Strategies for Valuing and Prioritizing Resilience Investments and Measuring Progress

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Resilience Training for States

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Goals for today

**Information Sharing**

- Metrics in practice to facilitate project valuation and prioritization
- Valuation frameworks and measuring progress
- Examples of valuing and prioritizing a resilience strategy
- Links to references and a glossary

**Method**

- Presentation
- Discussion
- Interactive polls
Availability of information

- Regulatory processes lead to publicly-available information that can be useful for (1) evaluating projects that have societal benefits and (2) measuring performance after the project has been installed.

- For this reason, there tends to be more information in the public domain for regulated utilities and less so for other utilities.
Metrics in Practice for Valuing and Prioritizing Resilience Projects
Metrics are important because they allow key stakeholders to assess the performance of systems before or after an investment.

Some metrics (e.g., costs of power interruptions) are critical inputs into the value proposition for new projects.
## Selected metrics in practice

<table>
<thead>
<tr>
<th>State</th>
<th>Metric</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Florida</td>
<td>IEEE 1366 reliability metrics</td>
<td>- SAIDI</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- SAIFI</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- CAIDI</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- MAIFI (see glossary)</td>
</tr>
<tr>
<td>Florida</td>
<td>L-Bar</td>
<td>- Average time it takes to restore power to all customers</td>
</tr>
<tr>
<td>Florida</td>
<td>Customer-specific reliability metrics</td>
<td>- Customers experiencing multiple interruptions (customers experiencing more than X outages of 1 minute or more per year)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Customers experiencing multiple momentaries</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Customer momentary events (customers affected by a momentary event)</td>
</tr>
<tr>
<td>Florida</td>
<td>Customer interruption cost</td>
<td>- Florida Power and Light uses Berkeley Lab’s ICE Calculator to estimate benefits of reducing SAIDI/SAIFI</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>State</th>
<th>Metric</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>North Carolina</td>
<td>Customer interruption cost</td>
<td>● Duke used Berkeley Lab’s ICE Calculator to estimate benefits of Grid Improvement Plan</td>
</tr>
</tbody>
</table>
|                  | IEEE 1366 reliability metrics         | ● Duke uses SAIDI  
● Duke uses SAIFI                                                                                                                    |
|                  | Reliability metrics                   | ● SAIDI (excluding MEDs)  
● SAIFI  
● CEMI-4 (customers experiencing more than four outages of 1 minute or more per year)  
● Miles of vegetation management                                                 |
|                  | Resilience metrics                    | ● Number of critical assets without power for more than N hours  
● Critical asset energy demand not served  
● Critical asset time to recovery                                                  |

Sources: [NCUC (2018)](#), [NCUC (2020)](#), and [RMI/RAP (2020)](#)
## Selected metrics in practice (3)

<table>
<thead>
<tr>
<th>State</th>
<th>Metric</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Georgia</td>
<td>IEEE 1366 reliability metrics (for ranking)</td>
<td>• Feeder-level and company-wide SAIDI</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Feeder-level and company-wide SAIFI</td>
</tr>
<tr>
<td></td>
<td>Loss of Load Expectation (for most planning processes)</td>
<td>• Expected number of loss-of-load days with events (Loss of Load Expectation; 1 day in 10 years)</td>
</tr>
</tbody>
</table>

Sources: [Georgia Power (2019)](https://www.georgiapower.com) and [Georgia PSC (2022)](https://www.psc.gatech.edu)
Interactive poll #1

What new metrics might be needed in your region to evaluate proposed or past investments in resilience?
Valuation Frameworks and Measuring Progress
## Selected economic and social valuation methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Units</th>
<th>Examples</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Least-cost, best-fit</td>
<td>$ divided by a non-monetary value</td>
<td>X dollars invested in grid to avoid Y number of fatalities</td>
<td>● Presumes that an investment is needed and helps prioritize options to achieve objectives</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X dollars invested in grid to reduce SAIDI by Y minutes</td>
<td>● Does not require monetization of any or all benefits of project</td>
</tr>
<tr>
<td>Cost-benefit analysis</td>
<td>$ divided by $</td>
<td>X dollars invested in grid leads to Y dollars in societal benefits</td>
<td>● Does not presume that an investment is needed</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>● Allows for an apples-to-apples comparison of options</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>● Can be extremely challenging to put a dollar value on some benefits</td>
</tr>
</tbody>
</table>

Source: [Woolf et al. (2021)](#)
Examples of information needed for valuing a strategy

<table>
<thead>
<tr>
<th>Cost</th>
<th>Benefits: Non-monetized</th>
<th>Benefits: Monetized</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Capital/installation</td>
<td>• Avoided pollution</td>
<td>• Avoided morbidity and mortality costs</td>
<td>• Real discount rate (or weighted average cost of capital)</td>
</tr>
<tr>
<td>• Annual operations and maintenance</td>
<td>• Avoided health/safety risk</td>
<td>• Avoided capital and O&amp;M costs to utility</td>
<td>• Lifespan of strategy</td>
</tr>
<tr>
<td></td>
<td>• Avoided damage to utility infrastructure</td>
<td>• Avoided interruption costs to customers</td>
<td>• Local, state, and federal incentives and rebates</td>
</tr>
<tr>
<td></td>
<td>• Reduction in frequency and/or duration of power interruptions</td>
<td>• Avoided “spillover” effects to regional economy</td>
<td>• Frequency and duration of power interruptions before and after investment</td>
</tr>
<tr>
<td></td>
<td>• Avoided impacts to national security</td>
<td>• Avoided aesthetic costs (if applicable)</td>
<td>• Detailed information about customers impacted</td>
</tr>
</tbody>
</table>
Forward- and backward-looking analyses

- Valuation activities can be conducted “ex ante” or “ex post”

  **Ex ante:** “Based on forecasts rather than actual results”

  **Ex post:** “Based on actual results rather than forecasts”

  **Ex ante analysis** is often used to identify a *proposed investment* and, in some cases, rank it among alternatives

    - Undergrounding circuit 1234 has *expected* net benefits of $1M over its lifespan

  **Ex post analysis** is often used to measure progress or performance of an *investment that has already been made*

    - Undergrounding circuit 1234 improved SAIDI and SAIFI by 21.2% and 19.4%, respectively.

  Source: Oxford Dictionary (2023)
Interactive poll #2

What resilience valuation methods have you observed in your region?
Examples of Valuing and Prioritizing Resilience Strategies
Example #1: Valuing a resilience strategy

- Berkeley Lab research into factors that impact long-term reliability of the U.S. power system led to research on the value of undergrounding power lines.

- Increase in % share of transmission and distribution lines that are underground has a statistically significant correlation with improved reliability/resilience (Larsen et al. 2020).
Despite the high costs attributed to power outages, there had been little or no research to quantify both the benefits and costs of improving electric utility reliability/resilience—especially within the context of decisions to underground T&D lines.

Source: Larsen (2016)
## Components of valuation framework (2)

**Key Stakeholders**:

<table>
<thead>
<tr>
<th><strong>Undergrounding Mandate</strong></th>
<th><strong>Selected Costs</strong></th>
<th><strong>Selected Benefits</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IOUs</strong></td>
<td>Increased worker fatalities and accidents*</td>
<td>Lower operations and maintenance costs for undergrounding*</td>
</tr>
<tr>
<td><strong>Utility ratepayers</strong></td>
<td>Higher installation cost of underground lines****</td>
<td>**</td>
</tr>
<tr>
<td></td>
<td>Increased ecosystem restoration/right-of-way costs**</td>
<td>**</td>
</tr>
<tr>
<td><strong>All residents within service area</strong></td>
<td></td>
<td>Avoided societal costs due to less frequent power outages***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Avoided aesthetic costs**</td>
</tr>
</tbody>
</table>

* Denotes degree of impact on overall results

Can you spot the metrics included in this valuation framework?
Estimated costs

[Graph showing estimated costs over time for different scenarios with a focus on "Undergrounding: Overhead Lifespan" and "Status Quo".]

[Bar chart indicating a significant increase in lifecycle costs with a minor contribution from environmental restoration and health & safety.]
Estimated benefits (1)
The initial valuation indicated that broadly mandating undergrounding when overhead T&D lines have reached the end of their useful life is not cost-effective for Texas IOUs.

What are the minimum conditions necessary for a targeted undergrounding initiative to have positive net benefits?
## Valuation results

<table>
<thead>
<tr>
<th>Impact Category</th>
<th>Undergrounding</th>
<th>Status Quo</th>
<th>Net Cost ($billions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental restoration</td>
<td>$2.8</td>
<td>$1.0</td>
<td>$1.8</td>
</tr>
<tr>
<td>Health &amp; safety</td>
<td>$0.56</td>
<td>$0.31</td>
<td>$0.2</td>
</tr>
<tr>
<td>Lifecycle costs</td>
<td>$52.3</td>
<td>$26.1</td>
<td>$26.3</td>
</tr>
<tr>
<td>Total net costs (Undergrounding)</td>
<td></td>
<td></td>
<td>$28.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Impact Category</th>
<th>Undergrounding</th>
<th>Status Quo</th>
<th>Net Benefit ($billions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interruption cost</td>
<td>$182.7</td>
<td>$188.4</td>
<td>$5.8</td>
</tr>
<tr>
<td>Avoided aesthetic costs</td>
<td>$12.1</td>
<td>$10.6</td>
<td>$1.5</td>
</tr>
<tr>
<td>Total net benefits (Undergrounding)</td>
<td></td>
<td></td>
<td>$7.3</td>
</tr>
</tbody>
</table>

| Net Social Benefit (Undergrounding) | $-21.0 |
| Benefit-cost ratio              | 0.3    |
Texas policymakers should consider requiring that all T&D lines be undergrounded in places where:

- there are a large number of customers per line mile (e.g., greater than 40 customers per T&D line mile)
- there is an expected vulnerability to frequent and intense storms
- there is the potential for economies of scale for installing underground T&D lines (e.g., installation costs decrease each year)
- overhead line rights-of-way are larger than underground line rights-of-way (i.e., less environmental footprint)

"Electric utility providers should evaluate strategic, targeted undergrounding of distribution lines in limited, appropriate circumstances based on the exposure to the threat of severe winter events."
Source: ORC (2021)
Residential rooftop and storage systems (PVESS) can mitigate long duration interruptions by providing backup power during power outages. This can reduce the economic and social impacts of power outages—a key resilience benefit.

The benefit-cost ratio (BCRs) of PVESS varies by region, depending on the cost of PVESS, the value of lost load (VOLL), and the likelihood of long duration interruptions.

Key Research Questions

- What is the regional distribution of the ability of residential PVESS to mitigate resilience events (long duration interruptions lasting longer than 1 day)?
- Assuming regionally-differentiated PVESS costs and VOLL, what is the benefit-cost of storage investments on existing PV systems?
- How does this benefit-cost change considering Inflation Reduction Act (IRA) support?

Source: Baik et al. (2023)
PVESS mitigates customer interruptions

- States with a high frequency of resilience events (e.g., Louisiana, West Virginia) showed significant load loss without PVESS, while regions less impacted had lower loss.

- **PVESS introduction mitigates or eliminates load loss across regions** (96% interruptions mitigated)

Left (A): w/o PVESS
Right (B): with PVESS

Expected annual loss of load (kWh)
Calculating the benefit-cost ratio

• Benefits of storage investments in regions were assessed using load served, event frequency, duration, and state-level VOLL estimates

• Benefit-cost ratio was computed by comparing benefits with annualized region-specific storage costs

\[
BCR_{FIPS} = \frac{\sum_1^m \sum_1^d (VOLL_{FIPS} \times \text{Expected number of resilience events}_{m,d} \times \text{Load served by PVESS}_{m,d})}{\text{Annualized cost of the PVESS system}_{FIPS}}
\]

where \( d = \text{resilience event duration interval (ranging from 1 day to 10 days)} \),
\( m = \text{month} \),
\( VOLL_{FIPS} = \text{VOLL estimate assigned to each FIPS region belonging to each state} \)
Distribution of benefit-cost ratios

- Resilience benefits from PVESS averaged 20% of total costs, ranging from 0% to 83% depending on load served, event frequency, duration, and state-level VOLL estimates.
- However, resilience was the only benefit considered in this research effort.
- Other benefit streams are often included as part of the decision to install PVESS.
Importance of scenario/sensitivity analyses

• Scenario and sensitivity-based analyses communicate the range of possible outcomes given uncertainties

• Four scenarios were analyzed individually and collectively: two storage cost scenarios, a high VOLL scenario, and a higher event frequency scenario

• Individual scenarios achieve BCR > 1.0 in some states

• We also evaluated the combined impact of storage cost reduction, a high VOLL, and increased frequency of resilience events

• Customers experiencing above-average long-duration event frequencies and higher VOLL are likely to observe resilience benefits greater than the cost of installing PVESS
Impact of federal incentives

- Incentives from the investment tax credit (ITC) were considered
- Applying a 30% ITC reduction to storage acquisition costs improved BCRs by 50% compared to no incentives
- Notably, some regions (e.g., West Virginia, Louisiana) show higher BCRs, yet BCRs are still below 1
- If only considering the resilience benefit, the ITC only incentivizes PVESS adoption for customers with high VOLL and higher frequency of long duration events
Interactive poll #3

What challenges do you foresee when reviewing a utility’s valuation and justification of a resilience investment?
Example #3: Prioritizing a resilience strategy

- The U.S. Department of Energy Grid Deployment Office is sponsoring the development of “Resilience Spotlights” that feature examples of how organizations value and prioritize a specific project among a portfolio of proposed projects.

- The first spotlight focuses on activities in New York City in the immediate aftermath of Super Storm Sandy.

- Resilience spotlights will be accessible at the DOE-GDO website.
Super Storm Sandy

- 20% of the city’s land area was flooded, exceeding FEMA’s “100-year” floodplain boundaries

- Loss of power to > 2 million Con Ed customers

- Full restoration took \(~14\) days

- **Major equipment failure:** Con Ed’s East 13th Street Substation flooded and failed due to record levels of storm surge.
Regulatory processes

• January 2013 (three months after storm): Con Ed proposed a portfolio of storm hardening projects in a general rate case filing.

• Many stakeholders in rate case had opposing views:
  • Hardening plan was too ambitious and expensive
  • Utility should develop a bigger “comprehensive and longer-term approach”

• Key point of dispute: What criterion should Con Ed use to evaluate hardening against flooding risks?

• Summer 2013: NYPSC ordered formation of a Storm Hardening and Resiliency Collaborative to work in parallel to rate case proceedings and consider:
  • Design standard
  • Approach to risk assessment and cost-benefit analysis
Project prioritization and valuation (1)

- The Collaborative developed a procedure for ranking the storm hardening projects that considered the following:

**Probability:** estimate likelihoods of significant storms and damage to infrastructure

**Consequence:** characterize physical and economic impacts of damage

**Priority:** run potential projects through models to rank them

<table>
<thead>
<tr>
<th>Models</th>
<th>Key Inputs</th>
</tr>
</thead>
</table>
| Risk Assessment and Prioritization Model | ● Location-based flood probabilities provided by proprietary New York City inundation models  
                                       | ● Wind damage probabilities derived from historical wind gust frequency distributions  
                                       | ● Costs of storm hardening measures  
                                       | ● Estimated power interruption durations with and without hardening measures  |
| Cost-Benefit Model                  | ● Costs of storm hardening measures (from the Risk Assessment and Prioritization Model)  
                                       | ● Estimated power interruption durations with and without hardening measures (from the Risk - Assessment and Prioritization Model)  
                                       | ● Extrapolated avoided cost (i.e., value of lost load) estimates based on Lawrence Berkeley National Laboratory’s [ICE Calculator](https://ice.lbl.gov) |
Project prioritization and valuation (2)

Source: ConEd (2013)
Response timeline

Tropical Storm Sandy
Oct 2012

Decision-Making

- Con Ed submits 1st storm hardening plan (includes E. 13th St.)
  - Jan 2013
- NYPSC orders creation of Storm Hardening and Resiliency Collaborative
  - Jul 2013
- Con Ed releases 1st Collab. Report
  - Dec 2013
- NYPSC approves 1st phase work
  - Feb 2014
- FERC issues revised definition of Bulk Electrical System
  - Mar 2014
- Con Ed releases 2nd Collab. Report
  - Nov 2014
- NYPSC approves 2nd phase work
  - Feb 2015
- Con Ed releases 3rd Collab. Report
  - Sep 2015
- NYPSC approves 3rd phase work
  - Jan 2016

Implementation

- 2013
  - Con Ed makes 1st set of E. 13th St. Measures (e.g., installing removable flood barriers, sealing penetrations, and elevating control cabinets)
- 2014-2015
  - Con Ed experiences permitting delays and makes major design updates
- 2016-2019
  - Con Ed makes final upgrades to E. 13th St. Substation (e.g., raising control room, installing electronic equipment, and replacing transformers)

01/13 06/13 01/14 06/14 01/15 06/15 01/16 06/16 ... 06/19
Example #4: Prioritizing a resilience strategy

- Regulations introduced in 2006-2007 required that Duke and other Florida utilities begin systematically collecting data on the relative performance of underground and overhead lines during extreme weather.

- An especially severe hurricane season in 2016-2017 demonstrated that underground lines were systematically less vulnerable to disruption than overhead lines.

- As a result, Duke Energy Florida (Duke) began a “Targeted Underground Program.”
In 2019, Florida required that the state’s electric energy utilities submit triennial “Storm Protection Plans” with new requirements including cost and benefit estimation, 10-year planning horizons, and more complete descriptions of proposed measures and implementation strategies.

Duke began working closely with Guidehouse, Inc. to develop and implement a decision-support framework and software tool in their storm preparation planning.
Duke’s three-part analytic framework

Risk modeling

Probabilistic weather modeling of storm scenarios using Monte Carlo methods, combined with spatial modeling of Duke distribution infrastructure, to estimate conditional probabilities of asset failures and the reductions in these probabilities as a function of storm hardening measures.

Benefit-cost modeling

Estimating Duke’s capital and operations and maintenance costs of storm hardening measures and prospective utility benefits in the form of reduced future costs from avoiding damage to infrastructure and storm restoration activities; quantifying customer benefits in terms of projected reduced outage times by customer class, and applying avoided customer costs from Berkeley Lab’s ICE Calculator, using the Calculator’s 16-hour avoided cost estimates as a simplifying assumption for outage times greater than 16 hours.

Decision analysis and prioritization

Calculating benefit-cost ratios and using them to rank projects and create a preferred portfolio, then applying funding and timing constraints, taking account of practical implementation constraints based on the judgment of Duke staff including subject matter experts.
Response timeline

Florida passes new legislation pertaining to storm hardening and cost recovery, with enforcement under the jurisdiction of the FPSC (includes underground vs. overhead data-gathering requirement).

FPSC approves Storm Hardening Plan with some modifications.

Duke Energy and FPSC review finds that underground facilities outperform overhead.

Cost base for Florida storm hardening broadened (“Storm Protection Plan Cost Recovery Clause”); new requirements for Storm Protection Plans (SPPs) enacted.

FPSC approves Duke Energy 2020 and 2022 SPPs with minor modifications; rejects objections to cost-benefit analysis.

Severe hurricanes 2004-2005

2006 Progress Energy submits first Storm Hardening Plan.

2007 Duke Energy (formerly Progress Energy) submits triennial hardening plans (2010, 2013, 2016) and implements a small number of undergrounding projects at intersections and interchanges.


2009 Severe hurricanes 2016-2017

2018 Duke Energy submits 10-year SPPs in 2020 and 2022; expands overhead-to-underground conversion initiative under “Lateral Hardening Program.”

2019

2020

2021

2022

Decision-Making

Implementation
Lessons learned

• Many, but not all, utility reliability and resilience investments are developed, proposed, and adjudicated in the **context of a general rate case**. This process is not always well-suited to addressing **novel, complex technical problems**.

• The need to address **low-probability/high-consequence events** requires flexibility in regulatory processes.

• **Collaborative work groups** can enable utilities to improve resilience planning methods and practice.

• **Requiring utilities to measure past performance** of underground lines has helped build confidence and justify future investments in this strategy.

• **Cost-benefit analyses** used in NY and FL could inform similar valuation and prioritization activities in other parts of the country.
Interactive polls #4 and #5

What is the most important criteria for prioritizing one resilience strategy over another?

Kahoot!
Questions to ask

► Is the utility putting an economic value on reliability or resilience? If so, what tools or techniques are they using?

► Does the utility track the performance of past investments? Can you describe how this performance is tracked?

► What technology would the utility install if it could only install one type of technology to make the grid more resilient?

► What is the biggest challenge that the utility has faced when attempting to identify, prioritize, and justify a resilience project?
Contact

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https://emp.lbl.gov/

https://www.energy.gov/gdo/grid-deployment-office
# Glossary of selected performance-based metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Description</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAIFI</td>
<td>System Average Interruption Frequency Index</td>
<td>Total number of interruptions that an average customer experiences over some time period</td>
</tr>
<tr>
<td>SAIDI</td>
<td>System Average Interruption Duration Index</td>
<td>Total number of minutes that an average customer is without power over some time period</td>
</tr>
<tr>
<td>CAIFI</td>
<td>Customer Average Interruption Frequency Index</td>
<td>Average number of interruptions per customer interrupted over some time period</td>
</tr>
<tr>
<td>CAIDI</td>
<td>Customer Average Interruption Duration Index</td>
<td>Time required to restore service for an average customer over some time period</td>
</tr>
<tr>
<td>MAIFI</td>
<td>Momentary Average Interruption Frequency Index</td>
<td>Total number of momentary interruptions (&lt; 5 minutes) that an average customer experiences over some time period</td>
</tr>
<tr>
<td>MED</td>
<td>Major Event Day</td>
<td>Any day with a daily reliability metric that exceeds a statistically-defined threshold based on the previous five years of daily data (e.g., IEEE 1366 standard)</td>
</tr>
</tbody>
</table>

Source: [CPUC (2021)](https://www.cpuc.ca.gov)
Useful references (1)


Useful references (2)


Useful references (3)


