THE VALUE OF LONG DURATION ENERGY STORAGE FOR IMPROVING GRID RELIABILITY AND RESILIENCE

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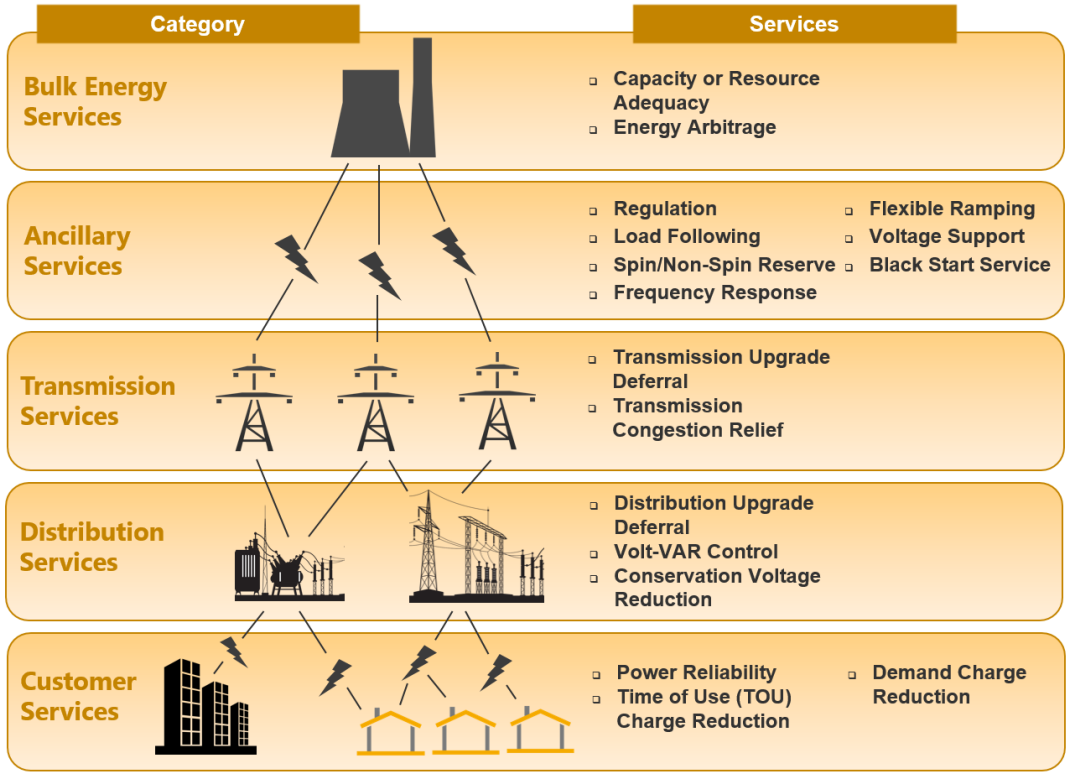
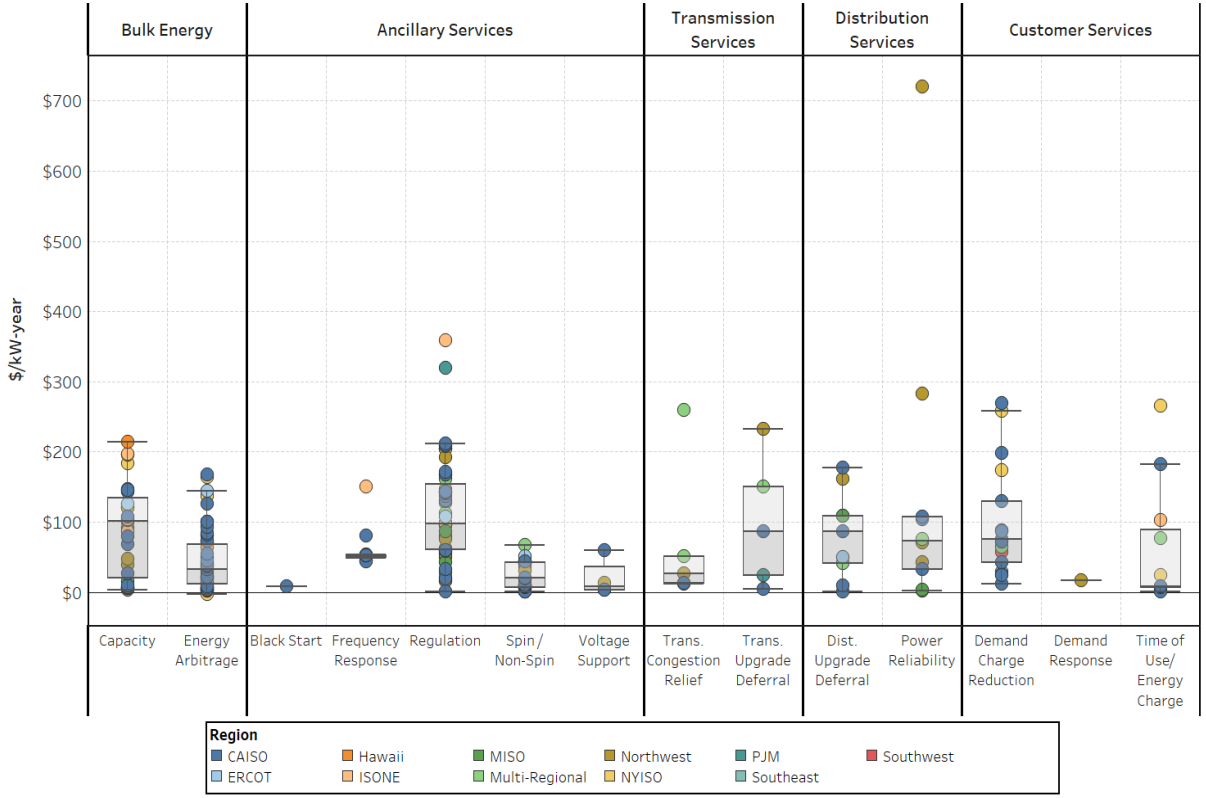
ENERGY STORAGE HOLDS TREMENDOUS VALUE

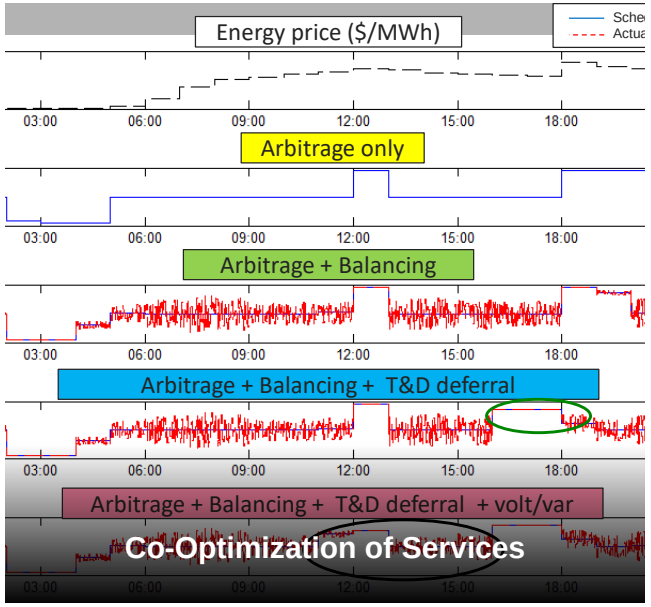


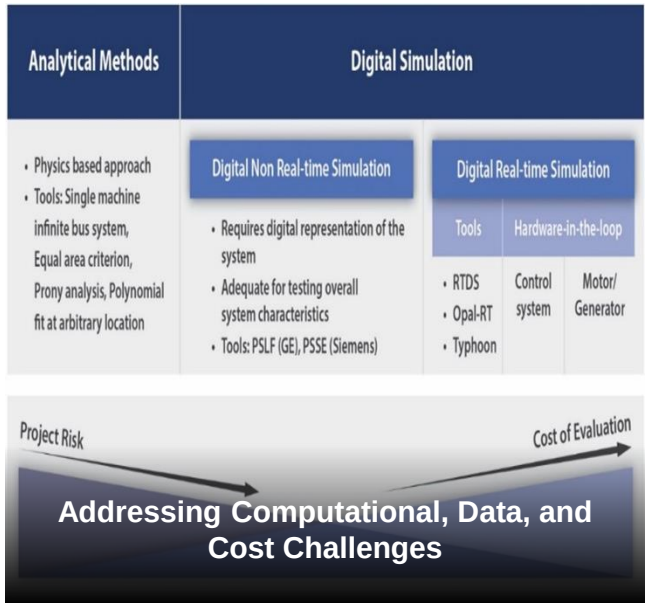


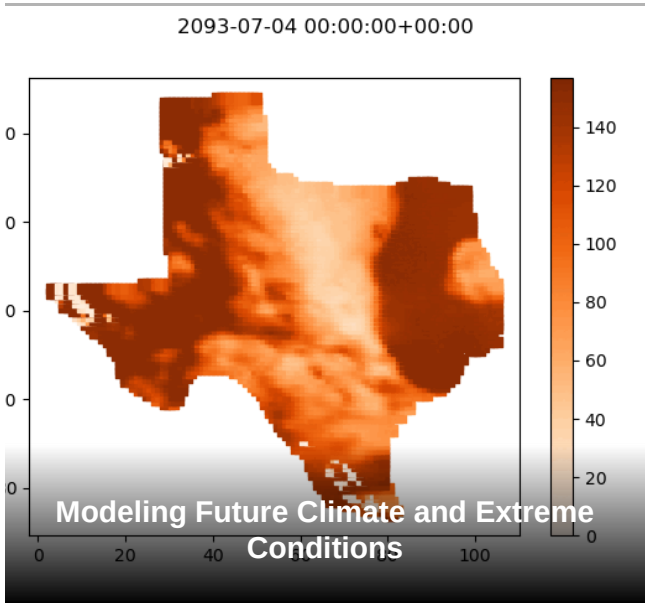
Source: Balducci, Patrick, Mongird, Kendall, and Weimar, Mark. Understanding the Value of Energy Storage for Power System Reliability and Resilience Applications. Germany: N. p., 2021. Web. https://doi.org/10.1007/s40518-021-00183-7.

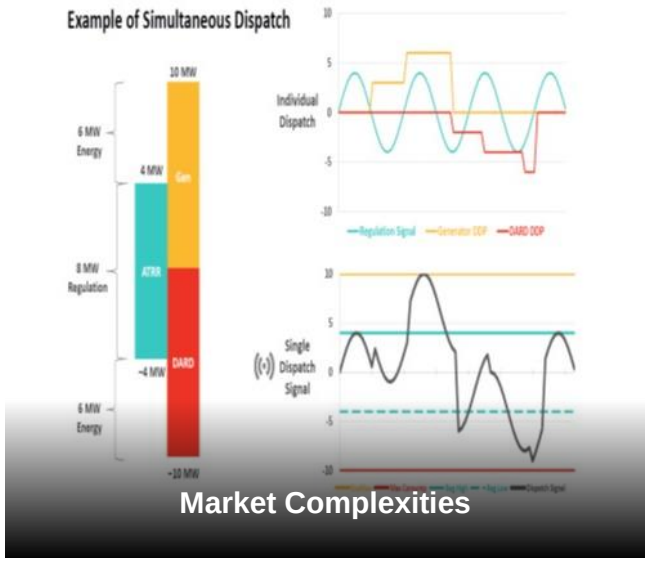
CHALLENGES TO ACCURATELY ESTIMATING RELIABILITY/RESILIENCE BENEFITS

- Multidimensional competition for energy – not all services can be provided simultaneously and there exists intertemporal competition for energy
- Most models cover small subset of hours in year and don't reflect future climate and extreme scenarios well
- Markets are complex and common practices of assuming perfect foresight into prices, price-taker position, and consistent performance lead to overestimation
- Resilience often captured indirectly
- Battery degradation is an important consideration
- Absence of a market to capture reliability/resilience benefits



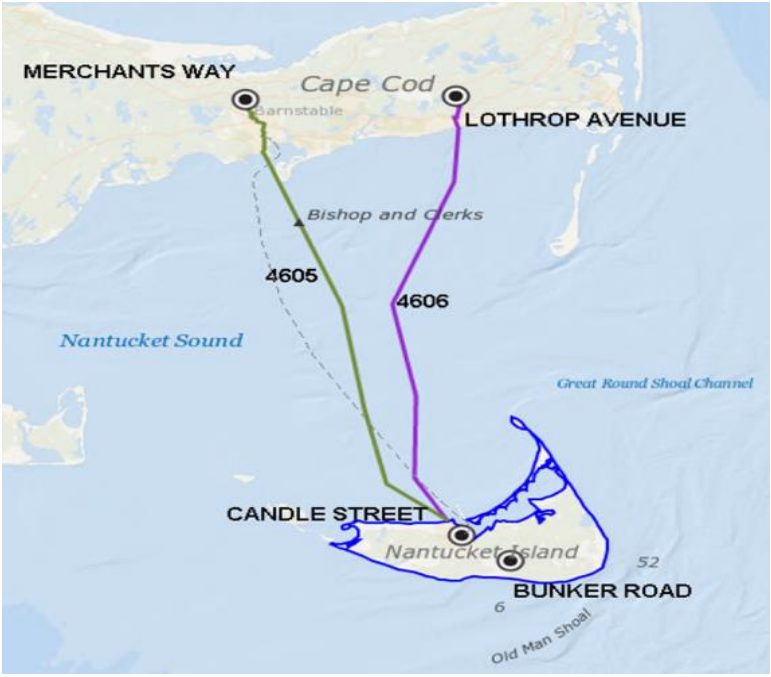






NANTUCKET ISLAND ENERGY STORAGE SYSTEM

- Nantucket Island located off the coast of Massachusetts
  - Small resident population of 11,000; population swells to over 50,000 in summer
  - Nantucket's electricity supplied by two cables with a combined capacity of 71 MW and two small on-island combustion turbine generators (CTGs) with a combined capacity of 6 MW
  - Rather than deploying 3rd cable, National Grid is replacing two CTGs with a single, large (16 MW) combustion turbine generator (CTG) and a 6 MW / 48 MWh Tesla Li-ion battery energy storage system (BESS.)
- Use cases evaluated
  - Non-market operations
    - ✓ Transmission deferral
    - ✓ Outage mitigation
    - ✓ Conservation voltage reduction
    - ✓ Volt-VAR optimization
  - Market operations
    - ✓ Forward capacity market
    - ✓ Arbitrage
    - ✓ Regulation
    - ✓ Spinning reserves

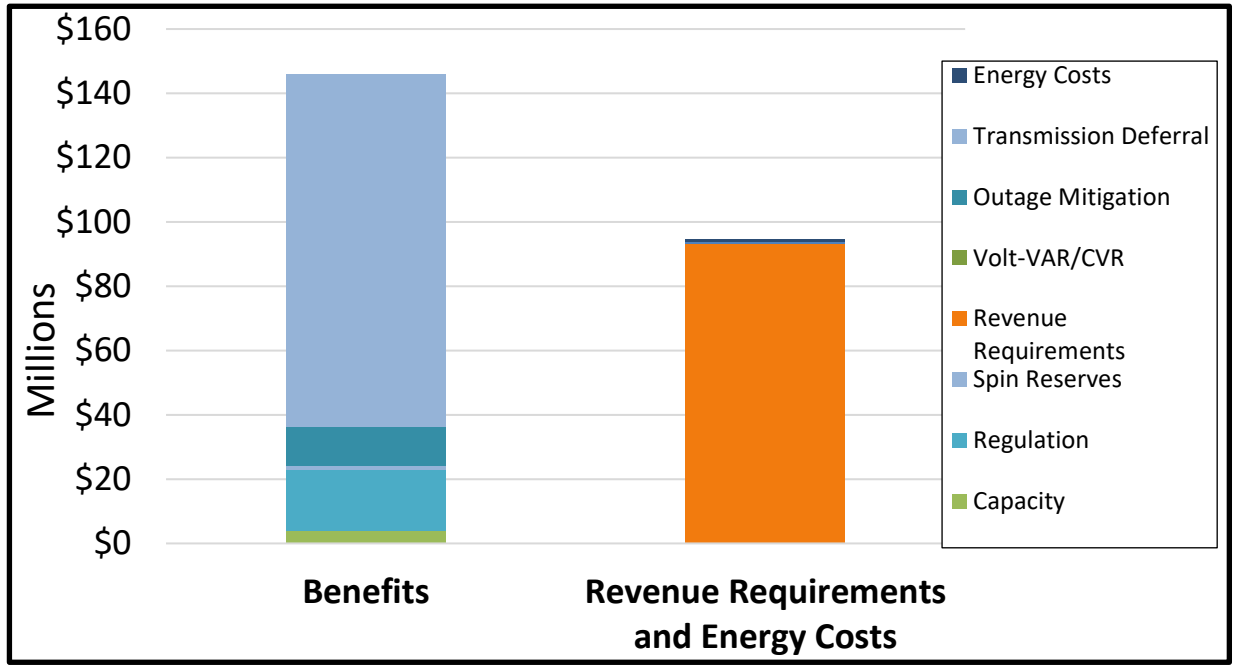


Nantucket Supply Cables

Source: Balducci, Patrick J., Alam, Md Jan E., McDermott, Thomas E., Fotedar, Vanshika, Ma, Xu, Wu, Di, Bhatti, Bilal Ahmad, Mongird, Kendall, Bhattarai, Bishnu P., Crawford, Aladsair J., and Ganguli, Sumitrra. Nantucket Island Energy Storage System Assessment. United States: N. p., 2019. Web. doi:10.2172/1564262.

NANTUCKET ISLAND CONCLUSIONS

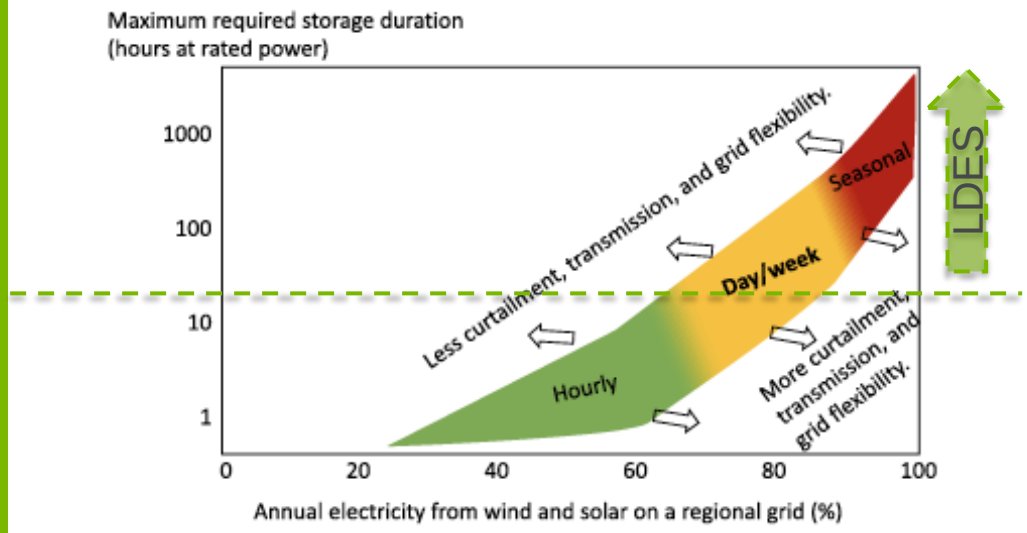
- Total 20-year present value benefits of BESS and CTG operations at $145.9 million exceed revenue requirements and energy costs at $93.9 million with an ROI ratio of 1.55
- Benefits largely driven by the transmission deferral use case, $109 million (75%) in present value terms.
- Regulation services - $18.8 million, 13% of total benefits
- Regulation service dominates the application hours, 7,900 hours each year



Benefits of Local and Market Operations (Base Case) vs. Revenue Requirements

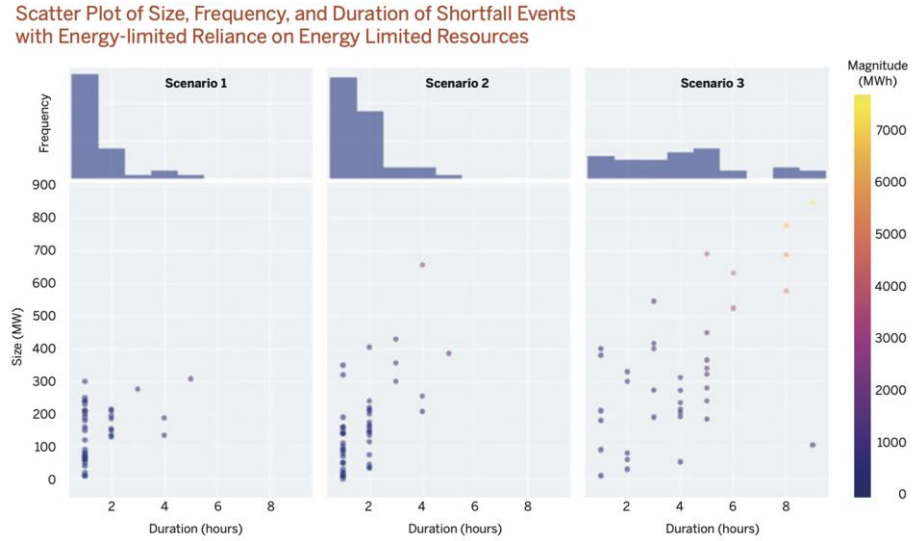
LONG DURATION ENERGY STORAGE (LDES) IS REQUIRED FOR DEEP DECARBONIZATION

Renewable Energy Penetration Necessitates LDES Investment



Source: Albertus et al. *Joule* (2020). Long-Duration Storage Applications, Economics, and Technologies.

Three Scenarios with the Same LOLE but Varied Reliability Needs



Redefining Resource Adequacy for Modern Power Systems (ESIG, 2021)

Redefining Resource Adequacy Task Force (2021). Redefining Resource Adequacy for Modern Power Systems. Reston, VA: Energy Systems Integration Group.

VALUING RESILIENCE

- Energy storage has demonstrated the capacity to enhance grid resilience
- Resilience benefits are poorly defined and generally ignored in energy storage valuation studies
- Resilience benefits are typically evaluated using customer damage functions and interruption cost studies, sometimes evaluated using willingness to pay studies (e.g., contingent valuation method) and input-output analysis
- Resilience value can be embedded in other value streams, including transmission deferral, voltage sag compensation, and outage mitigation
- Multi-hazard risk analysis that relies on expected value calculations based on probabilistic analysis, while addressing a broad range of hazards and values tied to lost economic productivity, infrastructure damage, and injuries/fatalities is required – annual risk premium
- More research is needed to properly value resilience

Cost Element	Included in Outage Cost Studies	Included in Resilience Valuation
Value of lost load	☑	☑
Penalties to utilities		◌
Lost energy sales		◌
Surging LMPs	◌	◌
Fatalities, injuries, morbidity	◌	
Infrastructure and property damage	☑	
Business closures and relocations	◌	
Displacement costs	◌	
Direct, indirect, induced effects	☑	

☑ Often included.
◌ Sometimes included.
Rarely or never included left blank.

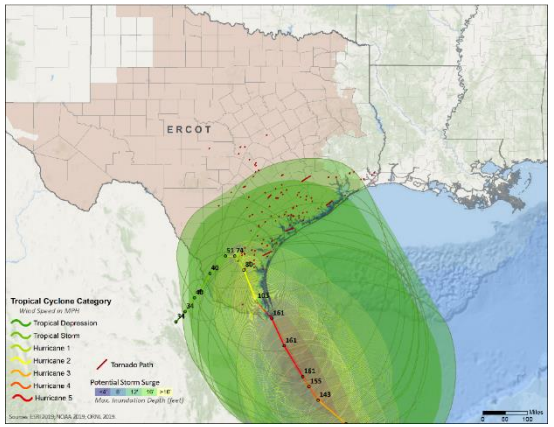
Treatment of Various Cost Elements Included in Outage Cost and Resilience Valuation Studies

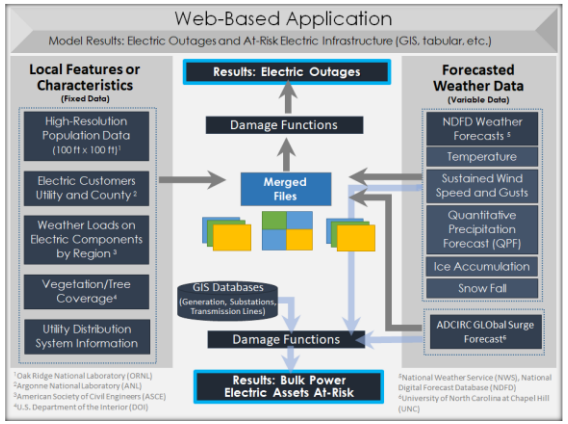
Source: Balducci, Patrick, Mongird, Kendall, and Weimar, Mark. Understanding the Value of Energy Storage for Power System Reliability and Resilience Applications. Germany: N. p., 2021. Web. https://doi.org/10.1007/s40518-021-00183-7.

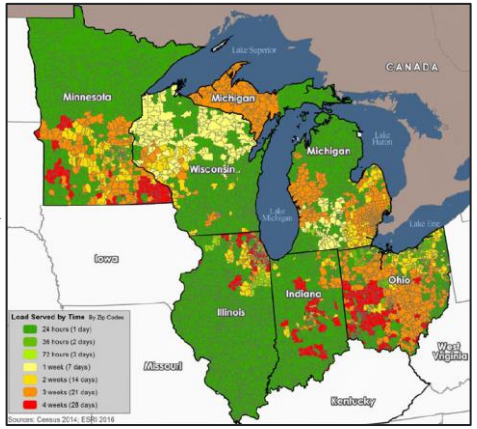
MULTI-HAZARD RISK ANALYSIS

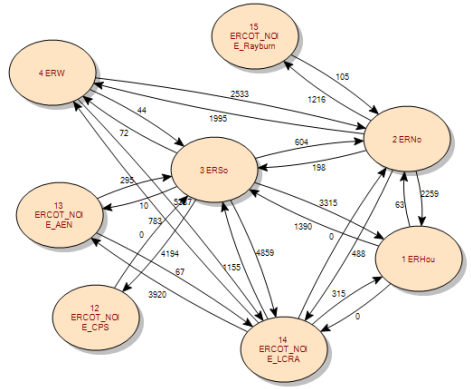
- LDES has demonstrated the capacity to enhance grid resilience, but resilience benefits are poorly defined and generally ignored in energy storage valuation studies and market structures.
- Reliability benefits are often evaluated using system models with inconsistent assumptions governing individual service values while resilience benefits are typically evaluated using customer damage functions and interruption cost studies, or sometimes evaluated using willingness to pay studies and input-output analysis.

- Multi-hazard risk analysis that relies on expected value calculations and an annual risk premium approach like the type used by insurers, while addressing a broad range of hazards and values tied to the value of lost load, surging locational marginal prices and potentially reduced economic productivity, would represent a significant advancement in the state of the art.
- Argonne has a suite of tools that can be used to evaluate the annualized risk premium associated with LDES' impact on resilience & reliability.









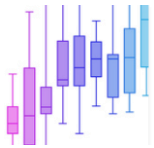
Threat Identification | Impact Assessment | Response & Recovery | Economic Valuation

FROM CLIMATE SCIENCE TO CAPACITY EXPANSION

Future Climate Scenarios

High-Frequency & High-Spatial Resolution Climate Model

Analyze and screen possible future weather patterns

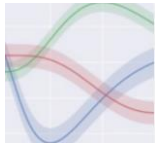


- Temperature
- Precipitation
- Wind/solar availability
- Extreme weather events

Climate to Grid Translation

Climate to Grid Translation Model

Generate probabilistic grid event scenarios



- Electricity demand
- Wind/solar profile
- Fuel supply constraints
- Grid asset de-rating
- Grid asset outage

Power System Planning with LDES

Argonne Low-carbon Electricity Analysis Framework (A-LEAF)

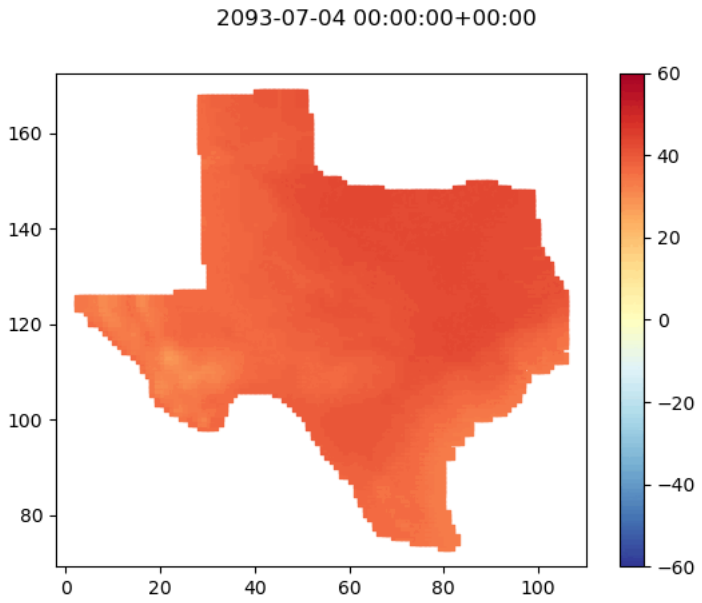
Power system capacity expansion planning and production cost simulations

- Value of LDES
- Generation portfolio
- Generation scheduling
- Load curtailment
- Energy prices

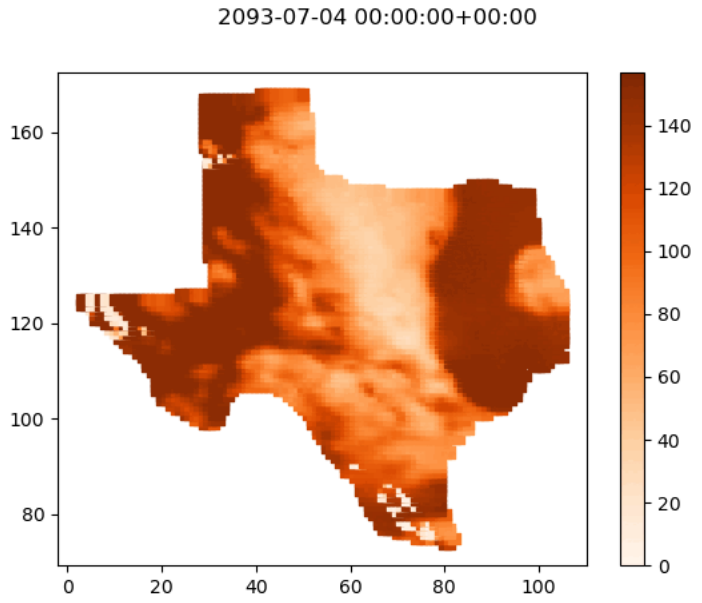
Argonne's Low-carbon Electricity Analysis Framework being Used to Evaluate the Role of LDES under Future Climate Scenarios and Extreme Weather Events

IDENTIFIED MULTIPLE HEAT- AND COLD-DRIVEN EVENTS

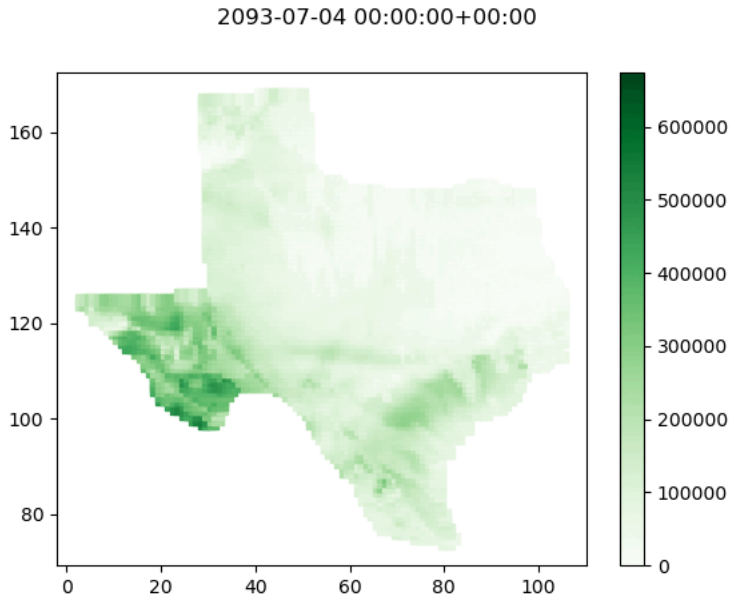
Hot: 2093 GFDL RCP8.5



Air Temperature [°C]



PV Output [MW]



Wind Output [kW]

CONCLUSIONS – KEY CONSIDERATIONS

Siting/Sizing Energy Storage	Siting/sizing of LDES by capturing/measuring location-specific benefits is key prior to LDES deployment
Broad Set of Use Cases	While most storage benefits are tied to energy and ancillary services, LDES will require consideration of reliability/resilience benefits to yield positive returns on investment in many cases
Regional Variation	Benefits will differ by region, market structures/rules, and VRE penetration rates
Model Considerations	Models require greater granularity and fidelity in identifying days/hours when LDES will be required for reliability services
Monetizing Benefits	New metrics (e.g., loss of LOLH95) and compensation mechanisms (e.g., 20+ hour capacity resource) are better suited to capture reliability risks and identify the role of LDES

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