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Selecting and Implementing Resilience Metrics in Existing Energy Sector Models

Caitlin Murphy

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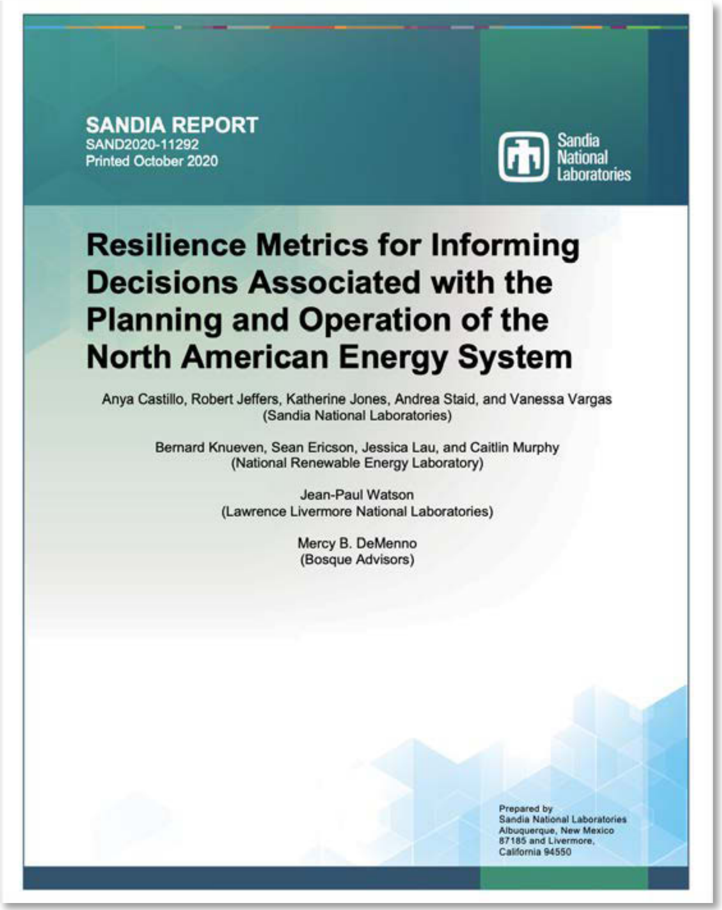
IEEE Task Force on Power System Resilience Metrics and Evaluation Methods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Resilience Metrics for Informing Decisions Associated with the Planning and Operation of the North American Energy System

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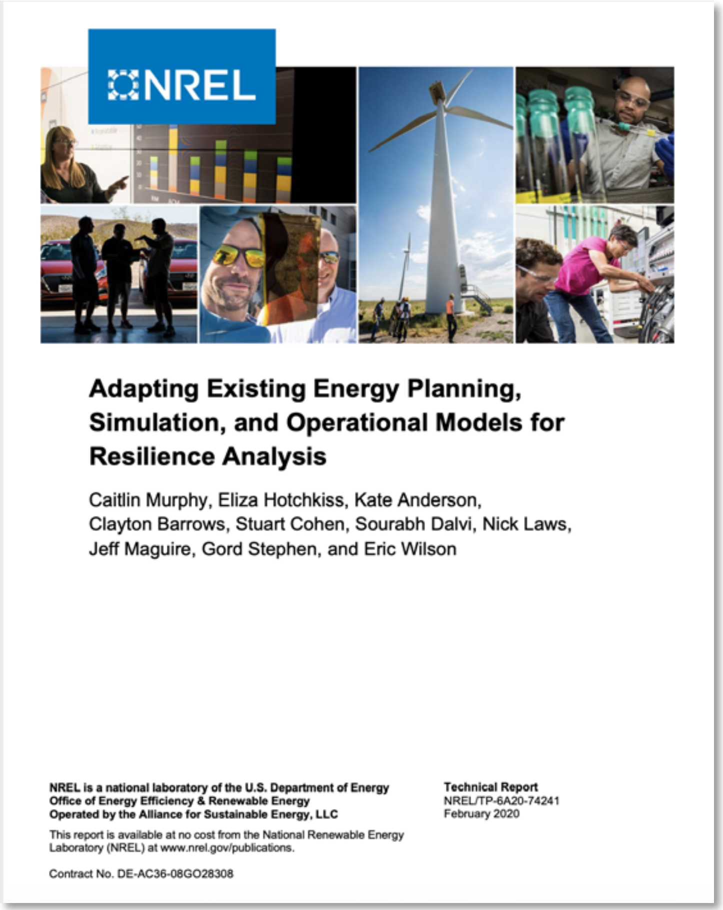
Castillo et al. (2020), SAND2020-11292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Adapting Existing Energy Planning, Simulation, and Operational Models for Resilience Analysis

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https://www.nrel.gov/docs/fy20osti/74241.pdf.

“Defining” Resilience: Mitigating Consequences

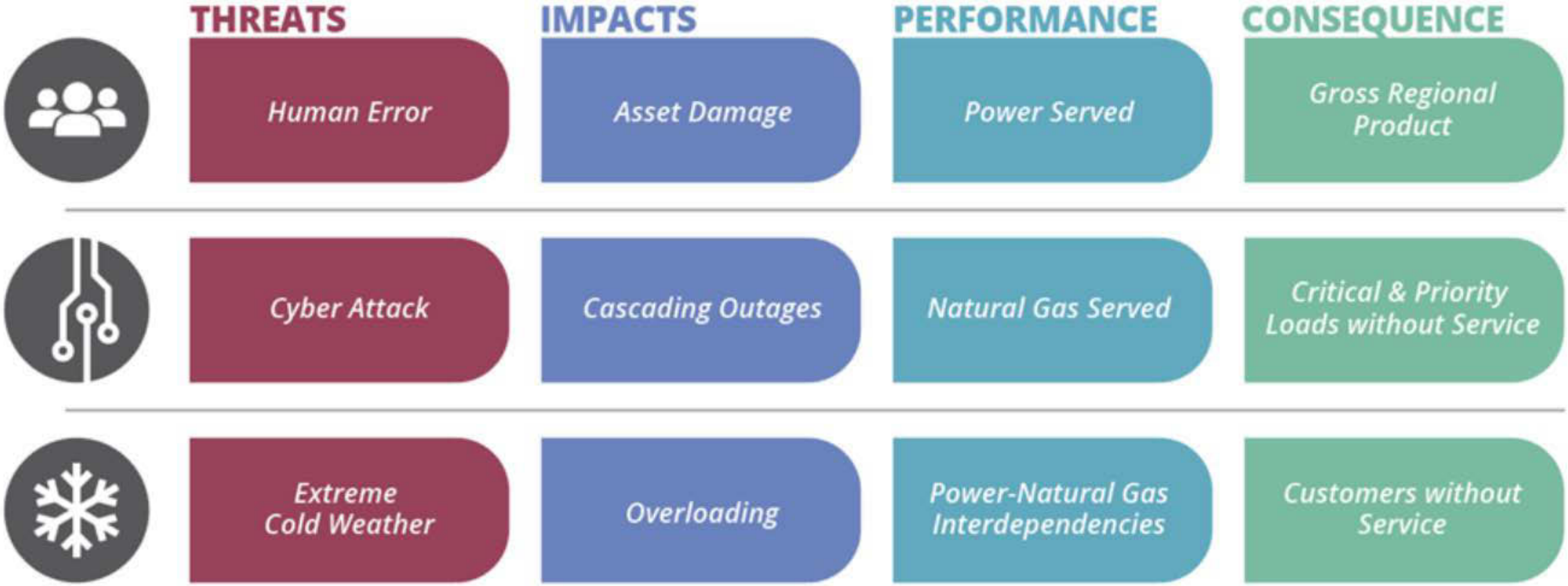


Figure 5. Notional Representation of the Translation of Threats into Consequences

Castillo et al. (2020), SAND2020-11292

Modeling Resilience: System Performance

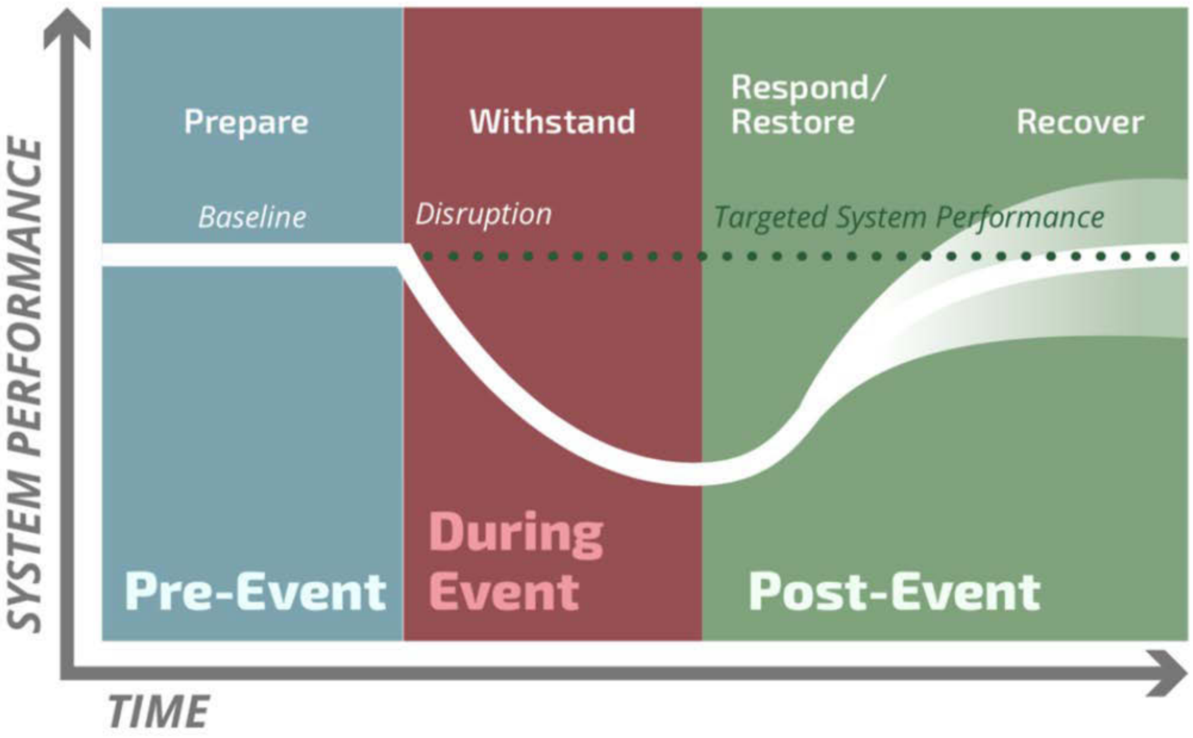
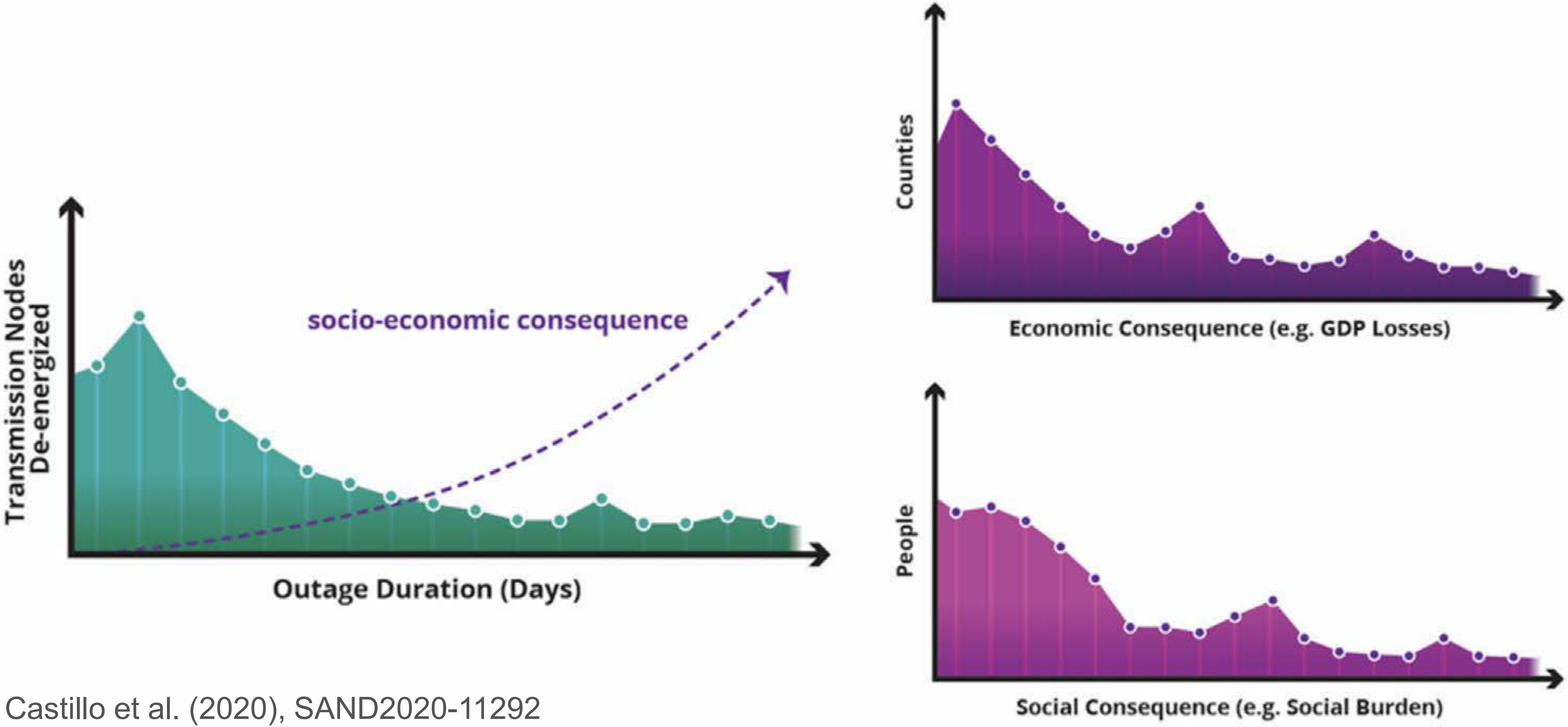


Figure 1. System Performance Curve and Timeline

Castillo et al. (2020), SAND2020-11292

Achieving Resilience: Considering Non-Linearities



Castillo et al. (2020), SAND2020-11292

Resilience Metrics (or Indicators)

Energy sector resilience can be quantified through temporally explicit performance-based metrics or indicators (e.g., comparing baseline and investment scenarios)

Table S.1. Examples of Consequence Categories for Consideration in Grid Resilience Metric Development

Consequence Category	Resilience Metric
Direct	
Electrical Service	Cumulative customer-hours of outages Cumulative customer energy demand not served Average number (or percentage) of customers experiencing an outage during a specified time period
Critical Electrical Service	Cumulative critical customer-hours of outages Critical customer energy demand not served Average number (or percentage) of critical loads that experience an outage
Restoration	Time to recovery Cost of recovery
Monetary	Loss of utility revenue Cost of grid damages (e.g., repair or replace lines, transformers) Cost of recovery Avoided outage cost
Indirect	
Community Function	Critical services without power (e.g., hospitals, fire stations, police stations) Critical services without power for more than N hours (e.g., $N >$ hours of backup fuel requirement)
Monetary	Loss of assets and perishables Business interruption costs Impact on Gross Municipal Product or Gross Regional Product
Other Critical Assets	Key production facilities without power Key military facilities without power

https://gmlc.doe.gov/sites/default/files/resources/GMLC1.1_Vol3_Resilience.pdf

This Study

- Challenge: Doing resilience analysis “right” requires substantial computational resources and data that are often not available; so what else can you do?
- Interim Solution: modify existing modeling tools to enable imperfect (yet impactful) resilience analyses
  - Define power interruption scenarios
  - Identify key metrics, based on existing model architecture
  - Perform preliminary scenario analysis to demonstrate the ability to inform decisions

https://www.nrel.gov/docs/fy20osti/74241.pdf

Power Interruption Scenarios

Power Interruption Duration

Advanced Notice	<12 Hours	>12 Hours
None	*Cyber Attack*	*Human Error*
<12 Hours		*Extreme Cold Weather*
>12 Hours		

https://www.nrel.gov/docs/fy20osti/74241.pdf

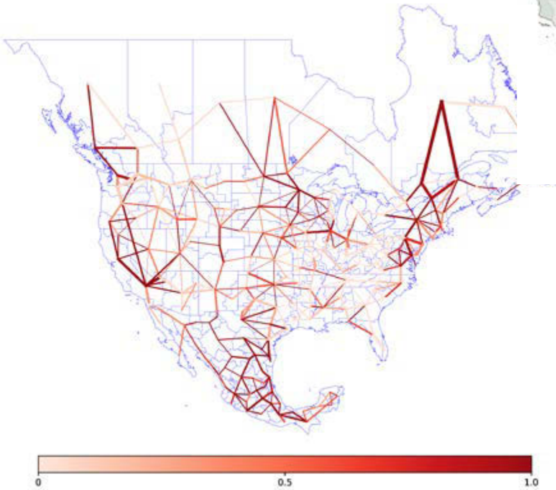
Approach

Adapt a wide array of energy sector modeling tools to enable imperfect (yet impactful) resilience analysis, sampling a variety of:

- Energy subsectors
- Geographic scales
- Modeling methods
- Resilience metrics

ResStock

REopt
Renewable Energy Integration and Optimization



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Results: ResStock

Model Description: Physics-based simulation of the energy use and thermal performance of the U.S. residential building stock

Model Update: Development of methods for (1) representing a power outage and (2) measuring thermal resilience

Power Interruption Scenario: Long- and short-duration extreme weather with "no notice"

Resilience Metric: time to unsafe indoor conditions

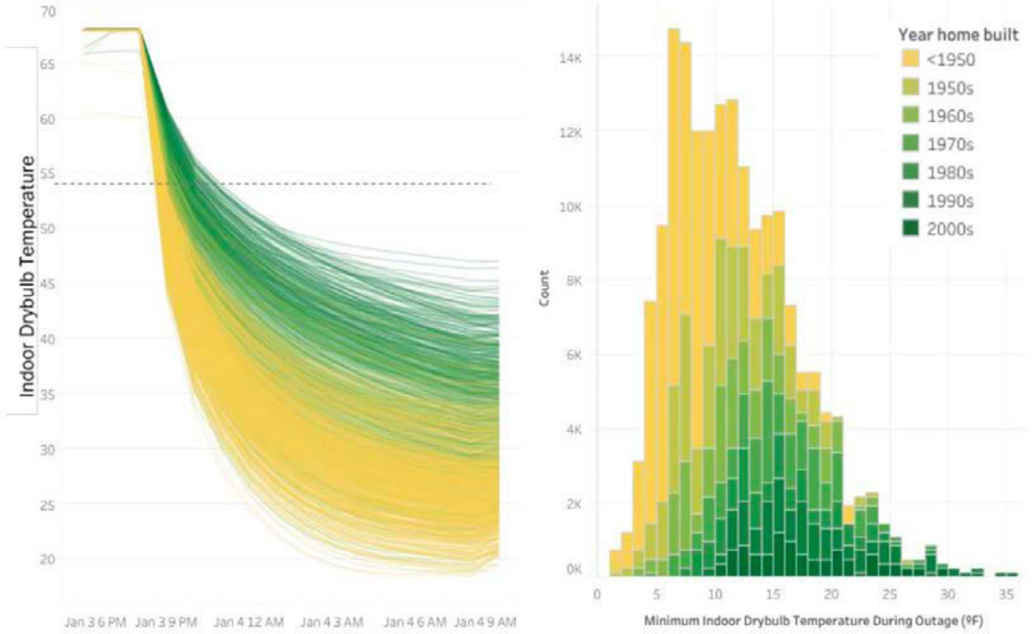

Figure 1. Internal temperature trajectories (left) and distribution of minimum indoor temperatures (right) for buildings in Buffalo, New York, during a power interruption resulting from a hypothetical 12-hour ice storm, as modeled in ResStock

Newer homes, presented in green, typically maintained a livable internal temperature for longer during the hypothetical ice storm, and they maintained higher temperatures overall over the course of the outage.

https://www.nrel.gov/docs/fy20osti/74241.pdf

Results: REopt

NREL's Renewable Energy Integration and Optimization Model

- Developed of a methodology for considering avoided power interruption costs in backup power system investments
- Explored a short-duration power disruption with no notice
- Evaluated an avoided outage cost

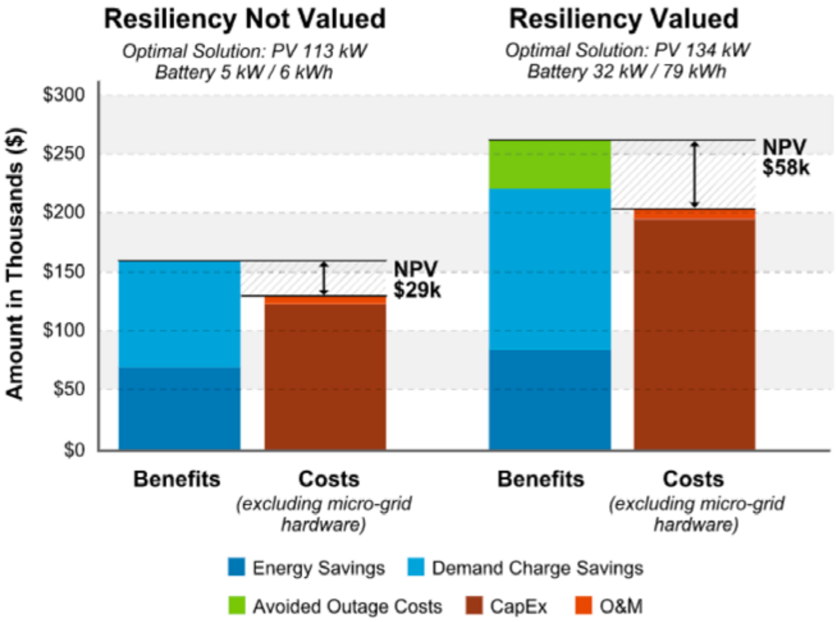

Figure 5. Accounting for the value obtained by mitigating the power interruption experienced by a facility or campus resulted in a cost-optimal backup power system that is larger and incorporates longer-duration storage, as modeled in REopt.

CapEx = capital expenditures, O&M = operation and maintenance

Results: PRAS

NREL's Probabilistic Resource Adequacy Suite (PRAS)

- Developed a sequential simulation mode for tracking storage device state-of-charge
- Explored a long-duration fuel supply disruption with no notice
- Evaluated the change in expected unserved energy (EUE) under different investments scenarios

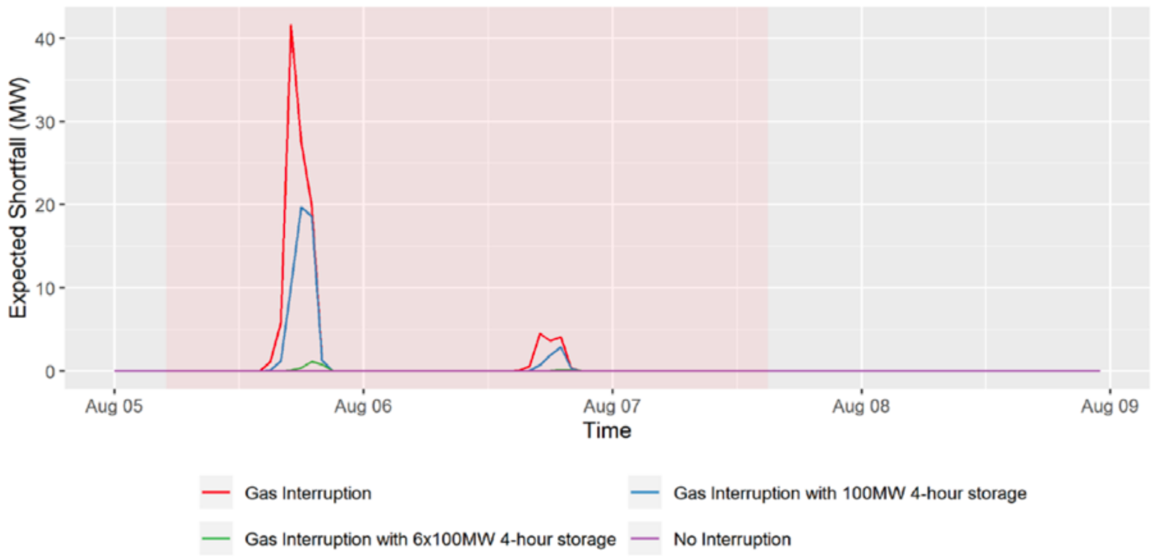

Figure 3. Expected unserved energy across natural gas disruption scenarios with varying levels of energy storage capacity, as modeled in PRAS

The four lines demonstrate the expected shortfall (in megawatts) that could occur under scenarios with varying assumptions about natural gas supply interruption and installations of four-hour battery storage systems. Obtaining the total lost load (in megawatt-hours) requires multiplying the expected magnitude and duration of the shortfall.

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Results: SIIP::Power

NREL's Scalable Integrated Infrastructure Planning (SIIP) Model: Production Cost Model

- Developed a methodology for co-optimizing the dispatch of generation with an outage duration-dependent power interruption cost
- Explored a long-duration power disruption with no notice
- Utilized and evaluated a location- and duration-dependent value of lost load (VoLL)

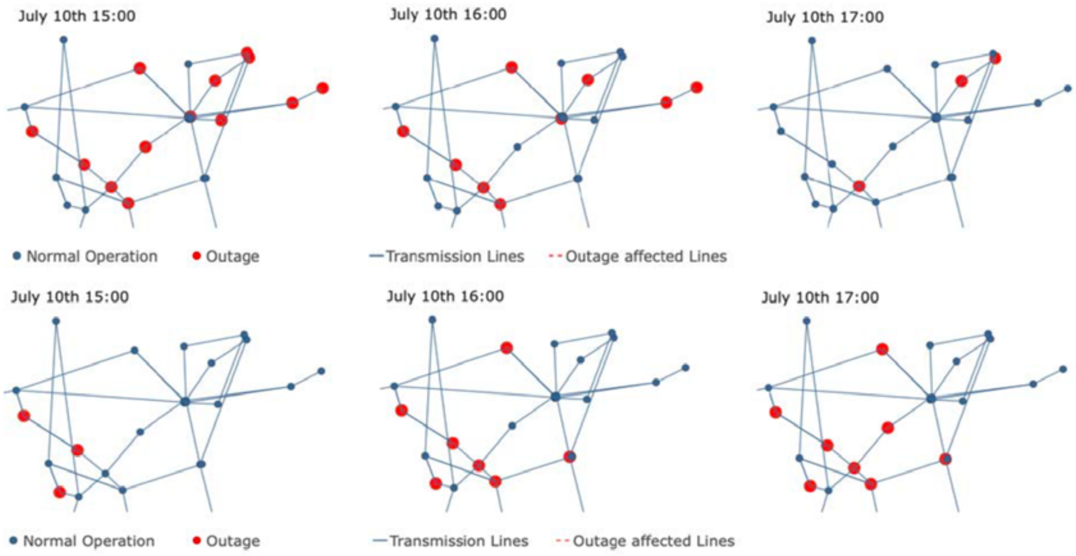

Figure 4. Under degraded conditions, considering a duration-dependent value of lost load resulted in a modified system dispatch, which reduced outage duration at each bus and overall system costs, as modeled in the production cost model framework in SIIP::Power.

Results shown here represent system dispatch in Region 1 of the RTS-GMLC under a power interruption scenario that resulted in a 15% loss in available generation capacity for 12 hours. The top row shows the dispatch pattern that resulted from consideration of a duration-dependent VoLL, whereas the bottom row considers only a static VoLL.

https://www.nrel.gov/docs/fy20osti/74241.pdf

Results: ReEDS

NREL's Regional Energy Deployment System Model

- Increased service requirements, outage rates for electricity generation assets, and outage rates for transmission assets
- Evaluated the impacts of redundancy on system performance, makeup, and costs

Table 5. Model Constructs Used to Analyze Resilience Planning in v2018 ReEDS

Modification (Scenario Abbreviation)	Intent	Model Constraints and Parameter Range
Increased operating reserve requirement	Greater flexibility responding to short-term outages	3%–15% of load required as spinning reserves
Increased planning reserve requirement	Improve resource adequacy under outages at peak	Regional planning reserve requirement increased by 40%[a]
Higher generator outage rates	Plan for more frequent generator outages	Generator forced outage rate increased by 50%[a]
Higher transmission outage rate	Plan for more frequent transmission outages	Transmission forced outage rate increased up to 50%[a]
Higher transmission outage rate plus option to purchase "resilience capacity"	Allow construction of resilient transmission capacity, e.g., undergrounding	Transmission forced outage rate increased up to 50%[a]

[a] Parameter increases or reductions reflect percent changes relative to default assumptions in the 2018 version of the ReEDS model.

Conclusions

- Challenge: Doing resilience analysis "right" requires substantial computational resources and data that are often not available
- Interim solution: be creative!
- Long-term solution: develop models that can directly quantify the resilience of energy infrastructure
  - Durability/survivability of equipment against threats
  - Financial risks associated with investments
  - Bulk power system recovery/restoration

Study URL:
https://www.nrel.gov/docs/fy20osti/74241.pdf

Thank you!

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