NREL
Transforming ENERGY

A Secure and Resilient Grid: Planning for All Hazards

Heidi Applegate
30th PPA Annual Conference, Saipan
September 26, 2023

Resilience

A system's ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions (Hotchkiss et al. 2019).

Energy Reliability and Resilience

	Reliability	Resilience
Definition	**A measure of whether a power system can provide regular, consistent power**, typically characterized by System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), and System Average Interruption Frequency Index (SAIFI) (Stout et al. 2019)	The 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 (Hotchkiss et al. 2019)
Event characteristics	Uncertainty associated with fluctuating load and generation, fuel availability, and failure of assets **under normal operating conditions**	**Low-probability, high-consequence events** that represent black-sky operating conditions and apply stress to a system over a large scale
Outage duration	**Seconds to hours**	**Days to months**
Spatial extent	**Concentrated area** (e.g., one facility, campus, or neighborhood)	**Large geographic region** (e.g., states, regions, or islands)
Economic losses	Losses largely limited to **unserved load for a subset of customers**	Losses arising from both **lost load and cascading impacts to the economy** (such as degraded water quality or delivery due to power loss)

Resilience Assessments

Conducting assessments allows researchers to develop replicable methodologies and learn about research gaps and needs.

Robustness
Are systems physically secure?

Redundancy
Are there single points of failure?

Resourcefulness
Do we have diverse options?

Response
Are systems automated and self-healing?

Recovery
Can systems recover?

The Resilience Assessment Process: Assess Baseline Conditions

Source: Anderson et al. 2019.

NREL's resilience assessment methodology is a cyclical process, starting with assessing baseline conditions:

- Identify the location, capacity, and other factors to help determine the ability to respond to and adapt to disruptions under different operational conditions.
- Identify which assets (property, people, information, missions) need to be protected.

The Resilience Assessment Process: Assess Baseline Conditions (Cont.)

Typical Baseline Data

Process-Based Information	Operational Data	Geospatial Data	Historical Data
Emergency management plan	Energy consumption per building (if available) or meter and tariff	Map of electrical and natural gas infrastructure	Grid outages
Continuity of operations or contingency response plan	Water consumption per building or meter	Map of water and sewage infrastructure	Disruption to utilities or services
Memorandums of understanding between site and community	Fuel consumption by fixed (electrical) equipment and mobile equipment	Map of site and facilities	After-action reports
Community and site development plans	List of critical facilities and missions	Map of communications networks	Weather-related events and sequences of events
Ordinances and codes	List of backup generators and locations	Map of critical infrastructure	Assessments of local environmental risks and hazards

Source: Anderson et al. 2019.

The Resilience Assessment Process: Identify and Score Hazards and Vulnerabilities

Source: Anderson et al. 2019.

The next step in the methodology is intended to uncover the potential hazards to the site that expose existing vulnerabilities in the infrastructure, processes, and systems required to perform work at the site.

Photos from iStock 1282387405 (left), iStock 461097289 (right)

Photo from iStock

Identify Hazards and Vulnerabilities:

Hazards

Anything that can damage, destroy, or disrupt an asset or site and is external and **not within control.** Examples:

- Hurricanes
- Cyberattacks
- Acts of terror
- Political upheaval.

Vulnerabilities

Weaknesses within infrastructure, systems, or processes that **are within control.** Examples:

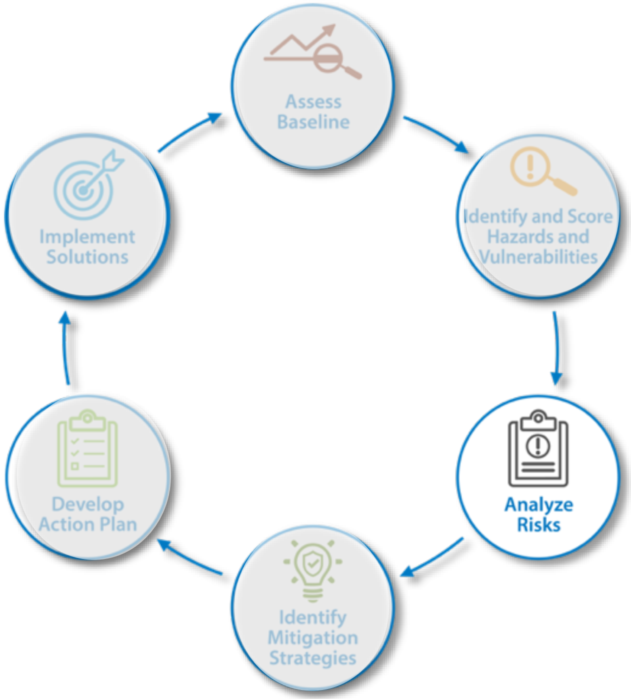
- Lack of redundant power generation
- Single points of failure in communications networks
- Ill-trained or overworked staff.

Supply Chain Components: Keys to Energy Security

Raw Materials | Manufacturing | Warehousing | Distribution | Retail

When identifying threats and vulnerabilities, also consider each supply chain step for key equipment and spare parts.

The Resilience Assessment Process: Analyze Risks



Source: Anderson et al. 2019.

- Which risks would have the highest impact?
- Which risks are the most likely to occur in the near term?

Risk Matrix

After relationships between hazards or threats and vulnerabilities are determined, a risk score can be calculated for each related hazard- or threat-vulnerability combination by multiplying the hazard or threat likelihood and vulnerability severity scores for each hazard- or threat-vulnerability combination.

Example risk matrix

VULNERABILITIES	Vulnerability Severity Score	Extreme Precipitation	Extreme Temperatures	Flooding	Landslides	Wildfire Interactions	Wind	Human Actions: Bad Actors	Human Actions: Accidents	Technological Design	Technological Materials	Technological Workmanship	Drought	Lightning
Threat Likelihood Score		9	7	7	7	5	5	5	5	5	5	5	5	1
Power system rules, regulations, and technical standards do not meet current and changing environmental conditions	9	81		63	63			45		45	45			
Corruption leads to code violations	9	81			63	45	45	45			45	45		
Dam construction does not follow design specifications	9	81	63		63	45	45	45	45	45	45	45		
Installation does not follow design specifications	9			63	63	45		45	45	45		45		
Lack of compliance with codes in design	9	81	63	63	63	45	45			45	45	45		
System operations are not flexible enough to respond to changes in demand and supply	7	63	49	49			35			35			35	7
Demand forecasting is not responsive to changing load conditions	7	63	49							35			35	
Heavy power sector reliance on hydro generation	7		49	49						35			35	
Inadequate domestic generation capacity requires costly energy imports	7		49	49	49	35	35	35	35	35	35	35	35	

Source: Kandt, et al. 2021.

The Resilience Assessment Process: Identify Mitigation Strategies

Source: Anderson et al. 2019.

- Which solutions would be effective in mitigating the risks?

Community Resilience Options

Energy Storage

Power Generation

Resilience Hubs

Network Infrastructure and Security

Electric Transportation

Source: Kramer, Belding, and Coney 2023.

Community Resilience Options (Cont.)

Emergency Services Support

Community Awareness and Education

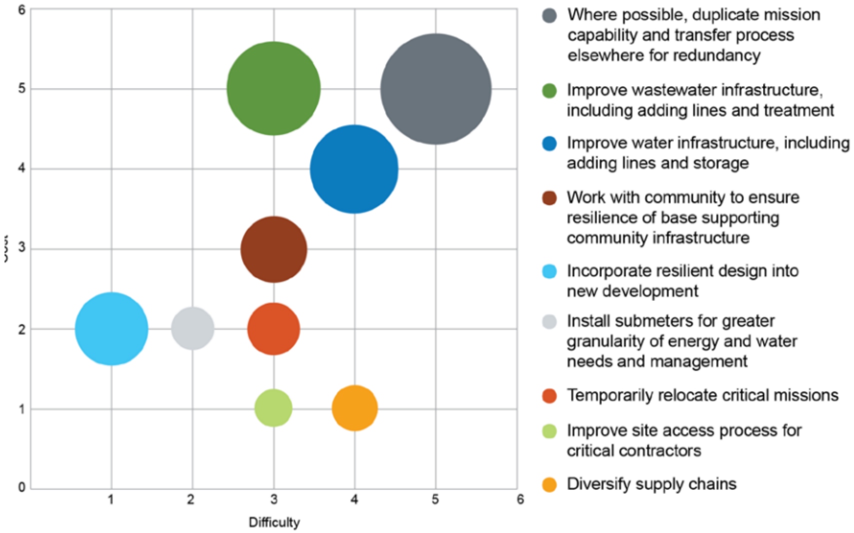
Efficiency-Resilience Nexus

Green Infrastructure

Financial Support

Note the wholistic approach to resilience. Utilities, community leaders, and citizens work in concert to achieve resilience.

The Resilience Assessment Process: Analyze Mitigation Strategies



This figure shows mitigation actions prioritized based on cost, difficulty, and risk reduction, where risk reduction corresponds to the size of the bubble.

Example Mitigations Scored by Difficulty, Cost, and Risk Reduction

Mitigation Action	Difficulty	Cost	Risk Reduction
Add backup power to critical loads	4	4	High (80%)
Improve water infrastructure by adding backup line and storage	3	3	Low (20%)
Develop memorandum of understanding with county to establish clear contingency plans	4	1	Med (50%)

Source: Anderson et al. 2019.

The Resilience Assessment Process: Develop an Action Plan

Source: Anderson et al. 2019.

- Which solutions can be implemented now vs. longer term?
- Which solutions will need investment vs. already have funds identified and established?
- Who will be responsible?

Develop an Action Plan:

Photo by Werner Slocum/NREL 78266

Choose mitigation strategies based on local and/or regional priorities:

- Most achievable (“quick win”)
- Least cost
- Highest-probability threat
- Key potential impact area (e.g., critical infrastructure, such as water treatment facilities and hospitals)
- Broadest impact.

Assign responsibility:

- Who will be able to champion the action?

Identify funding pathways:

- Where is funding available for the solutions?

The Resilience Assessment Process: Implement Solutions

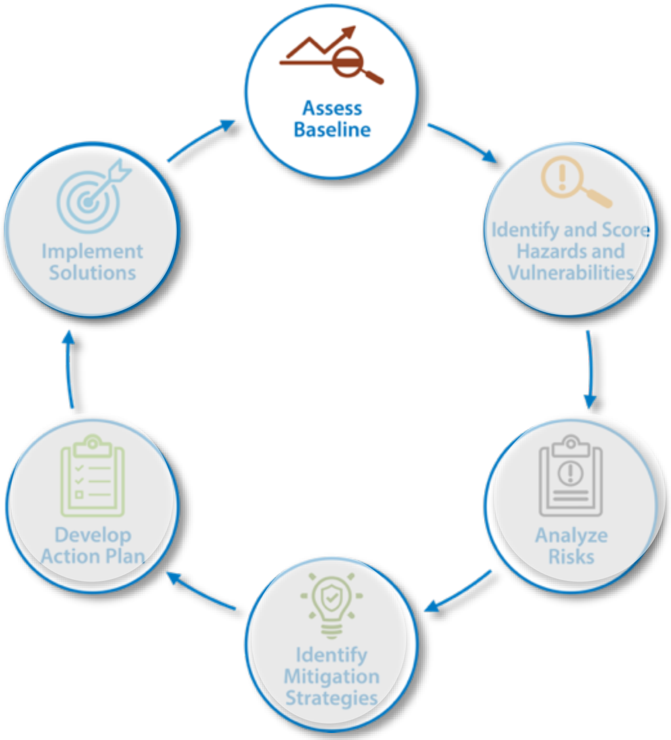
Source: Anderson et al. 2019.

- Take action!
- Monitor and evaluate progress.
- Reevaluate the plan if conditions, solutions, or funding change.

The Resilience Assessment Process Is Iterative

Reassess after implementing solutions.

- Threats and priorities might change.
- Unintended consequences might emerge.

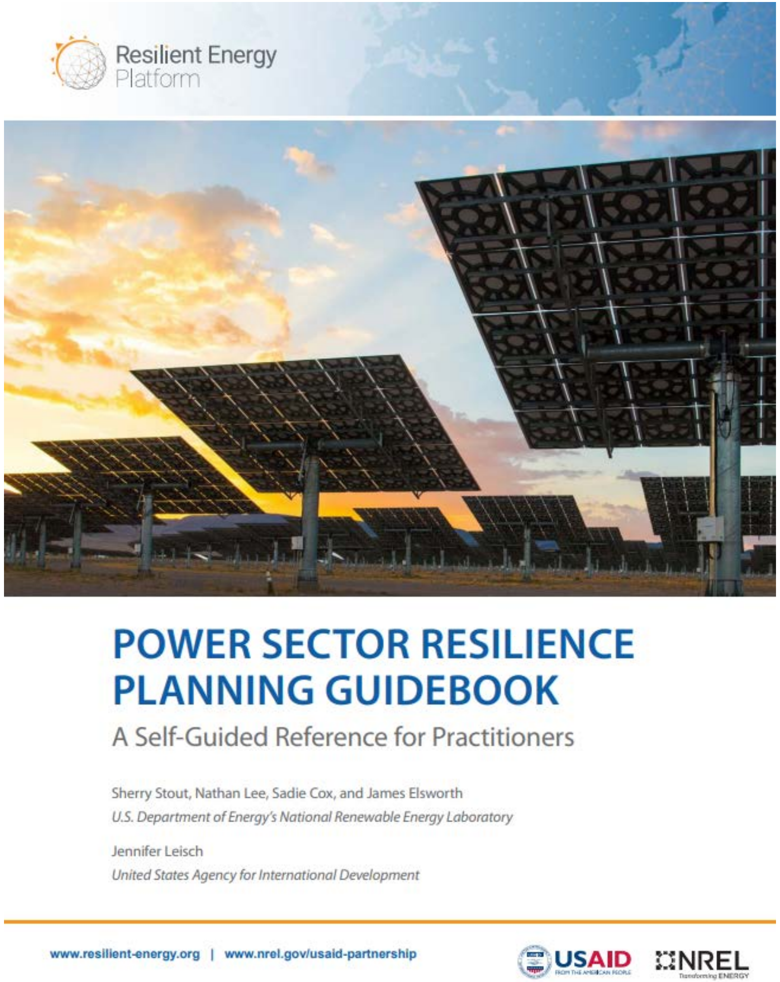


Source: Anderson et al. 2019.

Select Resources:

“Resilient Energy Platform”:
https://resilient-energy.org/.

***Power Sector Resilience Planning Guidebook*:**
https://resilient-energy.org/training-and-resources/publications/73489-guidebook-final.pdf/view.



Select Tools:

https://reopt.nrel.gov/tool

This tool helps:

- Evaluate the economic viability of distributed photovoltaics (PV), wind, battery storage, combined heat and power (CHP), and thermal energy storage.
- Identify system sizes and dispatch strategies to minimize energy costs.
- Estimate how long a system can sustain critical load during a grid outage.

https://www.nrel.gov/state-local-tribal/engage-energy-modeling-tool.html

This tool helps with:

- Planning electricity generation and transmission assets
- Analyzing the cost, land, and infrastructure implications of complex energy decisions
- Communicating the impacts of specific tactics for realizing energy goals
- Identifying the most economic path to achieving energy sector transition.

Comments/Questions?

www.nrel.gov

NREL/PR-5R00-87532

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of the Interior Office of Insular Affairs under Agreement IAG-22-22819-0. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

Photo from iStock-627281636

Transforming ENERGY

References

Anderson, Kate, Eliza Hotchkiss, Lissa Myers, and Sherry Stout. 2019. *Energy Resilience Assessment Methodology*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-7A40-74983. https://www.nrel.gov/docs/fy20osti/74983.pdf.

Hotchkiss, Eliza, and Alex Dane. 2019. *Resilience Roadmap: A Collaborative Approach to Multi-Jurisdictional Resilience Planning*. Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy19osti/73509.pdf.

Kandt, Alicen, Eliza Hotchkiss, Jordan Cox, Chris Hallock, and Kosol Kiatreungwattana. 2021. Nurseries Best Practices Guide for Energy and Water Efficiency, Renewable Energy, and Resilience. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5R00-80131. https://www.nrel.gov/docs/fy21osti/80131.pdf.

Kramer, Alexandra, Scott Belding, and Kamyria Coney. 2023. *Community Resilience Options: A Menu for Enhancing Local Energy Resilience*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-7A40-84493. https://www.nrel.gov/docs/fy23osti/84493.pdf.

Stout, Sherry, Nathan Lee, Sadie Cox, and James Elsworth. 2019. *Power Sector Resilience Planning Guidebook*. Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy19osti/73489.pdf.

Stout, Sherry, Nathan Lee, Sadie Cox, James Elsworth, and Jennifer Leisch. *Power Sector Resilience Planning Guidebook*. Resilient Energy Platform. https://resilient-energy.org/training-and-resources/publications/73489-guidebook-final.pdf/view.

USAID-NREL Partnership. 2023. “Resilient Energy Platform.” https://resilient-energy.org/.