Quantifying Resilience for Distributed Energy Storage Systems

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The U.S. Department of Energy's **Energy Storage for Resiliency Hubs** (ES4RH) initiative enhances the reliability, resilience, and affordability of the nation's electrical grid through strategic partnerships and local deployment of advanced energy storage systems to promote American energy independence and economic growth.

The Concept and Dimensions of Resilience

Energy system resilience: "a system's ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions through adaptable and holistic planning and technical solutions [in the context of energy grids and infrastructure system]" (Hotchkiss and Dane 2019; Leddy et al., 2023).

Regional resilience: "the capacity of a locality or region to prepare for, respond to, and recover from large multi-hazard threats with little impact on public safety and health, the economy, and national security" (Wilbanks 2007).

Quantifying Resilience: Metrics and Methodologies

Energy System Attribute-Based Metrics

- Metrics describing the properties or characteristics of a resilient system
- The 5 Rs framework: robustness, resourcefulness, redundancy, response and recovery
- Different scopes and metrics for transmission operators vs utilities vs distributed energy storage systems

Energy System Performance-Based Metrics

- Metrics intended to measure how disruptive events affect system performance and to guide decisions on resilience investments. Mostly measured in units (like MWh or MMBtu) or measurements derived from performance
- Examples include: percentage of energy delivered or time until restoration, MWh of load curtailed, percentage of customer demand met or expected demand not supplied, average number or percentage of critical loads that experience an outage

Local Outcome-Focused Metrics (ES4RH focus)

- Metrics that describe the expected consequences of a given disruptive event, which extend the performance of infrastructure to the consequences for society. Key categories include (Leddy et al., 2023):
- Economic: such as energy cost-savings
- Workforce development: such as number of project roles filled by local workers
- Geographic, safety and health: such as number of hospitalizations or loss of human life
- Service- or access- based: such as population with potential to access resilience hubs for critical services like electricity, heating, cooling, water, meals, medicine
- Environmental: such as indoor and outdoor air quality improvement

PNNL is developing a step-by-step guide for participant impact assessment, which is tailored to quantify the impacts of battery energy storage system (BESS) projects, with case studies from resiliency hubs and utilities.

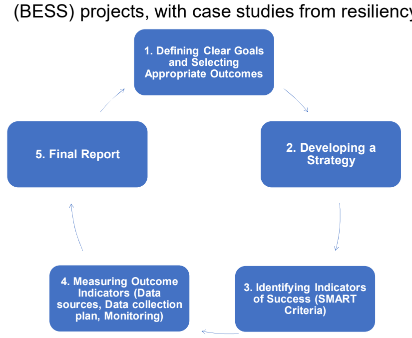

Figure 1: Key steps for participant assessment

***Primary data**:*
- ✓ *Surveys, interviews, engagement workshops, local observations*

***Secondary data**:*
- ✓ *Publicly available records includes utility bills, Census data, EPA/CDC databases*

***Monitoring**:*
- ✓ *Both baseline and post-deployment*

Application of Energy Storage in Resilience Hubs

Resilience hubs: "localized physical spaces – a building and related infrastructure – created to support residents, coordinate communication and services, and provide resource distribution before, during, or after a disaster" (Baja, 2018).

How Can Energy Storage Improve Resilience?

- **Backup Power During Outages**
- **Energy Cost-savings**
- **Grid Independence**
- **Workforce Development**
- **Integration with on-site Generation**

An example in ES4RH: Pine Point School

Pine Point School project: one of the 14 participants selected in the first cohort

- A pre-K to 8th grade public school in Pine Point, Minnesota, on the White Earth Reservation (82 students and 12 teachers). The school is a fully electric, energy efficient building, and currently utilizes 20kW of on-site generation.
- Local partners are working to support the installation of energy storage systems and expand generation capacity at the school site.
- Also serves as an emergency shelter for the local region, which faces periodic power outages caused by tornadoes.
- On-going meetings are being held to help the participant identify project goals and develop metrics to evaluate outcomes.

Table 1: Example Draft Project Goal Categories and Evaluation Metrics for Consideration

Category	Metrics
Services	1) Duration the hub can operate without external power during an outage
	2) Number of critical services (e.g., water) functioning during emergency use
Economic	3) Annual reduction in electricity bills ($ or %)
	4) Percentage of energy usage supplied by local generation and battery storage (%)
	5) Payback period (in years) for the generation addition and battery investment
	6) Number of new initiatives funded (e.g., new staffing, programs, or supplies)
Workforce	7) Number of roles filled by local workers during installation
	8) Percentage of overall project roles staffed by local workers
Security	9) Reduction in grid energy consumption (kWh/year)
	10) Percentage reduction in propane use for heating (%)

Key References

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Hotchkiss, E., and Dane, A. (2019). Golden, CO: National Renewable Energy Laboratory. NREL/TP-6A20-73509.
Leddy, L. et al. (2023). Golden, CO: National Renewable Energy Laboratory. NREL/TP-5R00-87053.
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