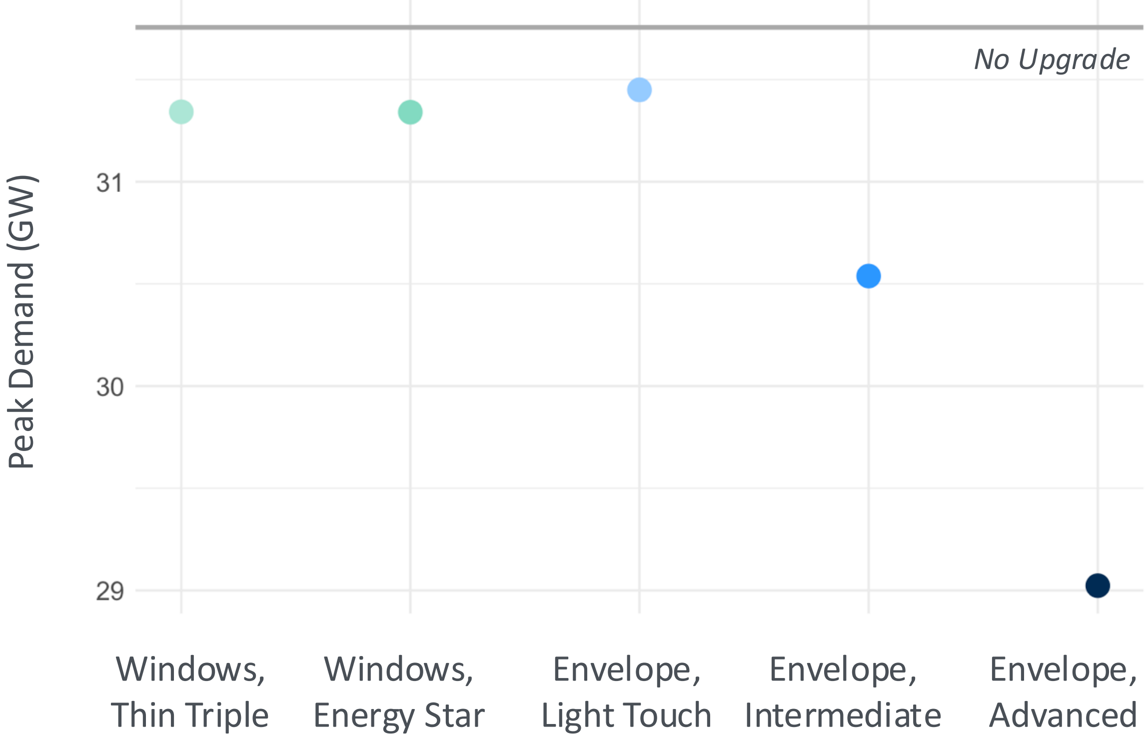
Relationship of Demand, Generation, and Installed Capacity

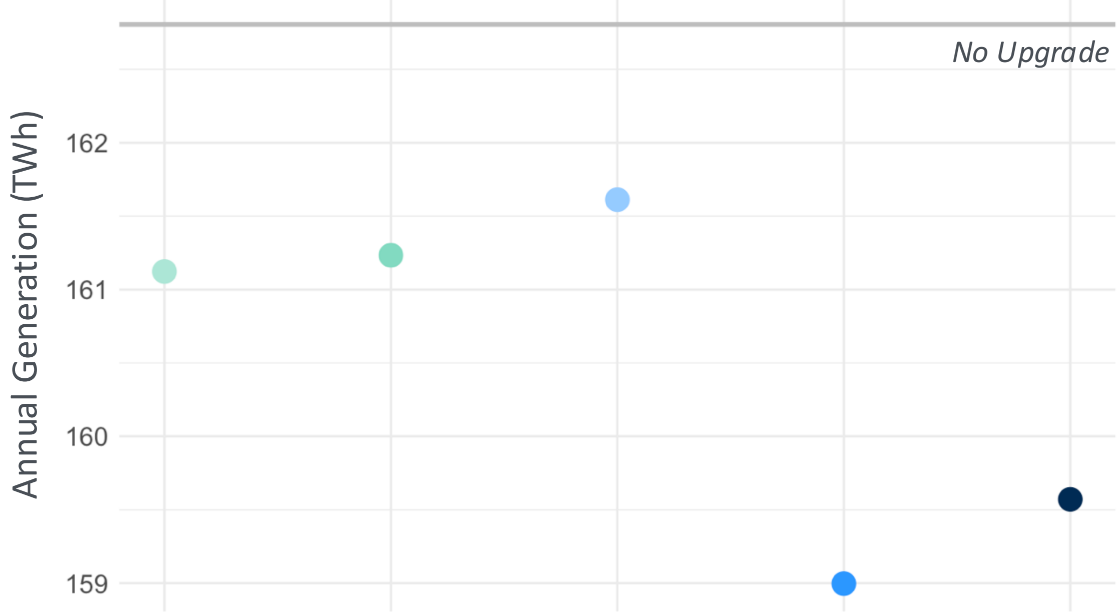
Findings

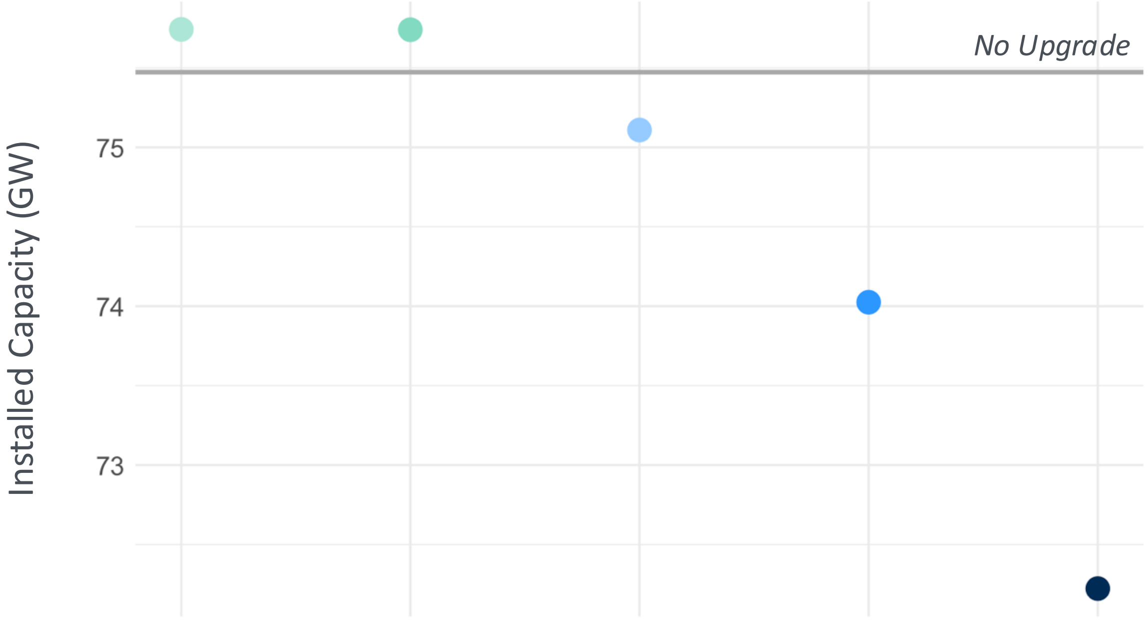
All upgrades reduce peak electricity demand, but not all upgrades affect generation and installed capacity equally. Impact on generation and capacity varies by upgrade type.

Example: Windows upgrades

- Increase installed capacity requirements
- But outperform some envelope upgrades in reducing total electricity generation.



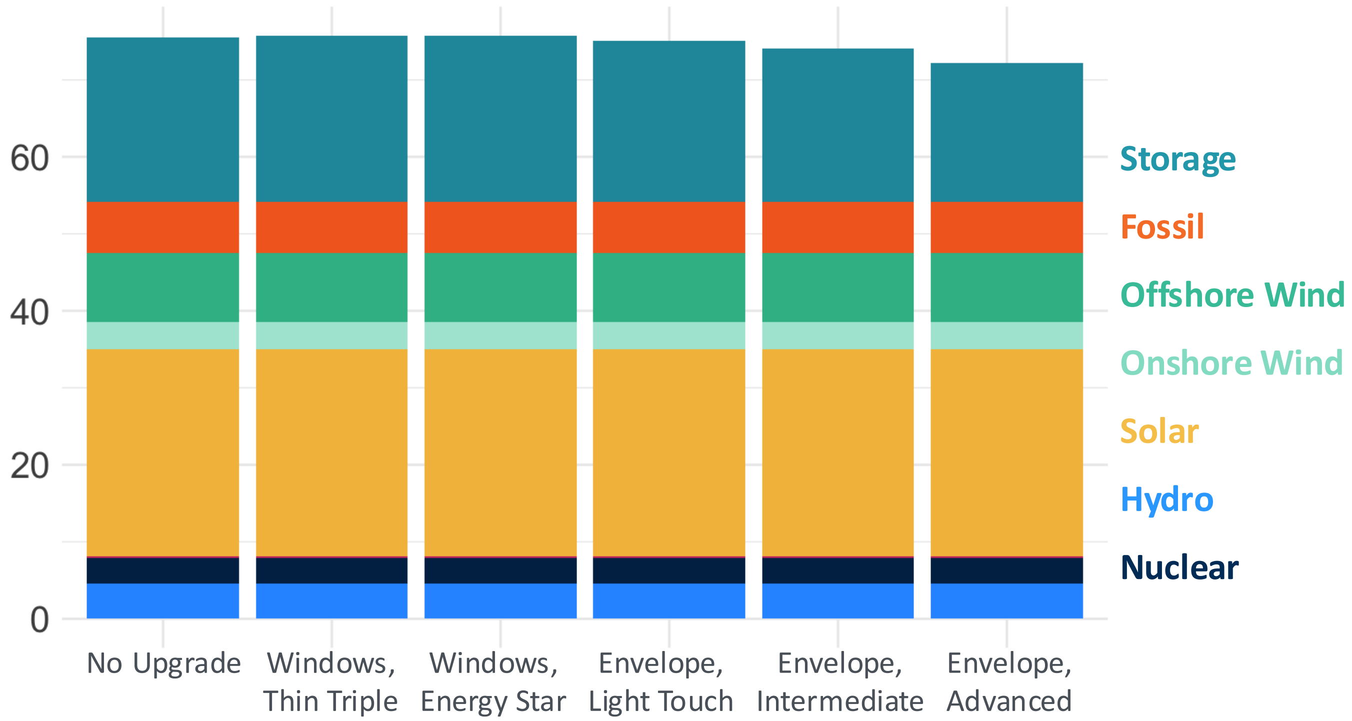




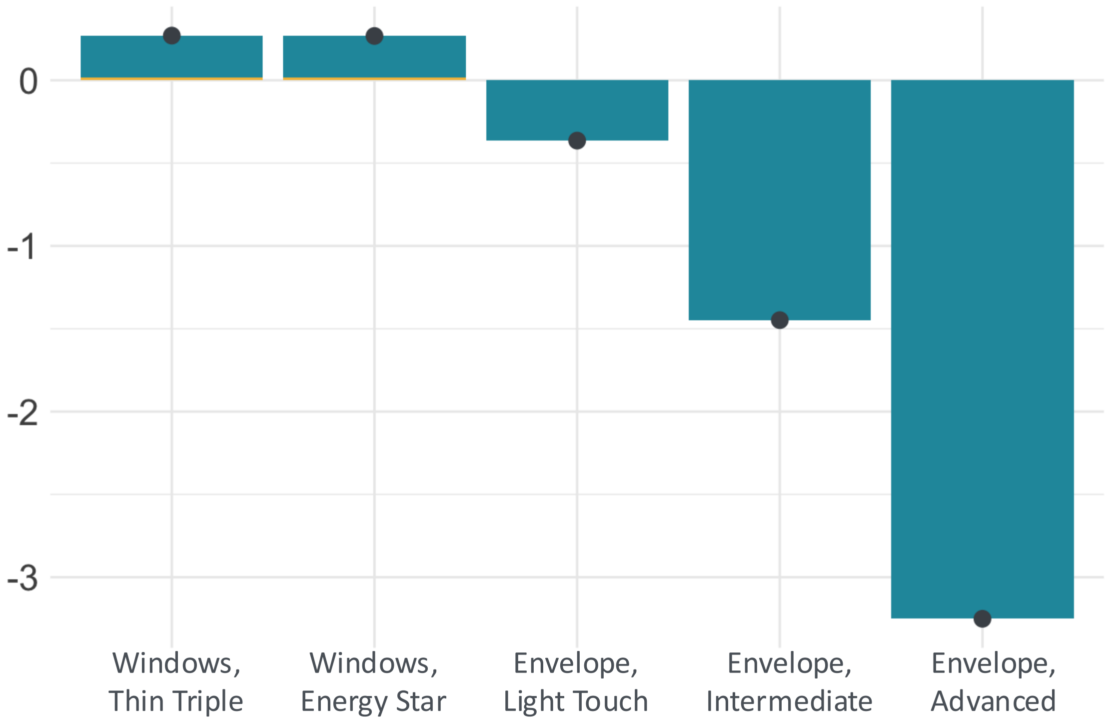
SOLUTION 2: PASSIVE SURVIVABILITY RETROFITS

Changes in Installed Capacity

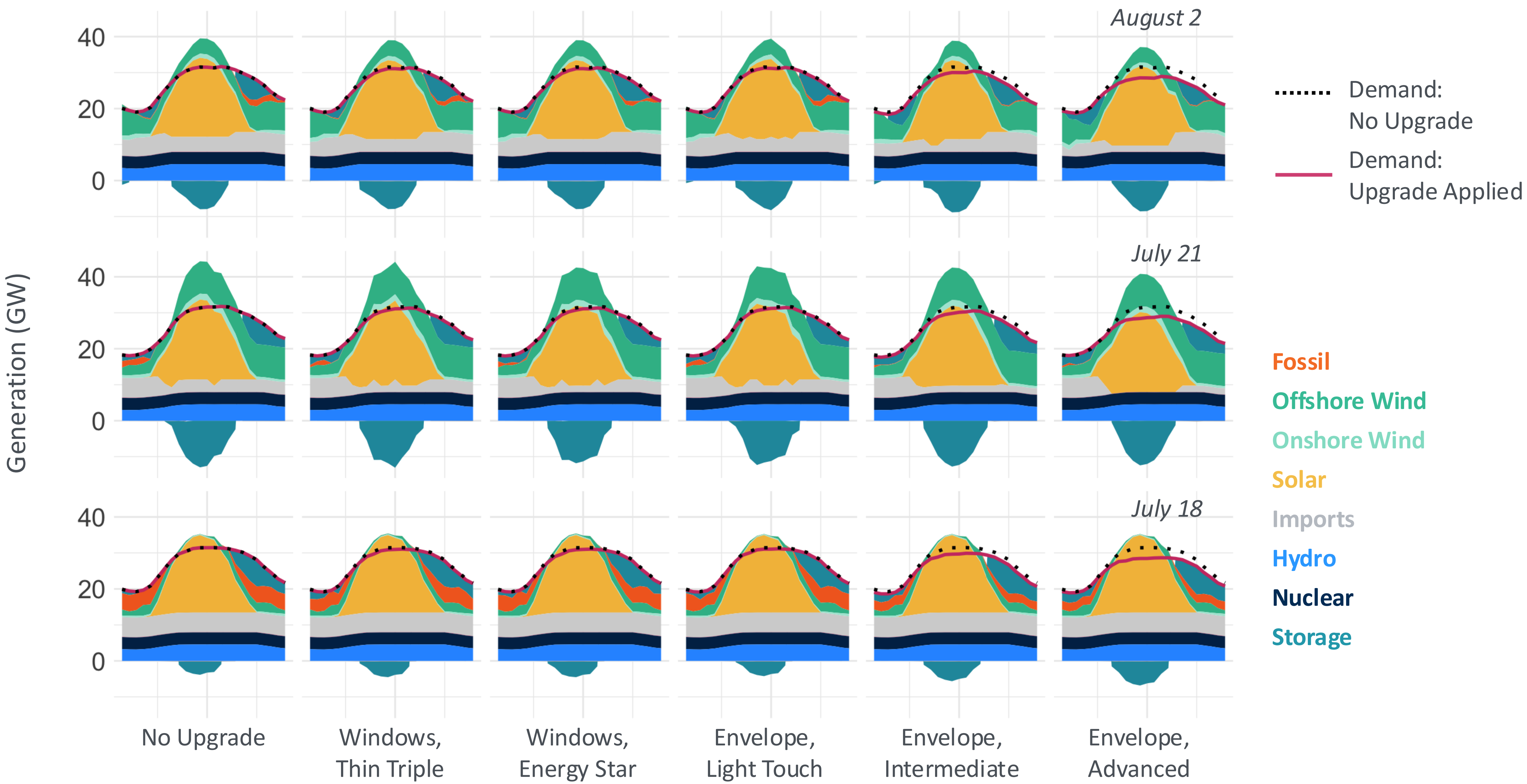
Total Installed Capacity (GW)



Difference from "No Upgrade" Scenario (GW)



Changes in Generation and Demand Across 3 Peak Summer Days



System Cost Reduction and Investment Incentives

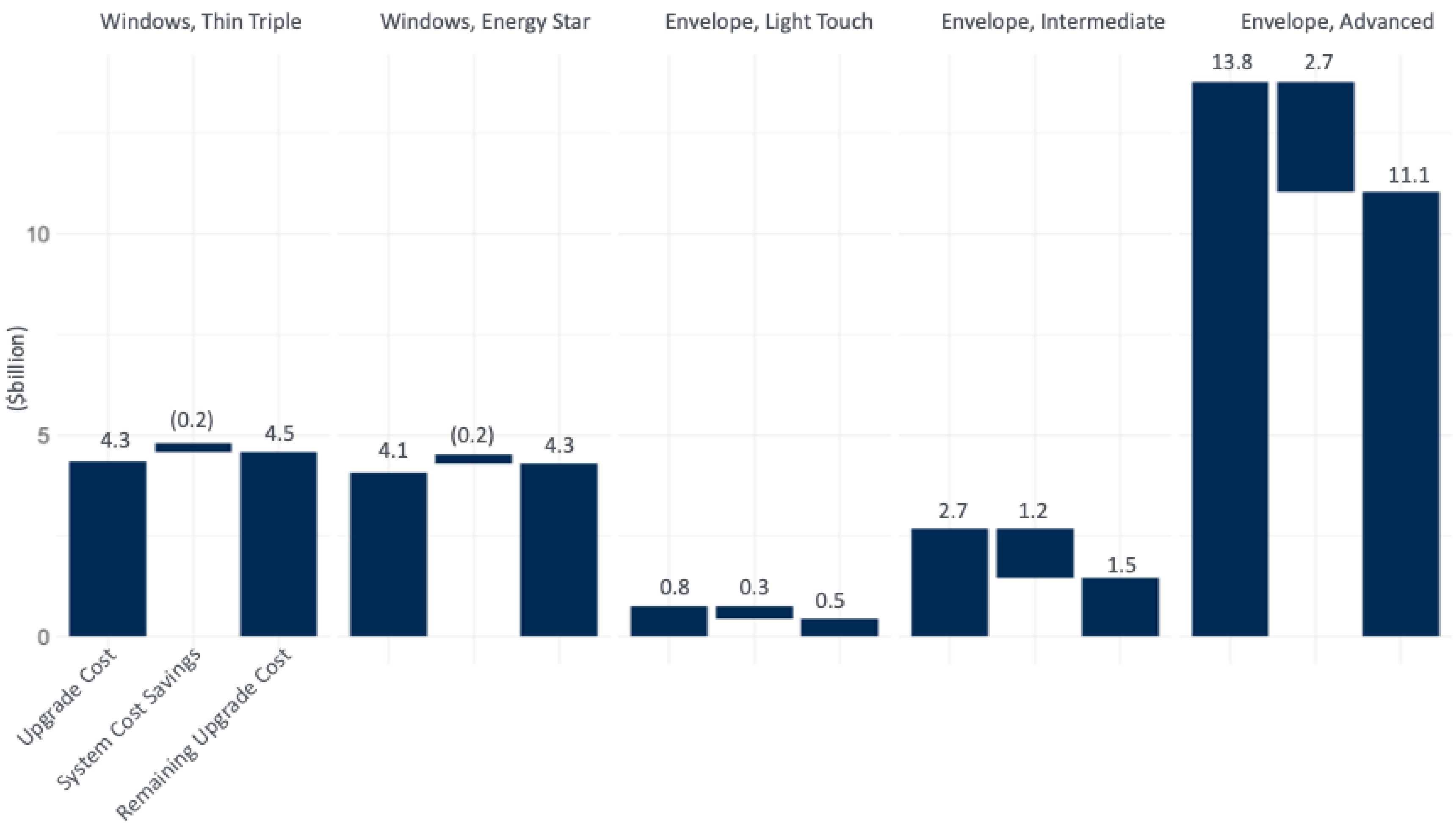
Findings

When power system benefits are considered, the net cost of upgrades can be significantly reduced.

Conclusions

Effects of Building Upgrades: Building upgrades, especially energy-efficient envelope measures, can significantly reduce electricity demand while improving passive survivability.

Building and Grid Interdependence: Resilient buildings can lower total grid investment and operational costs and are especially effective at reducing demand peaks and subsequent capacity investment needs



TAKEAWAYS

Existing electricity-adjacent infrastructure holds untapped potential to help meet peak demand in a decarbonized grid.

Achieving long-term resilience and decarbonization requires a proactive, systems-based approach. Coordinated planning across multiple sectors is essential, especially as electrification and decarbonization efforts accelerate.

Aligning financial tools across sectors—such as electricity, buildings, and rail—can unlock system-wide benefits that support economy-wide decarbonization, enhance electric reliability, and improve cost-effectiveness.

Presented By

Jill Moraski, PhD

Jill.Moraski@berkeley.edu

Jill Moraski works at the intersection of energy economics, power system modeling, and electricity regulation. As a specialist in grid modeling, regulatory and market design, and cross-sectoral resilience strategies, she integrates technical analysis and economic insights to assess grid reliability, inform infrastructure investment decisions, and support electricity market reforms. She has partnered with a diverse range of stakeholders—from system operators and utilities to regulators, government agencies, national labs, and NGOs—to address critical challenges such as integrating high penetrations of variable renewable resources, building the economic case for clean-firm technologies, and quantifying the grid value of cross-sectoral resilience investments.

Jill received her Bachelor of Arts in Computer Science from Wesleyan University in 2016 and her Ph.D. in Energy and Resources from the University of California, Berkeley in 2025.

APPENDIX A

Cost calculations

$$Freight\ Delivery\ Costs = \frac{U_p}{B_d}\left[R_f * d\right]$$

Where:

U_p is the total hours of annual transmission arbitrage
d is distance between price nodes
B_d is the storage duration (assuming each four-hour battery is meant to arbitrage four hours)
R_f is the freight delivery rate, and d is distance between regions (estimated at US$0.03/t-km)

$$Fixed\ Cost_{MES} = B_d * B_c + B_{SDI} + B_{FOM}$$

$$Fixed\ Cost_{2xStationaryGeneration} = 2(B_d * B_c + B_{SDI} + B_{FOM})$$

Where:

B_d is the duration of the storage
B_C is the capital cost of the battery
B_{SDI} is the siting, interconnection, and developer costs
B_{FOM} is the fixed operations and maintenance (FOM) costs

APPENDIX B

Methods: Building Upgrade Scenarios

Building Upgrade Measures
(ResStock)

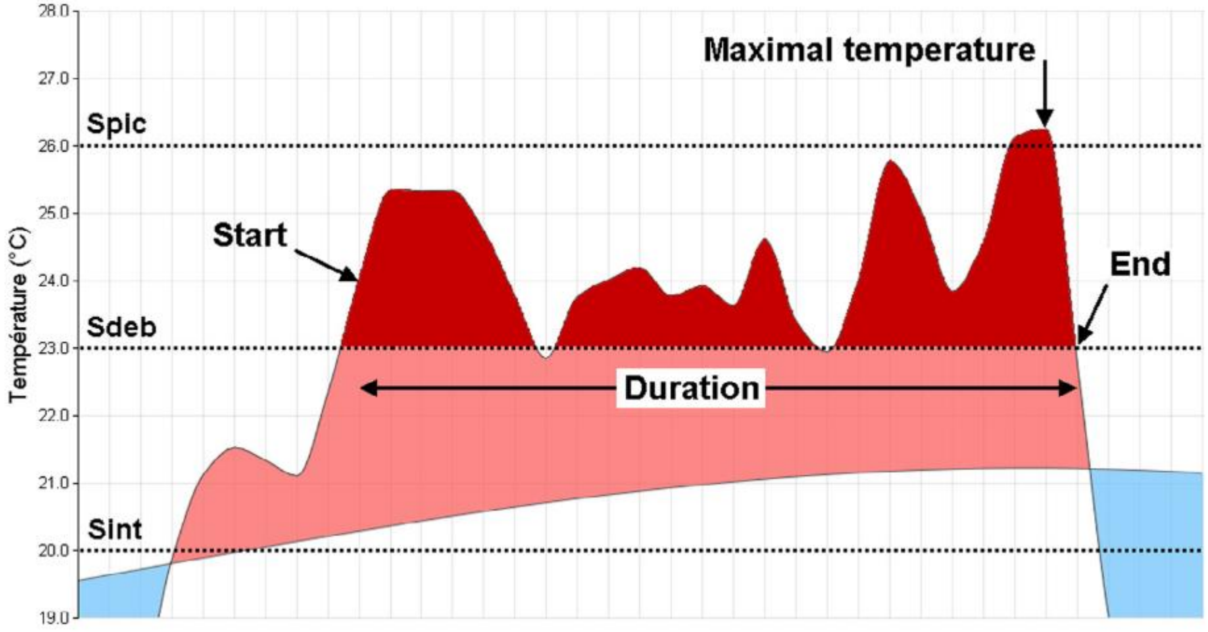
- 260 measure packages with 55 distinct measures
- Broken into 5 categories:
    - **Envelope**
    - Appliances, Pools, Lighting
    - Traditional Cooling/Heating
    - Replacement HVAC/Water Heating
    - Heat Pumps

Building Upgrade	Description
No Upgrade	Building stock as-is in 2018
Windows, Thin Triple	Replace all single and double-pane windows with thin triple-pane windows
Windows, EnergyStar	Replace all windows rated less efficient than EnergyStar with EnergyStar windows
Envelope, Light Touch	• Attic floor insulation • General air sealing
Envelope, Intermediate	• Attic floor insulation • General air sealing • Duct sealing • Drill-and-fill wall insulation • Foundation wall and rim joist insulation, with sealing of crawlspace vents
Envelope, Advanced	• Attic floor insulation • Duct sealing • Drill-and-fill wall insulation • Foundation wall and rim joist insulation, with sealing of crawlspace vents • EnergyStar windows • Exterior continuous wall insulation • IECC 2021 air sealing • Improved ventilation

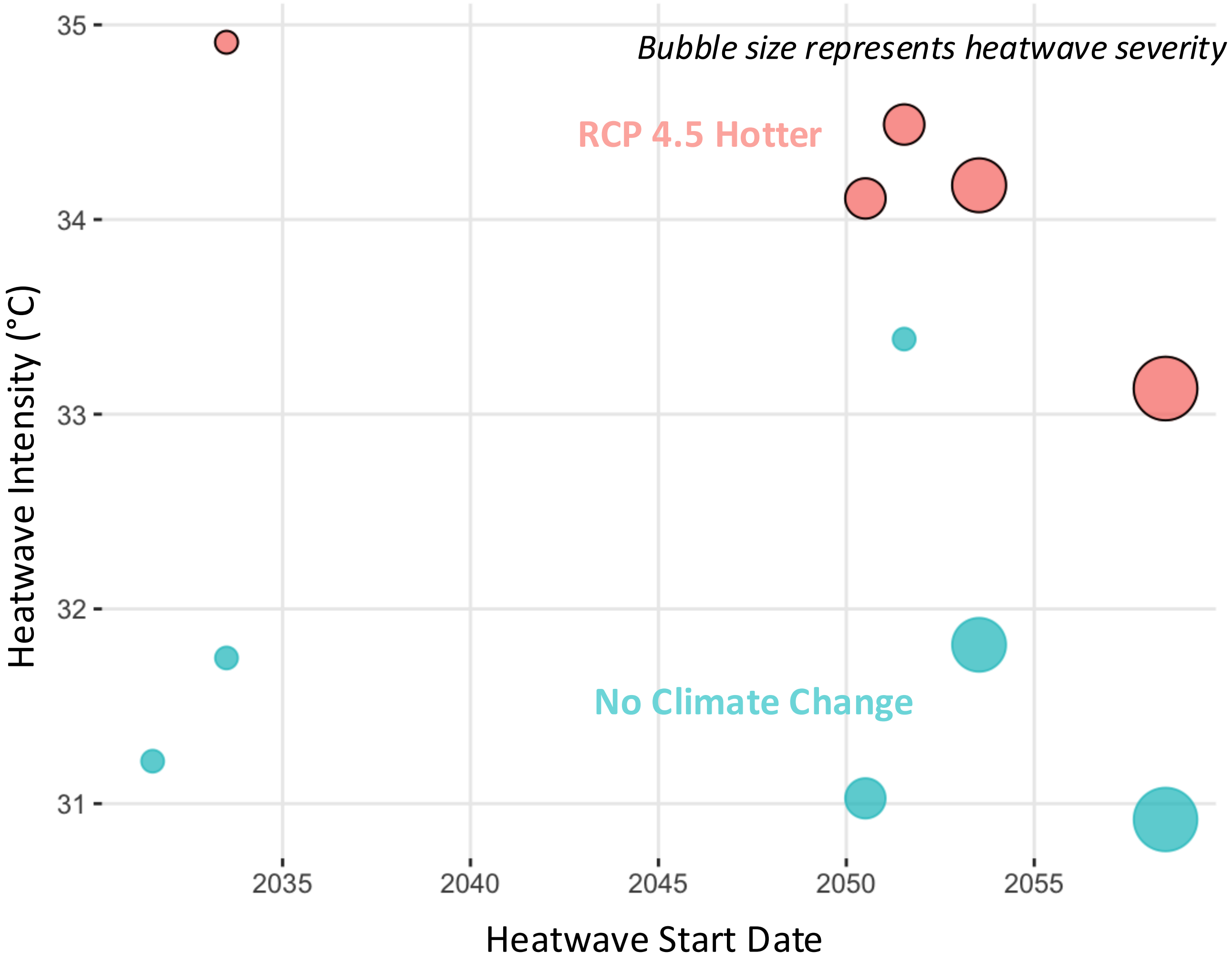
Present et al. (2024)

Methods: Heatwave Detection

- Adapted from *Ouzeau et al. (2016)*
- Calculated using mean daily temperature distribution over 40 years
- Three temperature parameters:
    - **Spic:** threshold for which a heat event is detected (99.5 %ile)
    - **Sdeb:** threshold that defines the beginning and the ending of the heatwave (97.5 %ile)
    - **Sint:** interruption threshold (95 %ile)
- Heatwave interrupted if:
    - Mean temp falls below Sint
    - 3 or more days below Sdeb
- 3-day minimum heatwave length (*Flores-Larsen et al. (2022)*)
- Heatwaves characterized by:
    - **Duration:** number of days
    - **Intensity:** maximum mean daily temperature
    - **Severity**: $\frac{\sum_{days} T_{avg\_day} - Sdeb}{Spic - Sdeb}$



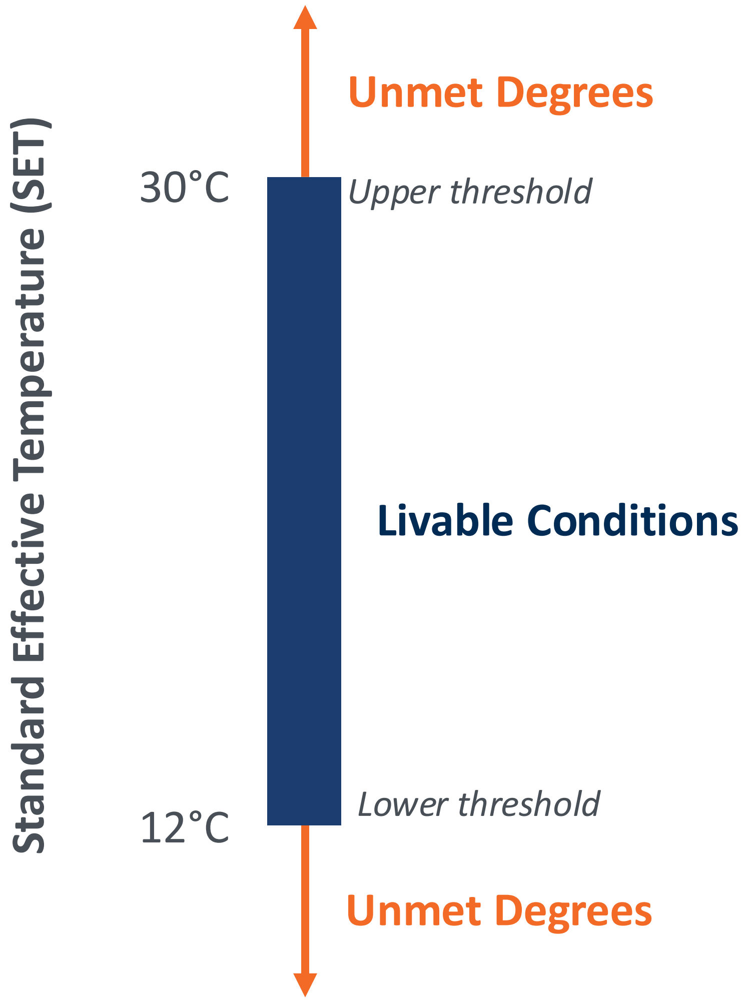
Methods: Heatwave Detection Results



Selected Heatwave Characteristics

Start Date	End Date	Intensity (°C)	Severity	Duration (Days)
7/5/33	7/10/33	35	7	5
7/5/50	7/9/50	34	8	4
7/17/51	7/23/51	34	8	6
7/14/53	7/20/53	34	9	6
6/30/58	7/5/58	33	10	5

Methods: Standard Effective Temperature (SET)



- **"Livable conditions"**: SET between 12.2°C and 30°C (*LEED v4.0*)
- **SET Unmet Degrees:** degrees below 12.2 °C (54 °F) or above 30 °C (86 °F)
- **Set Unmet Degree Hours (SETUDH):** cumulative sum over time of SET Unmet Degrees

$$SETUDH = \sum_t [SET_t - SET_{threshold}]_+$$

- **Passive Survivability:** cumulative SETUDH must not exceed 120 ◦C-hours
- **LEED Credit:** if passively survivable for a 7-day power outage during an extreme temperature event

Methods: Capacity Expansion Model

- Aims to minimize total fixed and variable costs for wind, solar, and NGCC plant
- Optimizes investments in generation, considering policy constraints (e.g., renewable generation requirements, carbon emissions caps).
- Dispatches generators to meet hourly demand and manages inter-regional transmission flows

Input Assumptions

- Hydropower generation predetermined based on demand and subregional monthly totals
- Transmission constrained by historical limits
- Existing generator data (capacity, costs, operational parameters) sourced from EIA National Electric Energy Data System (NEEDS)
- Future generator costs, heat rates, and operating parameters from NREL Annual Technology Baseline (ATB)

Objective

$$\min_{cap,p} \; z = \sum_{y}\left(\sum_{k} C_{k,y} * cap_{k,y} + \sum_{t,k,l} PC_{k,t,y*}p_{k,t,y}\right)$$

Subject To

$$LOAD_{l,t,y} \leq \sum_{kl(k,l)} p_{k,t,y} - \sum_{lp} exp_{l,lp,t,y} + \sum_{lp} imp_{l,lp,t,y}$$

$$p_{k,t,y} \leq cap_{k,y}$$

$$p_{k,t,y} \leq CAPFACT_{k,t,y}$$

Sets:

y – the set of model years

t – the set of model timesteps per year

k – the set of generators

l (lp alias) – the set of model regions

Parameters:

$LOAD_{l,t,y} \in \mathbb{R}$ – the hourly load in each region

$C_{k,y} \in \mathbb{R}$ – the fixed costs of resource k in year y

$PC_{k,t,y} \in \mathbb{R}$ – the production costs of resource k in each timestep

Decision variables:

$p_{k,t,y} \in \mathbb{R}$ – the hourly generation of generator k

$cap_{k,,y} \in \mathbb{R}^+$ – the total capacity of generator k in year y

$imp_{l,lp,t,y} \in \mathbb{R}^+$ – the hourly imports into region l from region lp

$exp_{l,lp,t,y} \in \mathbb{R}^+$ – the hourly exports from region l to region lp