



Electricity Markets & Policy
Energy Analysis & Environmental Impacts Division
Lawrence Berkeley National Laboratory

Quantifying grid reliability and resilience impacts of energy efficiency: Examples and opportunities

Juan Pablo Carvallo, Natalie Mims Frick, and Lisa Schwartz
Lawrence Berkeley National Lab

August 2022

2022 ACEEE Summer Study on Energy Efficiency in Buildings proceedings printed with permission.



The U.S. Department of Energy's Energy Efficiency and Renewable Energy's Strategic Analysis Team, supported this work under Lawrence Berkeley National Laboratory Contract No. DE-AC02-05CH11231.

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor The Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or The Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof, or The Regents of the University of California.

Ernest Orlando Lawrence Berkeley National Laboratory is an equal opportunity employer.

COPYRIGHT NOTICE

This manuscript has been authored by an author at Lawrence Berkeley National Laboratory under Contract No. DE-AC02-05CH11231 with the U.S. Department of Energy. The U.S. Government retains, and the publisher, by accepting the article for publication, acknowledges, that the U.S. Government retains a non-exclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this manuscript, or allow others to do so, for U.S. Government purposes.

Quantifying grid reliability and resilience impacts of energy efficiency: Examples and opportunities

*Juan Pablo Carvalho, Natalie Mims Frick and Lisa Schwartz,
Lawrence Berkeley National Lab*

ABSTRACT

Grid reliability and resilience are foundational to meeting electricity needs and have significant economic and societal impacts. Energy efficiency can help meet grid reliability objectives and improve resilience, but metrics and methods used today may not fully recognize these benefits. This paper explains how existing planning processes for bulk power and distribution systems capture the impact of energy efficiency on power system reliability and resilience, with illustrative examples. We identify limitations in using existing reliability and resilience metrics to quantify efficiency and other distributed energy resource (DER) benefits. The paper concludes with opportunities for regulators and utilities to enhance planning practices to better capture the reliability and resilience value of energy efficiency and identifies research needs.

Introduction

Utilities and regional grid operators conduct various types of power system planning to identify an optimal portfolio of resources to meet future electricity needs and policy and regulatory requirements. Best planning practices for the bulk power system (BPS) and distribution system consider cost, risk, and uncertainty and include both supply- and demand-side resources—energy efficiency and other DERs, including demand response (DR), distributed generation and storage, microgrids and managed electric vehicle charging. Energy efficiency, from traditional measures to more time- and location-sensitive approaches, provides important grid reliability and resilience benefits, on its own or integrated with other DERs (Table 1).

This paper discusses how reliability and resilience benefits of efficiency are currently considered and valued in electricity system planning, identifies policy challenges, offers regulatory opportunities for improvement, and describes research needs. It builds on existing research on the magnitude and cost of energy efficiency programs funded by utility customers and projections of future energy savings for utility systems. It also expands on recent reports documenting examples of utilities treating energy efficiency on a comparable basis to generating resources in bulk power system planning, and using energy efficiency and other DERs as non-wires alternatives to meet distribution system needs (Frick et al. 2020a, Frick et al. 2020b). The paper uses case studies to extract best practices in quantifying reliability and resilience benefits of energy efficiency. Examples in this brief focus on energy efficiency, but include other demand-side resources such as conservation and DR. A critical analysis of these best practices informs our findings for technical and regulatory challenges and supports our ideas for opportunities for improvement and further research needs.

Table 1. Example of energy efficiency’s reliability and resilience benefits

	Power system planning processes		
	Bulk power system	Distribution system	Demand-side management
Reliability	Energy efficiency contributes to meeting reliability needs at least cost and risk. In wholesale capacity markets, energy efficiency lowers capacity auction prices.	During power interruptions, lower loads due to energy efficiency measures allow more customers to be switched across feeders for faster restoration times.	Efficient equipment extends the duration of storage backup during interruptions.
Resilience	System operator calls for emergency conservation can prevent large-scale blackouts.	Lower loads reduce equipment overloading and thermal wear and tear, reducing the likelihood of equipment failure.	Efficient buildings maintain habitable indoor conditions for longer periods of time during power interruptions.

This paper does not explore in detail reliability and resilience benefits of DERs other than efficiency, such as DR, battery storage, microgrids, and managed charging of electric vehicles. For additional information on the reliability and resilience benefits of these DERs (Rickerson et al. 2019, Rickerson et al. 2022). In addition, this paper does not discuss utility distribution system efficiency measures—conservation voltage reduction or volt-VAR optimization.

This paper is organized as follows. The next section provides definitions of reliability and resilience as utilized in this work. The following three sections examine best practices to quantify energy efficiency benefits for reliability and resilience in (1) bulk power system, (2) distribution, and (3) demand-side management planning processes. The paper concludes by identifying technical and policy challenges, opportunities, and research needs. The examples and best practices in this paper draw from the U.S., but these planning practices are common around the world and our findings will be relevant for regulators, policy makers, and utilities in other regions and jurisdictions.

Definitions and Metrics

This brief focuses on reliability and resilience, and metrics used to measure these attributes, in the context of electricity system planning. Energy efficiency also offers important benefits for operation timeframes. We include a brief discussion on the use of conservation for reliability and resilience in operation timeframes in the section, “Evaluation of efficiency's reliability benefits in long-term BPS planning”. The working definitions of reliability and resilience that frame our discussion are as follows.

Reliability

A recent U.S. Department of Energy report defines electric reliability as “the ability to maintain the delivery of electric power to customers in the face of routine uncertainty in

operating conditions” (Eto et al. 2020). Different methods are used to measure and assess reliability in BPS and distribution systems.

Reliability metrics for the BPS focus on the operational (current or near-term conditions) and planning (longer term) time horizons as defined by the North American Electric Reliability Corporation (NERC):

- Operating reliability is the ability of the BPS to withstand sudden disturbances, such as electric short circuits or the unanticipated loss of system elements from contingencies, while avoiding uncontrolled cascading blackouts or damage to equipment (NERC 2020a).
- Adequacy is the ability of the electricity system to supply the aggregate electrical demand and energy requirements of the end-use customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements.

Reliability metrics for utility distribution systems focus on tracking the interruption of the delivery of electricity in sufficient quantities and of sufficient quality to meet electricity users’ applications of electricity. The focus on delivery is justified since 90% of interruptions occur within distribution systems (Eto 2016). Typical reliability metrics report the annual duration (e.g., System Average Interruption Duration Index (SAIDI) and Customer Average Interruption Duration Index (CAIDI)) and frequency (e.g., System Average Interruption Frequency Index (SAIFI) and Momentary Average Interruption Frequency Index (MAIFI)) of power interruptions experienced by an average customer (for additional information on reliability metrics, see NERC 2020, IEEE 2012 and EPA 2018). Losses of power that last five minutes or less are referred to as momentary interruptions, while those lasting more than five minutes are called sustained interruptions.

Resilience

The definition of resilience continues to evolve as the electricity industry internalizes recent weather events and threat trends, and measures of resilience are a relatively new area of research and development (Petit et al. 2020). Consequently, there are no widely accepted metrics comparable to reliability metrics or standards (Organization of MISO States et al. 2019, NARUC 2019, Roege et al., 2014). For this brief, we define resilience as “the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents” (Presidential Policy Directive 21).

Some authors identify resilience as a component of reliability with a focus on preparedness and recovery before and after events that may affect large populations (De Martini et al. 2020, ESIG 2021). Other authors view resilience as a distinct characteristic of electricity systems. The National Academies of Sciences indicates that "Resilience is not the same thing as reliability. While minimizing the likelihood of large-area, long-duration outages is important, a resilient system is one that acknowledges that such outages can occur, prepares to deal with them, minimizes their impact when they occur, is able to restore service quickly, and draws lessons from the experience to improve performance in the future." (National Academy of Sciences 2017, p.10)

Another perspective is that reliability and resilience are a continuum. On one end are common reliability events with local impacts and limited duration. On the other end are “Black

Sky Events” with larger, broader impacts occurring less frequently (Organization of MISO States et al. 2019). The Energy Infrastructure Security Council defines a black sky hazard as “a catastrophic event that severely disrupts the normal functioning of our critical infrastructures in multiple regions, for long durations.” (EIS Council, 2021)

Regardless of the precise definition of resilience, energy efficiency can provide value during extreme weather events. A recent example is the February 2021 extreme cold weather event in Texas and neighboring states that increased ERCOT's electricity demand for heating to historic levels. Recent analysis estimates that more than 40% of the state’s electric demand was for heating. In addition, the building stock in Texas was not designed for extreme cold, with little to no insulation and a high reliance on electric resistance heat. The analysis found that if homes had efficient building envelopes and heating systems, ERCOT’s electricity demand could have been reduced by at least 15 gigawatts, which would have dropped the peak enough to offset the loss of most of the generators that failed during the event (Wood et al. 2021).

Evaluation of efficiency's reliability benefits in long-term BPS planning

Long-term BPS planning is a process that estimates least-cost expansion options for the supply- and demand-side mix—considering risk and uncertainty—for a utility or region, based on forecasts for loads, fuel costs, technology costs, market prices, and other factors. Vertically integrated utilities conduct long-term BPS planning, focused on resource planning and delivering resources to load centers. Independent system operators and regional transmission organizations conduct planning processes focused on transmission. In long-term electric utility planning, reliability is typically treated as a “constraint” when determining the minimum cost system to attain prescribed levels of reliability. This constraint can be expressed in two measures—resource adequacy and operational reliability, defined in the previous section. Ensuring resource adequacy is one of the objectives of long-term planning studies. The results of these studies achieve prescribed levels of adequacy as their main measure of power system reliability.

Resource adequacy targets and performance can be measured in different ways. A common resource adequacy standard is that the electricity system does not experience a loss of load event more than one day over a 10 year period (NERC 2020b). The metric used to implement this standard is typically referred to as Loss of Load Expectation (LOLE). A less common but related resource adequacy metric, Loss of Load Probability (LOLP), describes the likelihood that the power system will not be able to meet load in a given hour within a specified period (typically one to five years). Direct implementation of the LOLP or LOLE requires planners to use probabilistic modeling, which can be complex and time consuming (see box “Deterministic and probabilistic modeling”). Instead, planning entities typically produce a deterministic resource adequacy metric, referred to as the planning reserve margin, which estimates the additional capacity needed to maintain the appropriate level of resource adequacy for their power system. It is commonly expressed as a percent increase over the system’s expected, weather normalized, peak-hour demand. Because there is no standard planning reserve margin in the United States, the margin varies significantly from utility to utility and between regional grid operators.

In probabilistic analysis, energy efficiency reduces the probability of load exceeding generation for specific hours of the year when generation availability is relatively low and load is relatively high, regardless of whether this is the annual peak hour. In deterministic analysis, energy efficiency contributes to system reliability when it increases the absolute value of the reserve margin at the system peak hour.

Following are two examples of how efficiency's reliability value is considered in long-term BPS planning. The first example identifies reliability benefits from efficiency using a deterministic modeling approach (NERC). The second example uses a probabilistic modeling approach (Northwest Power and Conservation Council).

Northwest Power and Conservation Council (probabilistic modeling approach)

The Northwest Power and Conservation Council is a regional planning entity in the Pacific Northwest. The Council is statutorily required to develop, with broad citizen participation, a regional power plan. The Council develops a 20-year regional power plan every five years. Its objective is to set forth a resource strategy that ensures an "adequate, efficient, economical and reliable power supply" at the lowest cost.

Each year the Council assesses the adequacy of the Northwest power supply over the next five years in its Power Supply Adequacy Assessment, based on its 5% annual LOLP adequacy standard (Northwest Power and Conservation Council 2011). In this case, the LOLP reflects the likelihood of one or more curtailment events occurring during an operating year, i.e., when load exceeds generation after accounting for the contribution of "standby resources." The standard requires that the probability of a future year experiencing one or more curtailment events must be 5% or less. The Council's LOLP analysis is a "chronological hourly simulation of the power system's operation over many uncertain conditions, including water supply, temperature (load variation), wind and solar generation and resource forced outages." The assessments assume existing resources only and that targeted levels of energy efficiency are achieved (e.g., as identified in the most recent Power Plan). The Council finds that efficiency is key to maintaining adequate supplies of power in the near term (Northwest Power and Conservation Council 2019).

The plan guides resource decision-making by the Bonneville Power Administration (BPA). BPA must submit for Council approval any new BPA energy resource acquisition greater than 50 average megawatts and acquired for more than five years, including energy efficiency. The Council's regional power plan also serves as a reference document for the region's public and investor-owned utilities, state regulatory commissions, and state energy offices.

Evaluation of efficiency's reliability benefits in distribution system planning

Distribution system planning assesses needed physical and operational changes to the local grid. Utilities use annual distribution planning processes to identify and define distribution system needs, identify and assess possible solutions, and select projects to meet system needs (Schwartz and Homer 2020). Some distribution capacity expansion needs for reliability can be deferred, mitigated, or avoided by using DERs as non-wires solutions (NWS, also called non-wires alternatives (NWA)) (Frick et al. 2020a).

States and utilities are beginning to identify NWAs that can address reliability needs, although they may not provide guidance on how to quantify that value. For example:

- In Maine, the definition of NWA includes reliability as one of its purposes. "Nonwires alternative means a non-transmission alternative or an infrastructure, technology or application that defers or reduces the need for capital investment in the transmission and distribution system and addresses system reliability needs proposed to be met by the transmission or distribution system investment" (35-A M.R.S §3131(4)(c)).
- Nevada requires a locational net benefit analysis (LNBA) as part of a utility's distribution system plan. The LNBA is defined as "a cost-benefit analysis of distributed resources that

incorporates location-specific net benefits to the electric grid.” The analysis is used to: (1) evaluate the economics of deploying distributed resources at different locations on the electric system, (2) evaluate the potential of distributed resources to defer traditional infrastructure upgrades, (3) understand the impact of distributed resources on long-term system needs related to load growth and reliability, and (4) inform the procurement process for non-wires solutions. The Public Utilities Commission of Nevada requires that “reductions to or increases in the reliability benefits of the electric grid” be considered when conducting an LNBA.

- Rochester Gas and Electric, an investor-owned utility in New York, identified that “NWA solutions utilize third-party Distributed Energy Resources (DERs) to postpone certain traditional construction projects needed primarily to correct system overloading conditions and, in some cases, system reliability issues. Other utilities in New York include reliability and resilience benefits in their benefit-cost analysis, discussed in the next section.

There are many examples of NWA including energy efficiency in the analysis (Frick et al. 2020a). The following examples highlight the use of efficiency to defer distribution system upgrades as part of an Integrated Distribution Plan (Xcel Energy), successful NWA project that relied heavily on efficiency to defer the distribution system need (Consolidated Edison), and implementation of a process to consider NWA in distribution system planning (NV Energy).

Xcel Energy

Xcel Energy's 2020-2029 Integrated Distribution Plan for Minnesota discusses the utility's work to update methodologies and distribution avoided costs for energy efficiency, as well as several new energy efficiency analyses, as "important complements to our annual [distribution] planning analysis."

The plan also discusses "geo-targeting" energy efficiency and DR to defer distribution system capacity upgrades, including a pilot program in two communities to test the viability of a geo-targeting strategy to provide a reliable alternative to traditional capacity upgrades¹.

Consolidated Edison

Consolidated Edison's Brooklyn Queens Demand Management program uses targeted energy efficiency and distributed generation—combined heat and power (CHP), fuel cells, and battery energy storage—to provide load relief in specific networks in Brooklyn and Queens. In addition to 52 MW of load relief already achieved, another 11 MW of additional relief was planned to be installed by the end of 2021. Energy efficiency projects have focused primarily on lighting, with incentive amounts and installation support varying by customer class. For CHP, the utility offered up to \$1,800 per kW, with a cap at \$1.5 million per project.

For fuel cells, the utility matched New York State Research and Energy Development (NYSERDA) incentives up to \$1,000 per kW, with an aggregate project cap of \$1 million. This matching program remained active through NYSERDA through the end of 2019. For both CHP and fuel cells, Consolidated Edison identified target zones and years projects were needed to guide development and offered an additional 25% incentive bonus on top of \$1,000 per kW for projects that alleviated constraints by meeting locational and temporal criteria. For battery

¹ For more information see the final pilot report at <https://www.mncee.org/non-wires-alternatives-path-local-clean-energy-appendices>

energy storage, the utility offered \$2,100/kW for selected customers in designated neighborhoods in Brooklyn and Queens whose systems could meet a minimum four-hour consecutive dispatch and be in operation by June 1, 2020.

NV Energy

In 2017, the Nevada Legislature passed legislation requiring utilities to submit a Distributed Resource Plan (DRP) to the Public Utilities Commission of Nevada (PUCN) by July 2019, and every three years thereafter, as part of its resource plan. Among other provisions, the legislation requires that DRPs evaluate locational benefits and costs of distributed resources (distributed generation systems, energy efficiency, energy storage, electric vehicles, and DR technologies). In 2019, the PUCN approved final regulations (Docket 17-08022) specifying DRP requirements for, among other things, NWA analysis, and locational net benefit analysis.

NV Energy considered three NWA projects to address reliability needs in its DRP. The traditional upgrade projects would address unplanned contingencies by installing a second transformer at an existing substation. The transformer would be used to support load on the substation in the event the first transformer were to go out of service. The utility considered a combination of energy efficiency, DR, solar photovoltaics and batteries for NWAs, sized to serve load on a continuous basis (as the second transformer would). Ultimately, NV Energy chose traditional solutions to meet these reliability needs because they were less costly. While the NWAs were not selected, this example does provide a framework for considering efficiency (or other DERs) as resource that can meet reliability needs².

Evaluation of efficiency's reliability benefits in demand-side management planning

DSM planning typically identifies energy efficiency and DR potential and designs programs and implementation plans. DSM planning typically involves a benefit-cost analysis (BCA), a framework that allows for explicit recognition of benefits for demand side interventions to capture potential resilience and reliability benefits.

A monetary metric that can be used to measure the reliability impact on customers is the value of lost load (VOLL). The VOLL is traditionally measured through customer interruption cost (CIC) surveys that treat residential, commercial, and industrial customers separately. CIC surveys, by themselves, are considered inadequate to measure the economic impacts of long-duration interruptions or resilience events due to the customer's inability to quantify the cost of an interruption at a scale they have not experienced before (Baik et al. 2021). In lieu of such surveys, regional economic models are employed to obtain suitable values. In either case, calculating credible values for the VOLL is challenging, which has hampered the application of a value-based approach to reliability in long-term planning. Even if calculating values for VOLL was straightforward, an additional challenge would arise in applying heterogeneous customer-level VOLL values to a system-level cost function.

Reliability improvements for demand-side management planning are explicitly considered in efficiency BCA in five states—Arizona, Connecticut, Massachusetts, New York, and Rhode Island.

² For more information on NV Energy's 2019 analysis, see https://www.nvenergy.com/publish/content/dam/nvenergy/brochures_arch/about-nvenergy/rates-regulatory/recent-regulatory-filings/nve/irp/NVE-19-04003-IRP-VOL1.pdf

- The Arizona Administrative Code’s cost-effectiveness clause states that “The analysis of a DSM program’s or DSM measure’s cost-effectiveness may include: 1. Costs and benefits associated with reliability, improved system operations, environmental impacts, and customer service.”
- In Massachusetts, the Three-Year Energy Efficiency Plan states that “energy efficiency continues to play an important role in reducing customer demand, and has a positive impact on system reliability.” (Mass Saves 2018, p. 14) The plan highlights how investments in weatherization and high efficiency heating equipment improve electric and gas winter reliability. The plan highlights passive housing as it “[...] offers the ultimate goal in high efficiency design; a building that uses little or no energy with additional resiliency benefits.” (Id., p. 33).
- Connecticut, Massachusetts and Rhode Island use the Avoided Energy Supply Components in New England (AESC) estimates of reliability benefits of efficiency from increased generation reserves, reduced thermal stress on transformers and conductors (reducing failures) and decreased probability of overloading transmission and distribution (T&D) equipment in their efficiency BCAs (Knight et al 2021). Using a VOLL of \$73/kWh and an average usage of 1.6 kWh/customer-hours, the AESC estimates that resources that reduce stress in T&D equipment in New England produce a benefit of about \$1/megawatt-hour. The report does not provide an estimate of the resilience benefits of efficiency interventions.
- The New York Benefit Cost Analysis (NY-BCA) handbooks recognize two reliability/resiliency categories (NY DPS, 2015). The first is the net avoided restoration costs, which capture the benefits of measures that reduce the cost of restoring power after an outage. However, the handbooks indicate that most DERs, including energy efficiency, cannot accrue this benefit because utilities are required to fix the outage cause regardless of whether customers can satisfy some or all of their energy needs through efficiency or other DERs. In this case, the narrow definition of “restoration” as electricity flowing through the utility grid, rather than customers satisfying end uses or needs, prevents further recognition of resilience benefits from efficiency and other DERs. The second reliability/resilience category recognized by the NY-BCA handbooks is the net avoided outage costs. The approach for estimating avoided outage costs relies on the VOLL, the average customer demand and the changes in SAIDI due to an intervention. The handbook is not explicit about how energy efficiency or other DERs accrue benefit from changes in SAIDI due to an intervention. However, efficiency can reduce the average customer demand, but it is not clear how the benefit is being used for efficiency in New York.

In addition, DSM plans are increasingly including energy efficiency and other DERs to improve distribution system reliability and resilience. For example, in its 2021-2022 DSM plan for Colorado, Public Service of Colorado (PSCO) discusses its geo-targeting pilot to defer the need for investment in a new distribution transformer and associated feeder upgrades. The utility selected the project because (1) the deferred benefit is large enough to justify incremental spending on efficiency and DR (the upgrade is estimated to cost more than \$10 million), (2) there is enough lead time to allow PSCO to implement targeted efficiency and DR programs, and (3) traditional solutions, such as switching demand from a feeder that is approaching its thermal limit to a nearby feeder that is not, can be used to protect reliability during the pilot if needed.

PSCO is conducting a pilot to keep feeder levels below their thermal limits while new housing developments are being constructed. The project goal is to acquire 3 MW of load reduction by 2023. The utility is using targeted approaches to market to home builders existing energy efficiency program offerings, such as incentives for air-conditioning and ENERGY STAR homes, in tandem with DR programs. For example, a builder can receive a rebate for installing a smart thermostat in a new home from both efficiency and DR programs to reduce the incremental cost of the thermostat to zero.

Challenges and opportunities to incorporate reliability and resilience benefits and go beyond current practices

In this section, we discuss challenges with existing metrics and assessment methods that do not fully capture the reliability and resilience benefits of energy efficiency and present opportunities for technical and regulatory approaches to improve their valuation.

Challenges with existing reliability metrics

In all electricity system planning processes—BPS, distribution system, and DSM—the traditional metrics used to measure reliability hinder the recognition of reliability benefits of energy efficiency. In addition, in DSM planning, the methods used to monetize reliability benefits in BCA do not often capture the benefits of energy efficiency. Traditional reliability metrics such as SAIDI and SAIFI were designed to provide a system-level (or sometimes feeder-level) measurement of the total duration and frequency of interruptions averaged over all utility customers. These metrics provide a useful and easy way for regulators to monitor and enforce the reliability performance of utilities. However, these metrics only reflect the availability of power to customers; they do not reflect (1) the actual impact of interruptions on the consumption or fulfillment of end-use services and (2) the reliability experienced by each individual customer.

The standard IEEE 1366-2012 introduced two customer-centric reliability metrics: Customers Experiencing Long Interruption Durations (CELID) and Customers Experiencing Multiple Interruptions (CEMI). At least ten U.S. states and several utilities have adopted CEMI reporting (Watts et al 2020). Grid Strategies developed a customer-centric framework for resilience that includes energy efficiency and distributed generation and storage at customer premises (Silverstein et al. 2018). Their proposal includes metrics similar to the CELID and CEMI. However, these standards are focused on counting customers suffering certain types of interruptions, rather than measuring the reliability experience of each customer individually. Hence, the challenges of recognizing the reliability benefits of customer-deployed energy efficiency remain as with the aggregate system-level metrics. The lack of individual customer reliability metrics (rather than aggregate customer metrics) means that there is no available framework to compare whether it is more cost-effective for reliability enhancements to deploy energy efficiency and other DER interventions or to upgrade the distribution system.

Further, NWS approaches recognize the benefits of energy efficiency for the distribution system, but do not capture direct reliability benefits for individual customers whose homes and businesses are hosting these measures. Since traditional system-level reliability metrics obscure the heterogeneity of the actual interruptions experienced by customers, NWS assessments that use these metrics will not capture these differences across customers. Customer-level metrics would (1) identify highly-valued or critical end-uses (2) ensure that these end-uses can be consumed at least at minimum sustainable levels, and (3) ensure that service for each customer

meets a minimum reliability standard with recognition of their level of vulnerability and adaptability. For example, a metric focused on life sustainment would identify a ventilator as a critical end use, determine its minimum daily energy needs, and ensure service to this customer can deliver that energy. These customer-level metrics would enable societally efficient investment decisions in customer- or utility-facing resources to meet such standards. The third version of Consolidated Edison's (ConEd) Electric Benefit Cost Analysis handbook recognizes this limitation: "Other reliability metrics will need to be developed to more suitably quantify reliability or resiliency benefits and costs associated with localized projects or programs" (ConEd, 2020, p. 31). Customer-level (or demand-side) reliability metrics are particularly important when approaching reliability from an energy justice perspective to ensure that unreliability is not inequitably distributed across customers (Carvallo et al. 2021, Baker 2019, Farley et al. 2021).

BCA frameworks use the VOLL to monetize the benefits of increased reliability (or, equivalently, reduced unreliability). The examples of BCA reviewed in this paper reflect several challenges:

- The VOLL typically reflects the cost of energy not served to customers, instead of costs of the consequences that accrue to customers and society as a whole during interruptions. The use of retail rates to calculate the VOLL substantially underestimates the VOLL for all customer segments. For example, the NY-BCA handbook allows utilities to use the retail rate as the VOLL, effectively valuing lost load at 10–20 cents per kWh. In contrast, a properly calculated VOLL using CIC surveys as in New England's AESC produces values of 73 dollars per kWh, about 300-700 times higher³.
- States that require the use of a VOLL for BCA limit it to a single value per customer segment, which does not capture heterogeneity across customers and interruption types. In reality, the VOLL is highly dependent on their memories of and experiences with outages, on individual customer preference, their location, and the duration of the interruption (LaCommare et al. 2018).
- Current VOLL approaches are generally not time sensitive, assigning the same value to load lost at any time of day and season.
- The calculation of VOLL is often based on short-duration outage data, limiting its application to resilience. None of the BCA frameworks we reviewed measure or monetize resilience benefits of energy efficiency or DERs more generally.

Challenges with resilience metrics

The main challenge with resilience metrics is that they are nascent and not yet widely adopted. DOE's efforts to develop and implement metrics will contribute toward better-informed investment and operational decisions to maintain or enhance resilience (Petit et al. 2020). Resilience metrics can broadly be considered in two categories: attribute-based and performance-based. Attribute-based metrics address the question, "What makes my system more/less resilient?" They can provide a baseline understanding of the system's current resilience, relative to other systems. Performance-based metrics are quantitative approaches to answer the question, "How resilient is my system?" These approaches interpret quantitative data that describe infrastructure outputs for specified disruptions and assess infrastructure resilience (Vugrin et al.

³ For details on the estimation of the VOLL for New England see section 11.1 in Avoided Energy Supply Components in New England: 2021 Report

2017). All of these metrics are focused on system- or grid-level analyses and likely would not capture the resilience benefits of customer-level energy efficiency, including by customer and geographic subsets. Recent research identifies ways that relevant resilience value can be identified and captured at the community and customer levels by identifying critical loads, quantifying grid impacts of catastrophic events, and using high temporal and spatial granularity to quantify the benefits of interventions (Twitchell et al. 2020)

Opportunities to improve quantification of efficiency’s reliability and resilience benefits

We offer the following recommendations for utilities and regulators to consider for improving the quantification of reliability and resilience benefits of energy efficiency. Many of the recommendations focus on methodological advancements, bringing utilities' analyses in line with best practices. Others can be implemented as utilities adopt new technologies—for example, tapping the capabilities of advanced metering infrastructure to detect power outages at customer premises, instead of the feeder or substation level.

Utilities can take advantage of these opportunities in their next integrated resource plan, distribution system plan, DSM plan, and grid modernization filing. State utility regulators can encourage methodological improvements by establishing clear principles and providing more explicit guidance on evaluating reliability and resilience (Kahrl 2021). Specifically, regulators can develop or refine planning rules, establish consistent evaluation criteria across planning processes (where applicable), require that all available options be considered to meet electricity system needs, and, in orders on current utility plans, require utilities to make improvements in the next planning cycle.

Develop and use customer-level metrics to measure reliability and resilience.

Research by Pacific Northwest National Laboratory finds that resilience benefits are fundamentally localized, and community- and customer-level metrics are necessary to identify cost-effective resilience investments by utilities and customers (Twitchell et al. 2020). Researchers identified five principles for a "locational planning framework": (1) define critical loads, (2) identify major events of concern, (3) establish planning objectives, (4) engage in iterative planning between the project and the local grid to meet the needs of both, and (5) consider questions of ownership, cost allocation, and rate design. While the framework was developed for resilience value of energy storage, a similar framework could be used to identify and assess the resilience benefits of energy efficiency.

A recent report by Synapse and Sandia National Laboratories also proposes customer-level performance metrics for resilience, including for customer and geographic subsegments, supplementing annual event-level and system-level metrics (Kallay et al. 2021a). In addition, metrics such as “passive survivability” and “hours of safety”—customer-level resilience benefits—have been proposed to track capability of buildings to maintain indoor air temperature within safe levels during heat waves or cold snaps. A well-insulated and highly efficient house can maintain indoor temperature during relatively short duration power interruptions (Sun et al. 2021), but this benefit is not reflected in any traditional resilience metric. An ongoing DOE-funded project is developing a standardized methodology to value energy efficiency and other DER technologies for energy resilience of buildings under extreme heat or cold events with power outages.

The equitable distribution of efficiency's resilience benefits is an important consideration. Low-income households typically live in older, less-efficient buildings, with potential serious consequences during extreme weather events.

State regulators can encourage or require utilities to develop, track, and report on customer-level metrics to better capture the full value of behind-the-meter energy efficiency interventions for both reliability and resilience. Metrics can include data on customer energy burdens and building condition and location in Environmental Justice communities to support equity indicators for energy efficiency programs.

Use better data and methods to monetize reliability.

The limitations we identify in this paper with respect to using the VOLL to monetize reliability can be addressed with better data and methods. For example, Berkeley Lab recently developed a hybrid approach to assessing the VOLL and calculating customer, utility, and economy-wide impacts of widespread, long-duration interruptions by combining CIC surveys and macroeconomic models (Baik et al. 2021). Utilities can use time-sensitive VOLL in tandem with the time-sensitive value of energy efficiency will better capture the reliability and resilience benefits of energy efficiency.

Improve traditional VOLL approaches through development and use of a framework to quantify DER resilience benefits for the BPS.

The National Renewable Energy Laboratory recently created a framework to quantify resilience benefits in a BPS planning process using duration-dependent customer damage functions that improve on traditional approaches (Anderson et al. 2021). Customer damage functions expand the concept of the VOLL by adjusting the value depending on duration, season, and time of day, among other factors. For example, a customer that can shift load for two hours would have a lower VOLL for an interruption shorter than that, but its VOLL would increase with a longer interruption in which the consumption of this end use is definitely lost. Least-cost investment decisions can then account for resilience impacts on customers reflected in the damage functions. Utilities could apply such customer damage functions to assess the resilience benefits of energy efficiency.

Strengthen BCA frameworks and expand their application.

BCA frameworks can capture the benefits of efficiency on a wide array of dimensions, including reliability and resilience. However, reliance on imperfect VOLL definitions, lack of rigorous guidelines for measurement of efficiency impacts on reliability and resilience, and lack of quantification of resilience benefits are clear areas for improvement.

Sandia National Laboratories and Synapse recently produced a BCA framework that explicitly recognizes resilience as a key goal when planning grid investments (Kallay et al. 2021b). While their framework does not especially focus on energy efficiency investments, it suggests several resilience benefits that regulators and utilities can investigate further for valuation and monetization. Example benefits include reducing emergency staff deployment costs, avoiding loss of quality of life, and avoiding damages to goods and infrastructure⁴.

Many efficiency measures provide ongoing benefits by reducing peak demand year-round, not just during the peak hour or top demand hours of the year. Instead of simply evaluating annual or seasonal values, state regulators could support more complete quantification

⁴ See the National Standard Practice Manual (NSPM) for DER for a comprehensive list of benefits.

of efficiency's reliability and resilience contributions to electricity systems by encouraging or requiring greater consideration of the time-sensitive value of efficiency in BCAs (Frick and Schwartz 2019).

Treat energy efficiency as a resource, and consider its time-sensitive value, in long-term BPS planning.

Some improvements to quantifying the reliability and resilience benefits of energy efficiency may require broader changes to BPS planning processes. Recent Berkeley Lab research identifies asymmetries in the way energy efficiency and supply side resources are assessed in BPS planning processes (Frick et al. 2020b). Utilities' limited use of energy efficiency as a resource suggests that the reliability contributions of efficiency to the BPS are often not adequately captured. Utilities can model energy efficiency on a par with supply side resources to appropriately consider its time-sensitive value 8,760 hours a year and support quantification of efficiency's contributions to BPS reliability and resilience.

Integrate energy efficiency with other DERs.

Analyzing the interactions of energy efficiency with other DERs in BPS planning models is important for accurate valuation of efficiency's value for reliability (State and Local Energy Efficiency Action Network 2020). In addition, energy efficiency coupled with smart controls and other demand flexibility measures can promote resilience by helping to prevent outages and speed outage recovery time. Higher levels of DERs increases the need to address interactions of DERs with one another and with the electric grid. As a first step, utility BPS analysis should consider the interactive impact between all types of resources in system expansion models. For example, the impact of efficiency and DR may alter the dispatch of existing resources and the amount, type and schedule of future development of conventional generation in system expansion models. Accounting for DER interactions helps align planning estimates of impacts (amount, timing, and expected useful lives)—for valuation and cost-effectiveness screening—with actual impacts estimated through ex post assessments.

Measure and value conservation and load shedding as resilience strategies and compensate them accordingly.

Significant resilience benefits can accrue from emergency conservation measures. For example, the August 2020 California heat wave and February 2021 Texas storms would have caused significantly higher damage without voluntary energy efficiency measures and involuntary load reductions (CAISO 2021, Busby et al. 2021). In August 2020, “For the third consecutive day, the California Independent System Operator (ISO) said consumer conservation efforts had averted rotating power outages” (CAISO 2020). Because these are not programmatic energy efficiency interventions, their contribution to system resilience is typically not formally measured or valued, and there is limited information on compensating consumers for reducing load as a resilience strategy. This may be changing. For example, California Governor Newsom recently signed a Proclamation of a State of Emergency that requires the state Department of Finance to provide payments to utilities to compensate large energy users for reducing their electricity during extreme heat events (California Office of Governor Gavin Newsom 2021). State regulators can investigate the use of conservation and load shedding to improve electricity system resilience, as well as potential compensation strategies.

Track improvement in restoration time as a reliability benefit of energy efficiency.

Some BCA frameworks track improvements in restoration time as a reliability benefit of DERs, but they do not identify energy efficiency impacts on restoration time. In calculating net avoided restoration costs, utilities and regulators could account for potential improvements in restoration time due to lower loads caused by energy efficiency interventions. Lower loads could allow more customers to be supported by alternate circuits when a distribution segment is unavailable. This would lead to either reduced interruption time for customers that are transferred to a backup circuit or to overall reductions in average restoration time for customers in an affected area.

State regulators can encourage or require utilities to develop, track, and report on customer-level metrics to better capture the full value of behind-the-meter energy efficiency interventions for reliability, including tracking improvements in restoration time.

References

- Anderson, K, X. Li, S. Dalvi, S. Ericson, C. Barrows, C. Murphy, E. Hotchkiss. 2021. [Integrating the Value of Electricity Resilience in Energy Planning and Operations Decisions](#). IEEE Systems Journal 15, 204–214.
- Baik, S.H., N.L. Hanus, A.H. Sanstad, J.H. Eto, P.H. Larsen, P.H. 2021. [A Hybrid Approach to Estimating the Economic Value of Enhanced Power System Resilience](#). Lawrence Berkeley National Laboratory.
- Baker, S. 2019. [Anti-Resilience: A Roadmap for Transformational Justice within the Energy System](#). Harvard Civil Rights- Civil Liberties Law Review (CR-CL), Vol. 54, pp. 1-48 (2019), Northeastern University School of Law Research Paper No. 346-2019.
- Busby, J.W., Baker, K., Bazilian, M.D., Gilbert, A.Q., Grubert, E., Rai, V., Rhodes, J.D., Shidore, S., Smith, C.A., Webber, M.E. 2021. [Cascading risks: Understanding the 2021 winter blackout in Texas](#). Energy Research & Social Science 77, 102106.
- CAISO. 2020. ["Conservation needed earlier in day; Flex Alert issued for 2 to 9 p.m. Grid operator urges consumers to continue doing their part to keep power on,"](#) August 19.
- CAISO, California Public Utilities Commission, California Energy Commission. 2021. [Root Cause Analysis: Mid-August 2020 Extreme Heat Wave](#).
- California Office of Governor Gavin Newsom. 2021. ["Proclamation of a State of Emergency."](#)
- Carvallo, J.P., F.C. Hsu, Z. Shah, J. Taneja. [Frozen Out in Texas: Blackouts and Inequity](#).
- Consolidated Edison. 2020. "Electric Benefit Cost Analysis Handbook v3.0"
- De Martini, P., J. Taft, J. Paladino, F. Kahrl, F.S. Kasina, R. Orans. 2020. [Modern Distribution Grid, Volume IV](#). Prepared for U.S. Department of Energy.
- Energy Systems Integration Group (ESIG). 2021. [Redefining Resource Adequacy for Modern Power Systems](#): Redefining Resource Adequacy Task Force.

- Eto, J. 2016, “How Reliable Is Transmission Compared to Distribution and What Do Power Interruptions Really Cost Customers” (paper presented at National Association of Regulatory Utility Commissioners Winter Committee Meeting, February 14–17, 2016)
- Eto, J., K. Hamachi LaCommare, M. Yue. 2020. [Grid Modernization: Metrics Analysis \(GMLC1.1\) – Reliability](#).
- EPA. 2018. [Assessing the Electricity System Benefits of Energy Efficiency and Renewable Energy](#).
- Farley, C., J. Howat, J. Bosco, N. Thakar, J. Wise, J. Su, L. Schwartz (technical editor). 2021. [Advancing Equity in Utility Regulation](#). Lawrence Berkeley National Laboratory.
- Frick, N., T. Eckman, G. Leventis, A. Sanstad. 2020a. [Methods to Incorporate Energy Efficiency in Electricity System Planning and Markets](#). Lawrence Berkeley National Laboratory.
- Frick, N., S. Price, L. Schwartz, N. Hanus, B. Shapiro. 2020b. [Locational Value of Distributed Energy Resources](#). Lawrence Berkeley National Laboratory.
- Frick, N., L. Schwartz. 2019. [Time-Sensitive Value of Efficiency: Use Cases in Electricity Sector Planning and Programs](#). Lawrence Berkeley National Laboratory.
- Kahrl, F., L. Schwartz. (technical editor). 2021. [All-Source Competitive Solicitations: State and Electric Utility Practices](#). Lawrence Berkeley National Laboratory.
- Kallay, J., A. Napoleon, B. Havumaki, J. Hall, C. Odom. A. Hopkins, M. Whited, T. Woolf, M. Chang, R. Broderick. R. Jeffers, B.M. Garcia. 2021a. [Performance Metrics to Evaluate Utility Resilience Investments](#). Sandia National Laboratories.
- Kallay J., S. Letendre, T. Woolf, B. Havumaki, S. Kwok, A. Hopkins, R. Broderick, R. Jeffers, K. Jones, M. DeMenno. 2021b. [Application of a Standard Approach to Benefit-Cost Analysis for Electric Grid Resilience Investments](#). Sandia National Laboratories.
- Knight, P., M. Chang, D. White, J. Hall, D. White, J. Frost, B. Havumaki, C. Odom, D. Bhandari, C. Lane, A. Hopkins, S. Kwok, B. Biewald, P. Chernick, J. Harvey, L. Deman, J. Rosenkranz, J. Gifford, P. Yuen. 2021. [Avoided Energy Supply Components in New England: 2021 Report](#). Prepared by Synapse Energy Economics, Resource Insight, Les Deman Consulting, North Side Energy, and Sustainable Energy Advantage. AESC Study Group.
- LaCommare, K.H., J.H. Eto, L.N. Dunn, M.D. Sohn. 2018. Improving the estimated cost of sustained power interruptions to electricity customers. *Energy* 153, 1038–1047. <https://doi.org/10.1016/j.energy.2018.04.082>
- Maine Revised Statute (M.R.S.) [Section 35-A Public Utilities, Chapter 31, Section 3131. 4c](#)
- Mass Saves. 2018. [Massachusetts Joint Statewide Electric and Gas Three-Year Energy Efficiency Plan 2019– 2021](#). Mass Saves.
- New York Department of Public Service (DPS) 2015. [Staff White Paper on Benefit-Cost Analysis in the Reforming Energy Vision](#), Proceeding 14-M-0101.
- Northwest Power and Conservation Council. 2011. [A New Resource Adequacy Standard for the Pacific Northwest](#).

- Northwest Power and Conservation Council. 2019. [Pacific Northwest Power Supply Adequacy Assessment for 2024](#).
- NV Energy. 2019. [Joint Application of Nevada Power Company d/b/a/ NV Energy and Sierra Pacific Power Company d/b/a/ NV Energy for approval of the first amendment to its 2019-20138 triennial Integrated Resource Plan to include a Distributed Resources Plan](#). Nevada PUC Docket 19-04003.
- Organization of MISO States, National Rural Electric Cooperative Association, Edison Electric Institute, National Association of State Utility Consumers Advocates, L. Schwartz (technical editor). 2019. [Utility Investments in Resilience of Electricity Systems](#). Future Electric Utility Regulation report no. 11.
- PPD 2013. [Presidential Policy Directive 21—Critical Infrastructure Security and Resilience](#). February 2013.
- Petit, F., V. Vargas, J. Kavicky (M. Kintner-Meyer, J. Eto, principal investigators). 2020. [Grid Modernization: Metrics Analysis \(GMLC 1.1\) – Resilience](#). Prepared for U.S. Department of Energy.
- Rickerson, W., J. Gillis, M. Bulkeley. 2019. [The Value of Resilience for Distributed Energy Resources: An Overview of Current Analytical Practices](#). Prepared for the National Association of Regulatory Utility Commissioners.
- Rickerson, W., K. Zitelman, K. Jones. 2022. [Valuing Resilience for Microgrids: Challenges, Innovative Approaches, and State Needs](#). National Association of Regulatory Utility Commissioners.
- Schwartz, L., J. Homer. 2020. [Distribution Planning Regulatory Practices](#). Integrated Distribution System Planning Training for MISO/Midwest Region.
- Silverstein, A., R. Gramlich, M. Goggin. 2018. [A Customer-focused Framework for Electric System Resilience](#).
- State and Local Energy Efficiency Action Network. 2020. [Determining Utility System Value of Demand Flexibility from Grid-Interactive Efficient Buildings](#). Prepared by: Tom Eckman, Lisa Schwartz, Greg Leventis, Lawrence Berkeley National Laboratory.
- Sun, K., W. Zhang, Z. Xeng, R. Levinson, M. Wei and T. Hong. 2021. [Passive cooling designs to improve heat resilience of homes in underserved and vulnerable communities](#). Energy & Buildings.
- Twitchell, J.B., S.F. Newman, R.S. O’Neil, M.T. McDonnell. 2020. Planning Considerations for Energy Storage in Resilience Applications. Pacific Northwest National Laboratory. <https://energystorage.pnnl.gov/pdf/PNNL-29738.pdf>
- Watts, C., C. McCarthy, B. Levite. 2020. [Moving Beyond Average Reliability Metrics](#). S&C Electric Company.
- Wood III, P., R. Gee, J. Walsh, B. Perlman, B. Klein, A. Silverstein. 2021. [Never Again: How to Prevent Another Major Texas Electricity Failure](#).
- Vugrin, E., A. Castillo, C. Silva-Monroy. 2017. *Resilience Metrics for the Electric Power System: A Performance-Based Approach*. Sandia National Laboratories.