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Energy Storage Benefit Quantification for Grid Reliability and Resilience

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ENERGY STORAGE DIVISION

U.S. DEPARTMENT of ENERGY BATTELLE

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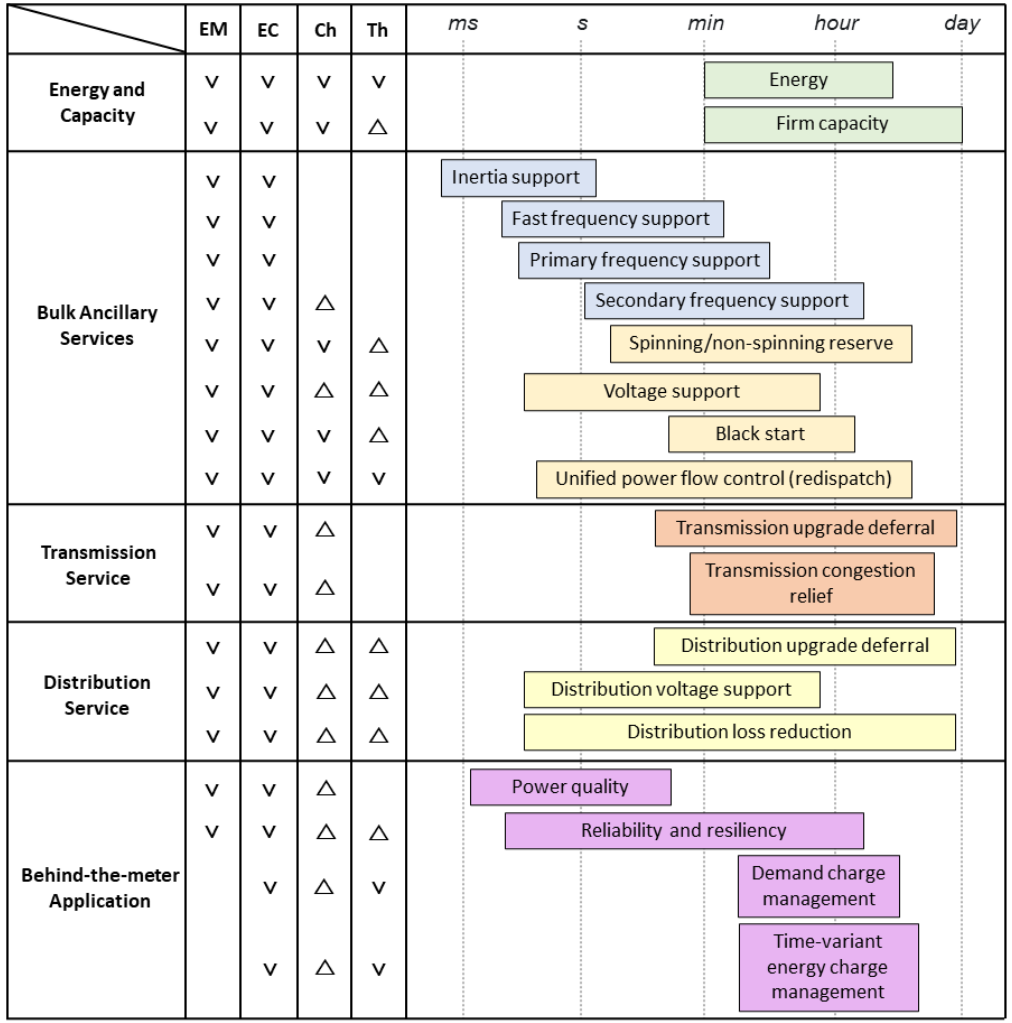
Project Overview

- **Project Goal**: Develop a modeling and assessment framework to quantify how storage enhances grid reliability and resilience
- **Current Practice**: Storage is widely promoted for resilience and reliability, but lacks clear metrics, data needs, and standardized methods for quantifying benefits
- **Why PNNL**: Unique capabilities in storage modeling and valuation; established frameworks and integrated platforms with embedded data and models; strong industry partnerships and project experience focused on resilience and reliability.
- **Innovation**: Advanced framework integrating metric identification, data requirements, available datasets, and procedures to systematically quantify storage benefits for reliability and resilience
- **Impact:** Enables consistent, transparent, and data-driven evaluation of storage for outage mitigation, resilience improvement, and enhanced reliability for customers
- **Alignment:** Supports OE goals by establishing standardized methods to quantify storage benefits for resilience and reliability

Background and Motivation

- Increasing operational challenges from aging infrastructure and growing system complexity
- Storage as a solution across the grid, especially for enhancing reliability and resilience
- Lack of clear metrics, data needs, and standardized quantification methods
- Need for an advanced framework to assess storage benefits and guide deployment decisions

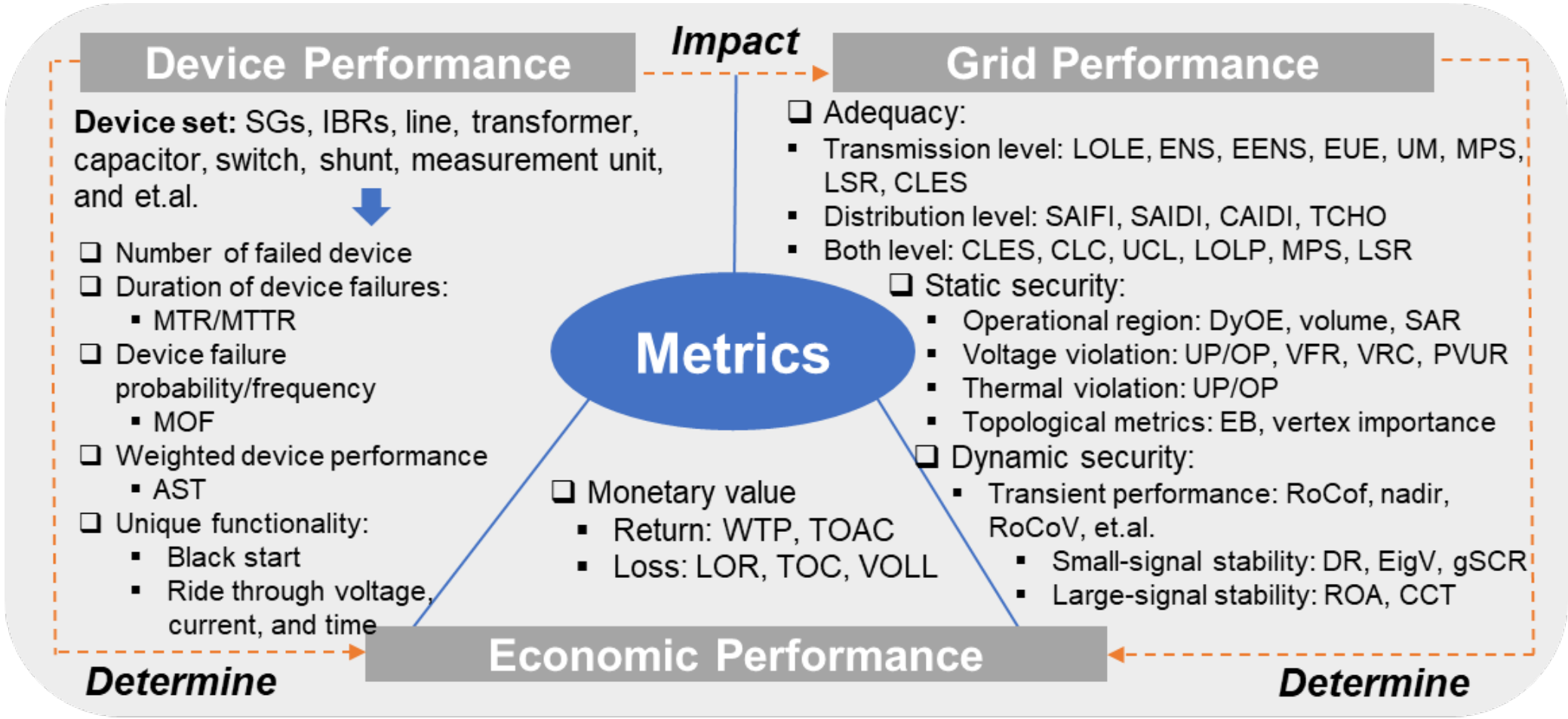


Overview of the Proposed Assessment Framework

We propose a comprehensive framework built on the following core components:

- **Metrics**: Identify key metrics
- **Required Data Inputs**: Define the types of data needed to compute each metric
- **Relevant Datasets**: Identify available datasets to supply the required inputs
- **Quantification Approach**: Implement systematic steps to generate metrics through storage modeling and dispatch, simulations, event-based analysis, and comparative scenarios (with and without storage)
- **Comprehensive Outputs**: Provide not only key metrics but also additional results to support deeper understanding (e.g., storage dispatch, usage pattern, cost of enhanced resilience)

Metrics Library



Identification of Metrics and Data Requirements

- The stakeholders are interested **distribution system resilience** and **end-user service reliability**
- Metrics should be able to collectively capture both the **technical** and **economic** impacts of power interruptions under normal and extreme conditions.

Metrics

- Lost Load (kWh/year)
- Outage Duration (minutes/year)
- Outage Frequency (times/year)
- Value of Lost Load ($/year)

Required Data Inputs

- Load information
- Storage technology specifications
- Outage data or reliability records
- Value function of lost load

Datasets: Energy Storage and Interruption Cost

- **Energy Storage Cost and Performance Database** offers up-to-date cost and performance metrics for a variety of energy storage technologies.
- **Interruption Cost Estimate (ICE) Calculator** provides data on the economic costs associated with power interruptions.
  - Extract **Cost Damage Function (CDF)**
  - Revise CDF to ensure applicability under extreme conditions (e.g., outage durations exceeding 16 hours).

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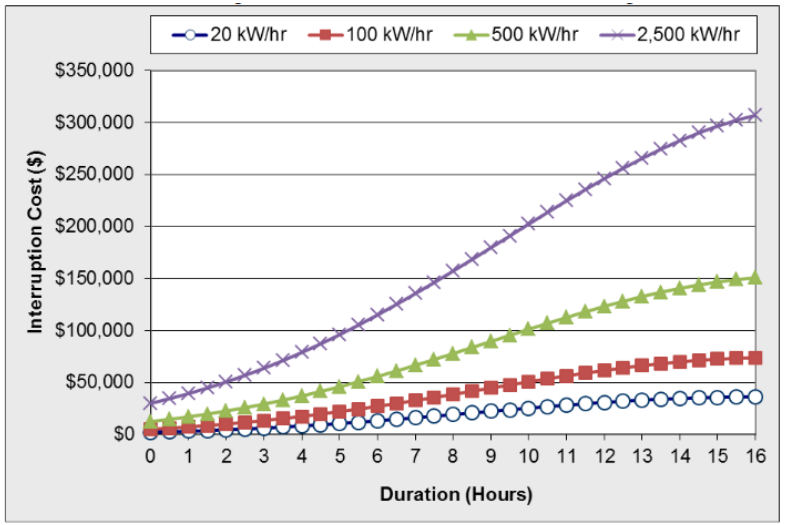
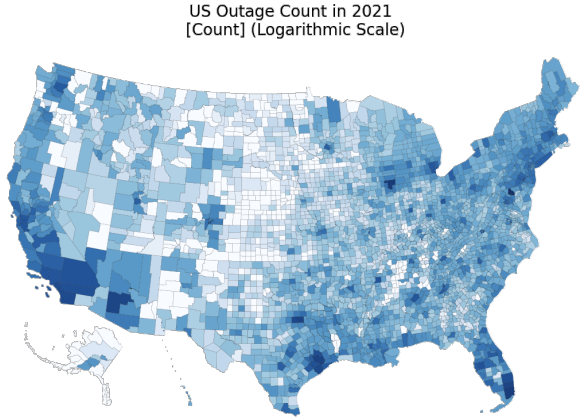
ICE CALCULATOR

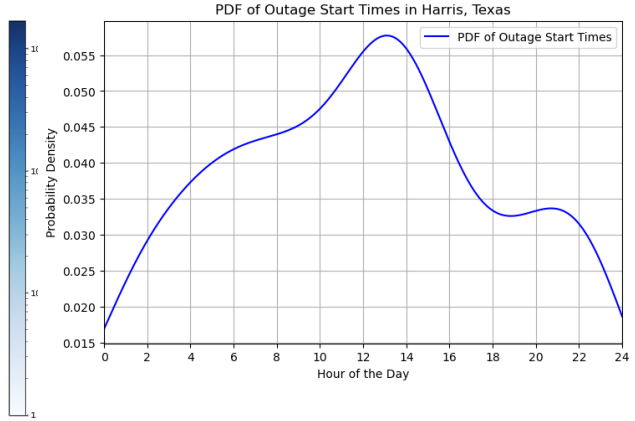


Source: M. Sullivan, et.al, "Updated Value of Service Reliability Estimates for Electric Utility Customers in the United States," LBNL--6941E, Jan. 2015.

Datasets: Outage and Reliability Records

- The **Environment for the Analysis of Geo Located Energy Information (EAGLE-I)** monitors power distribution outages for over 146 million customers, covering more than 92% of the US and Territories.
  - Clean, aggregate, and structure outage data by **location** and **time**
  - Extract the probability distribution functions (PDF) for
    - Date of outage
    - Start time of outage
    - Outage frequency and duration
- **U.S. Energy Information Administration (EIA)** tracks and publishes comprehensive electric power reliability data across the United States.

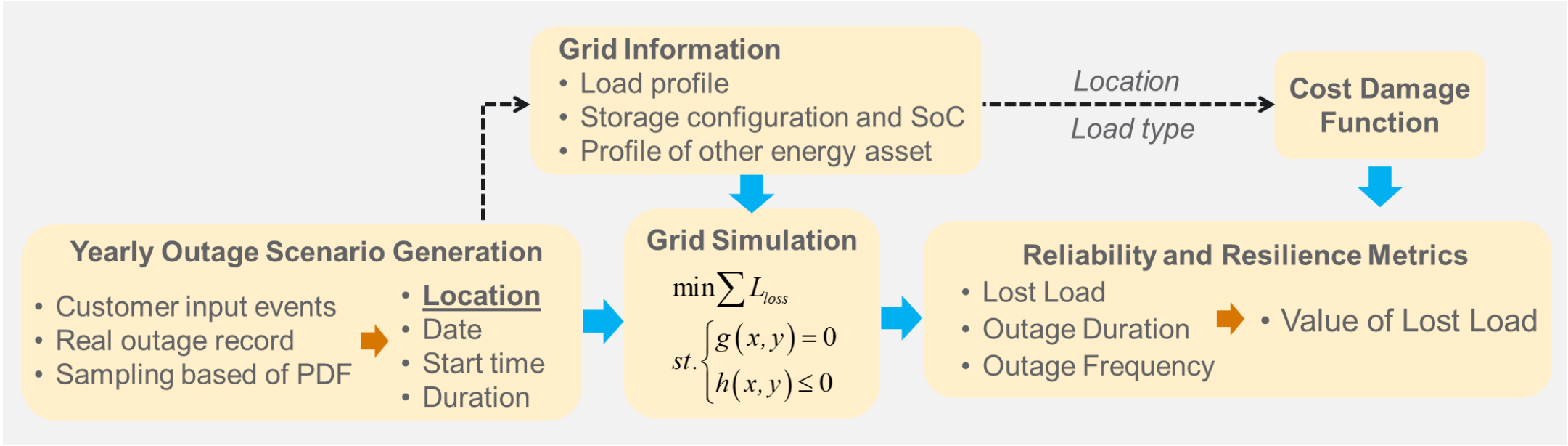




Utility Name	State	SAIDI	SAIFI
Adams-Columbia Electric Coop	Wisconsin	229.1	1.087
Agralite Electric Coop	Minnesota	238.438	1.364
Alameda Municipal Power	California	6.69	0.031
Alaska Electric Light & Power Co.	Alaska	74	1.94
Albany Utility Board	Georgia	116.272	1.28
City of Alexandria - (MN)	Minnesota	10.157	0.293
Alger-Delta Coop Electric Assn	Michigan	189.1	1.045
Altamaha Electric Member Corp	Georgia	424.713	1.997
City of Ames - (IA)	Iowa	33.21	0.4
Amicalola Electric Member Corp	Georgia	1461.38	4.766
City of Anaheim - (CA)	California	28.35	0.585
City of Anderson - (IN)	Indiana	326.919	1.973
Connexus Energy	Minnesota	54.841	0.616

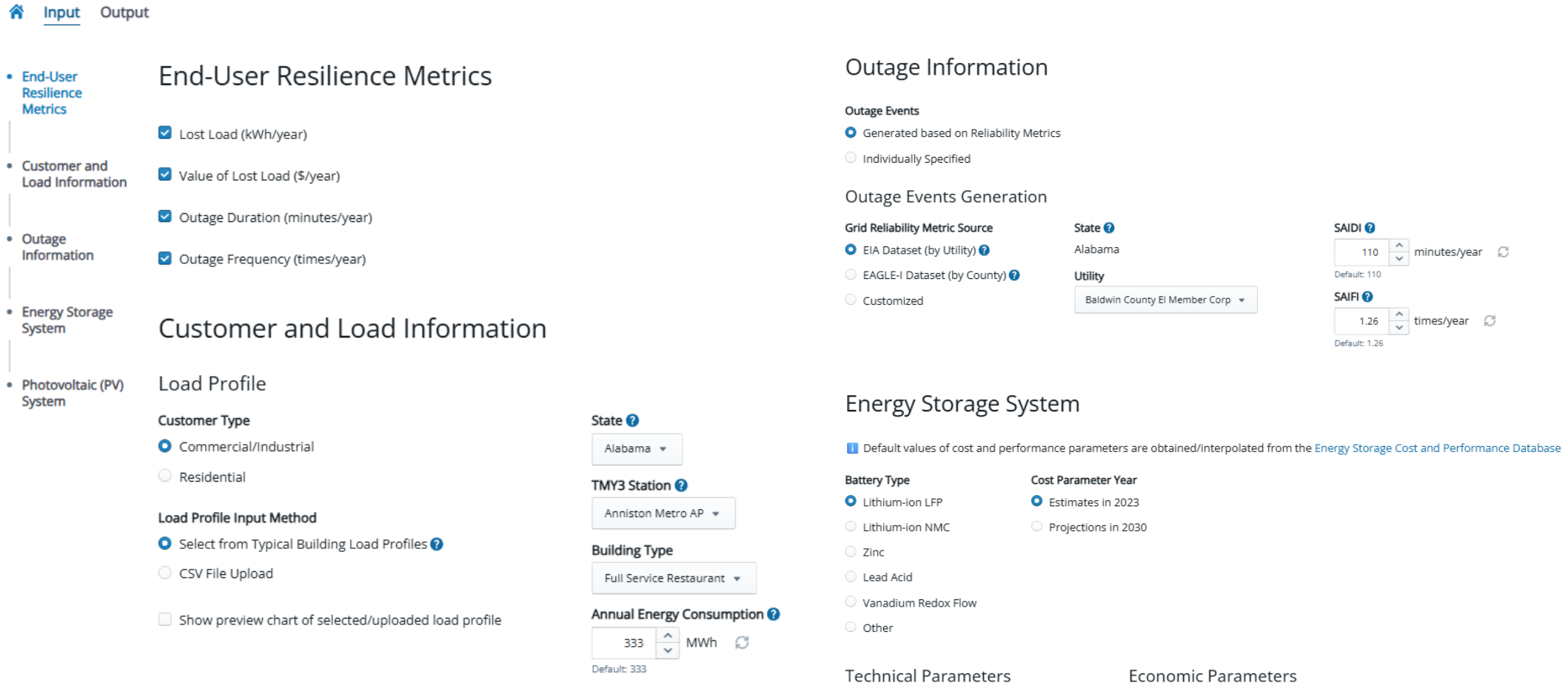
Quantification Approach

Monte Carlo simulation enables rigorous assessment of storage benefits for improving reliability and resilience by accounting for stochastic variability and operating conditions, while capturing complex interdependencies across scenarios.



Energy Storage Benefit Quantification App for Reliability and Resilience

A **web-based, easy-to-use app** that is **flexible and configurable** for customized storage benefit quantification.



User-Centered and Structured Output

Summary of Benefit

- Tabular comparison of metric evaluation results

← VIEW ES4RES DEMO INPUT

Annual Energy Service Disruption Metrics

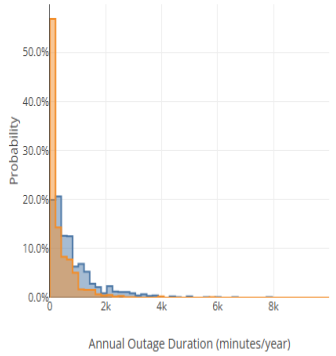
	Baseline	With Storage Solution	Improvement
Lost Load (MWh/year)	0.59	0.17	0.43 (72%)
Value of Lost Load ($/year)	47K	15K	32K (68%)
Outage Duration (minutes/year)	839	350	489 (58%)
Outage Frequency (times/year)	2.5	1.2	1.3 (50%)

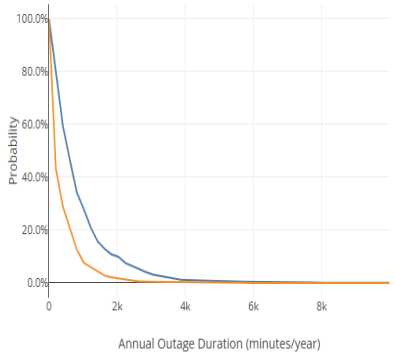
Upfront Investment Costs

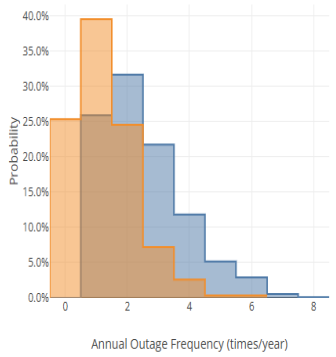
Components	Cost ($)
Energy Storage System	
Energy Components	44,700
Power Components	7,300
Fixed Investment	0
ES System Subtotal	*52,000*
Photovoltaic System	
Power Components	900,000
Fixed Investment	20,000
PV System Subtotal	*920,000*
Total	**972,000**

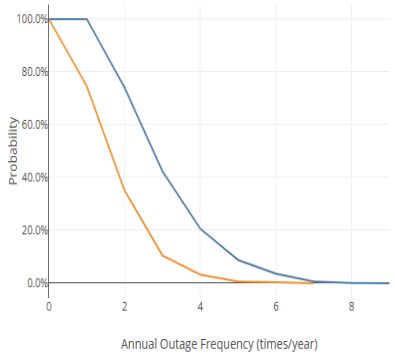
Overall Assessment

- Discretized probability distribution plots
- Complementary cumulative distribution plots



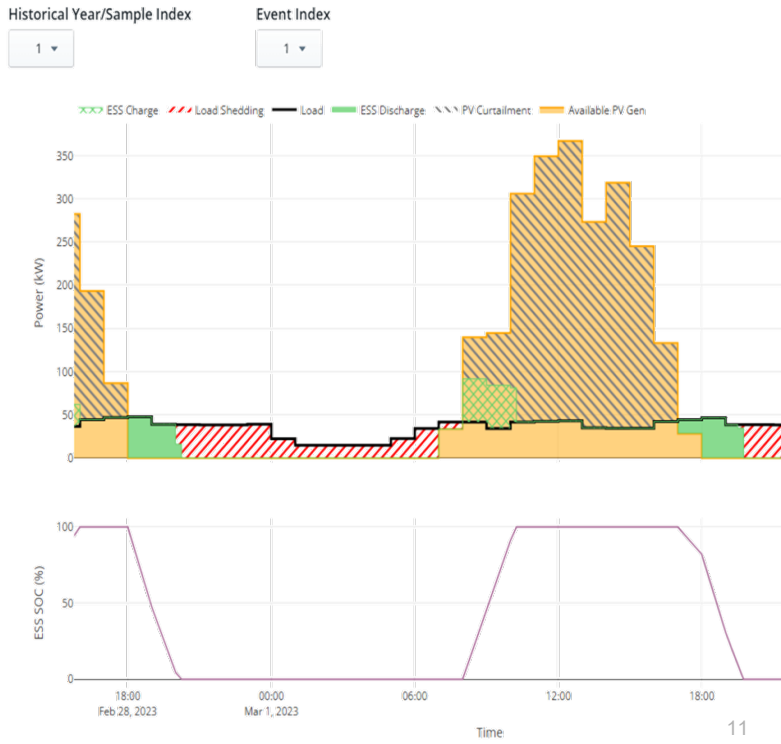






Event-Oriented Analysis

- Time-series visualization of ESS charge/discharge, load served/shedding, and other system components



Conclusions and Future Work

Conclusions

- Developed a comprehensive framework to quantify storage benefits for resilience and service reliability
- Demonstrated how metrics, data, and procedures can be systematically aligned
- Developed a web application to support customized storage benefit quantification for diverse resilience and reliability objectives

Future Work

- Advancing the framework by expanding metrics, datasets, and storage models to accommodate evolving stakeholder needs
- Enhance platform usability, visualization, and decision-support features
- Use the framework and platform to provide technical support for storage deployment in resilience and reliability projects

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Acknowledgment

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The Office of Electricity leads the U.S. Department of Energy's research and development to strengthen and modernize our nation's power grid to maintain a reliable, affordable, secure, and resilient electricity delivery infrastructure.

https://www.energy.gov/oe/energy-storage

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Thank You

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