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Valuing Resilience for Microgrids: Challenges, Innovative Approaches, and State Needs

Wilson Rickerson, Converge Strategies
Kiera Zitelman, National Association of Regulatory Utility Commissioners
Kelsey Jones, National Association of State Energy Officials

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Executive Summary

The United States depends on the delivery of reliable, affordable, clean, and safe electricity. Electric utilities invest billions of dollars each year in generation, transmission, and distribution assets to meet this need. However, experiences with recent natural disasters of increasing frequency and duration demonstrate the shortcomings of this approach in the face of modern threats. Further, as customers rely on electricity for a broader range of important needs, such as transportation, as well as critical life-saving services and mission critical facilities such as water treatment, medical care, shelters, telecommunications, and more, the need to minimize the likelihood and impacts of outages grows.

Against this backdrop, resilience has emerged as a key consideration to guide electricity spending, whether from utilities, customers, or taxpayers. Although reliability has been defined and measured for decades with broadly accepted metrics that measure how many customers lose power and at what frequency and duration, resilience considers the electricity system's response to a disruption and its subsequent impacts on customers. Developing tools and methods to accurately assess the costs and benefits of resilience investments is a critical step toward the goal of mitigating the impacts of outages on customers and society.

Today, electric system resilience is largely treated as an externality due to challenges estimating the costs of long-duration outages, impacts of outages on society, and increasing reliance on electricity for a growing set of interdependent services. These interdependencies include the water, wastewater, telecommunications, natural gas, and health sectors. Without knowing how much a given resilience investment will benefit customers or society more broadly, investors, policymakers, and regulators are less likely to make or approve such investments, and less able to prioritize those investments. State Energy Offices and public utility commissions (PUCs) lead the development of state-level energy policy and utility regulation, respectively, and each has interests in encouraging appropriate public and private investments in resilience. To this end, the National Association of State Energy Officials (NASEO) and National Association of Regulatory Utility Commissioners (NARUC), with the support of the U.S. Department of Energy (DOE) Office of Electricity (OE), formed a joint Microgrids State Working Group to explore the costs and benefits of microgrids, barriers to broader deployment of microgrids to meet resilience and other objectives, and policy and regulatory strategies to optimize investments in resilience, including but not limited to microgrids.

Although no universally accepted valuation tool for resilience exists, National Laboratories, utilities, researchers, and state and federal agencies have collaborated to develop, apply, and improve a number of approaches to quantify resilience, several of which are still in progress at the time this report is published (**Table 2**). This report seeks to share these important advances by discussing current definitions of resilience (Section 1), how microgrids are defined and used to meet resilience objectives (Section 2), new approaches to valuing resilience (Section 3), steps State Energy Offices and PUCs have taken to further resilience valuation efforts (Section 4), and finally, considerations and suggested next steps for State Energy Offices and PUCs (Section 5). Relevant examples of specific microgrid projects and resilience valuation efforts are included throughout the report. While this report is written specifically for NASEO and NARUC members, it may be useful for utilities, local governments, and individual customers interested in improving the way public and private dollars are spent to achieve resilience outcomes.

Introduction and Context

Threats to the electricity grid are increasing in frequency, severity, and impact. The National Oceanic and Atmospheric Administration (NOAA) tracks weather and climate related natural disasters that cause more than $1 billion in damages and has counted eight such events in the first six months of 2021, causing 331 deaths and $29.4 billion in collective damage (NOAA, 2021). Winter Storm Uri, in February 2021, caused power outages for millions of Texans for days in below-freezing temperatures. The storm revealed the dependence of critical services like water treatment and natural gas supply on electricity, magnifying the hardships to customers left without access to heat and water for an extended period (Pillon, 2021). In late August 2021, Hurricane Ida brought heavy rains, strong winds, and widespread flooding from New Orleans to New York City, resulting in power outages for 1.2 million customers in eight states (EIA, 2021). Five days after the storm, more than 800,000 Gulf Coast customers were still without power in temperatures exceeding 100 degrees (Bogage, 2021).

With extreme weather events and no-notice events such as cyber security breaches occurring at greater frequency and intensity, traditional reliability investments that may have powered through previous events are no longer meeting customer needs and expectations. On the Gulf Coast, for example, Entergy's billions of dollars of investments in concrete and steel transmission and distribution poles and substation elevation failed to prevent widespread, multi-day outages driven by Hurricane Ida's excessive wind speeds (Morehouse and Tamborrino, 2021). In early 2021, Oregon's Bootleg Fire burned more than 100,000 acres and led to important transmission lines, including those providing electricity to the California grid for peak demand, going down (Haskell, 2021). In this environment of increased threats and growing reliance on electricity for services such as heating and transportation, state public utility commissions (PUCs) and State Energy Offices are looking for opportunities to decrease the likelihood and impacts of power outages.

The concept of resilience has emerged as a priority for the energy system. Beyond reliability, which measures system preparedness for routine, recurring challenges, resilience encapsulates the system's ability to anticipate, absorb, adapt to, and recover from all threats, including high-impact, low-frequency (HILF) disruptions like 2021's most severe winter and summer storms (EPRI, 2021). Utilities, policymakers, and regulators have not agreed upon a universal definition of resilience (Kallay et al., 2021a). NARUC proposed a definition for state utility regulators in 2013; the White House released a definition focusing on critical infrastructure protection in 2013; FERC put forward a definition for federal regulators in 2018; and the National Renewable Energy Laboratory's 2019 definition highlighted the importance of multi-stakeholder planning (see **Text Box 1**). Although the definitions overlap by mentioning recovery from a disruptive event, they differ in scope and specificity.

Text Box 1: Defining Resilience

NARUC: "Robustness and recovery characteristics of utility infrastructure and operations, which avoid or minimize interruptions of service during an extraordinary and hazardous event." (Keogh & Cody, 2013)

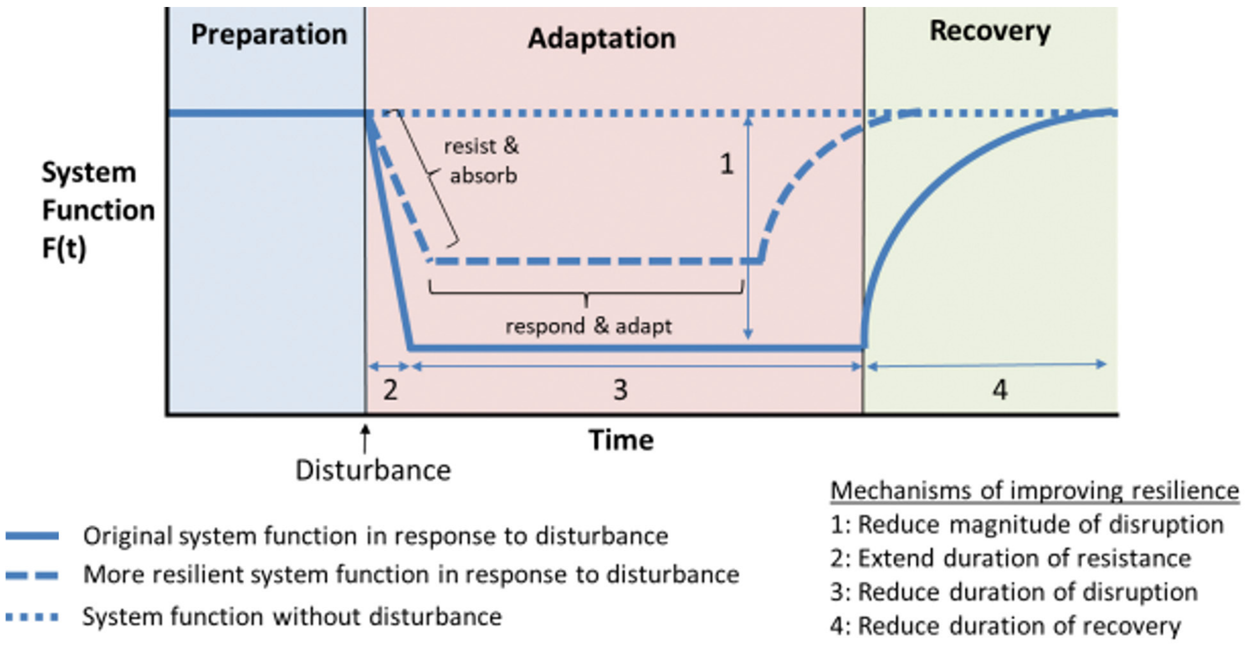
Presidential Policy Directive: "The ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents." (White House, 2013)

Federal Energy Regulatory Commission: "The ability to withstand and reduce the magnitude and/or duration of disruptive events, which includes the capability to anticipate, absorb, adapt to, and/or rapidly recover from such an event." (FERC, 2018)

National Renewable Energy Laboratory: "The ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions through adaptable and holistic planning and technical solutions." (Hotchkiss & Dane, 2019)

With this lack of national consensus, some states have taken steps to develop more specific definitions of resilience to more clearly guide preparedness, adaptation, and recovery from events. The California Public Utilities Commission (CPUC) offered a definition of resilience in a July 2020 staff concept paper that centers on impact reduction: "Resiliency refers to the ability to mitigate the impact of a large, disruptive event by any one or more of the following mechanisms: 1. Reducing the magnitude of disruption; 2. Extending the duration of resistance; 3. Reducing the duration of disruption; 4. Reducing the duration of recovery." These objectives are shown graphically as a "resilience trapezoid" (**Figure 1**), in which a more resilient system (the dashed line) exhibits all four characteristics as compared to typical system function during a disturbance (the solid line).

Figure 1: Resilience Trapezoid



When looking to improve system resilience, one place to start is by evaluating all possible risks and potential impacts of man-made and natural hazards on the electricity system. This process would allow PUCs and State Energy Offices to better understand which resilience projects to prioritize and properly assess where the largest vulnerabilities are. One tool to support this is a set of the U.S. Department of Energy's Office of Cyber Security, Energy Security, and Emergency Response's (CESER) State and Regional Energy Risk Profiles.[1] These profiles are available for all 50 states and the District of Columbia and include information on potential hazards that could lead to energy system disruptions. Investing in grid modernization and ensuring electricity infrastructure is updated will provide additional resilience benefits.

Despite various definitions of resilience, data suggest that strengthening existing electric distribution infrastructure or investing in new distribution-level resources will play a critical role in improving resilience. A brief on resilience technologies as part of NARUC's "Regulator's Financial Toolbox" series notes the potential for capital investments, hardware and software, vegetation management, human capital, and customer-side resilience measures to help the grid be more resilient (NARUC, 2022). With more than 90 percent of outages resulting from failures in the distribution network (Silverstein, Gramlich, & Goggin, 2018), strengthening distribution infrastructure is an important way of improving system resilience. State PUCs and State Energy Offices are considering a range of programs and investments in the distribution system to enhance resilience by reducing the likelihood, duration, and geographic area of outages.

1 State and Regional Energy Risk Profiles are available at: https://www.energy.gov/ceser/state-and-regional-energy-risk-profiles.

Traditionally, expenditures have been guided by imprecise approaches that fail to account for the impacts of outages or anticipate HILF events such as Winter Storm Uri. Such approaches include replacing equipment after a certain lifetime, assuming it will soon fail, and identifying poorly performing segments of the distribution network for upgrades. New approaches to analyzing the costs and benefits of resilience investments, such as microgrids, can enable more efficient use of ratepayer and taxpayer resources to deliver better outcomes.

To share state practices and challenges in this space, State Energy Offices and PUCs joined the NASEO-NARUC Microgrids State Working Group (MSWG) to explore benefits and costs of microgrids, identify challenges and barriers to microgrid development, and share successful approaches to deploying microgrids to achieve state policy goals. The MSWG is funded by the U.S. Department of Energy, Office of Electricity, which supported the development of this paper. While this paper is written with MSWG members in mind, it may be useful to utilities, emergency management agencies, community development organizations, municipal governments, and other stakeholders that can benefit from engagement with MSWG members on resilience investments and programs.

2. Role of Microgrids for Resilience

Microgrids are one of many tools to improve resilience. This section summarizes broadly accepted definitions for microgrids and discusses how microgrids are used to enhance resilience (Section 2.1), concluding with a discussion of state-level resilience efforts (Section 2.2).

2.1 Defining Microgrids

DOE's Microgrid Exchange Group developed a broadly accepted definition of a microgrid in 2012:

> "[A microgrid is] a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode" (Ton & Smith, 2012).

This definition involves four distinct components:

1. **Load(s):** the consumer(s) of electricity. Load can be designated as critical, high-priority, or low-priority.
2. **Distributed energy resources (DERs):** resources that either supply (generate, store, and /or discharge) electricity or strategically conserve and optimize the use of electricity (i.e., energy efficiency or demand response). DERs include generation, storage, and load control technologies.
3. **Controls:** the management system of the microgrid. A microgrid controller performs multiple functions, including: (a) identifying when and how to connect and disconnect from the grid; (b) maintaining real and reactive power balance when the microgrid is disconnected and operating in islanded mode, and (c) dispatching DERs to support load.
4. **Interconnection/point of common coupling (PCC):** the point at which the microgrid connects to the distribution network.

Microgrids can involve single or multiple facilities, DERs, and customers (meters). Some states have developed classification systems grouping similar types of microgrids together, helping to guide efforts to standardize the regulatory treatment of microgrids. The New Jersey Board of Utilities (NJ BPU) developed one system for microgrids according to the number of customers (NJ BPU, n.d.):

- **Level 1** or single customer: serving one customer through one meter.
- **Level 2** or single customer/campus setting (partial feeder microgrid): serving multiple facilities, controlled by one meter at the PCC.
- **Level 3** or multiple customers (advanced or full feeder microgrid): serving multiple facilities/customers on multiple meters. The DER(s) may be located on a different site from the facilities/customers. While the advanced microgrid has one PCC, the individual facilities/customers within the advanced microgrid may have their own individual connections to the distribution grid.

As disruptions to electricity service increase in frequency, duration, and impact, microgrids have the potential to meet the objectives of residential, commercial, and industrial customers, municipalities, and distribution utilities, particularly during outages. A 2020 report prepared by the National Renewable Energy Laboratory (NREL) and Smart Electric Power Alliance (SEPA) notes "the primary value proposition of microgrids is their ability to island and provide resiliency to communities as well as to the grid" (NREL & SEPA, 2020). Across customer types and microgrid configurations, a microgrid meeting the DOE's definition would use control equipment to learn of an outage, island from the distribution grid, and generate and distribute electricity within the microgrid boundary.

The capacity of a microgrid is almost always less than a customer's (or customers') peak power demand, as customers designate critical load during the microgrid design process. For example, a microgrid powering a hospital would support electricity-dependent life-saving services, but not necessarily the hospital's normal level of power demand. Once the distribution utility restores power, the microgrid could either cease generating and distributing power entirely, function at a level below full capacity, or continue to generate and distribute at full capacity while customer(s) return to depending on the distribution utility for some or all of their power needs. Key to microgrids' resilience value is the ability to island and function independently from the grid, under both normal and abnormal conditions.

For residential customers, Level 1, 2, or 3 microgrids powering critical infrastructure (such as water treatment, emergency services, and food/gas distribution) can make outages far less threatening to human health and safety by providing a basic level of service for the connected facility or facilities during a broader grid outage. Commercial and industrial customers can use microgrids to avoid costly outages; particularly in facilities such as data centers, where even a momentary loss of power can result in substantial damages. Municipalities are increasingly considering single- or multi-facility community microgrids to power lifesaving functions such as heating/cooling, medical services, and other capabilities for community members. As customers increasingly rely on electricity, particularly as transportation and heating electrification trends continue, the definition of critical load is expanding to cover more facilities (Enchanted Rock, 2021). Multiple distribution utilities are already using substation-level microgrids to continue power flow when transmission or distribution lines are impacted by a disaster, with several examples located in areas subject to wildfire-driven public safety power shutoffs (PSPS) in California. A 2019 CPUC decision designated types of critical facilities that should receive as much notice as possible prior to PSPS events to "assist those facilities to maximize resiliency during de-energization and re-energization by implementing advanced planning" (CPUC, 2019, p. 74).

As discussed in NARUC and NASEO's January 2021 paper, *User Objectives and Design Approaches for Microgrids: Options for Delivering Reliability and Resilience, Clean Energy, Energy Savings, and Other Priorities,* microgrids are highly specialized according to customer needs and site characteristics (Zitelman, 2021). Specific types of discrete customers may know their own value of resilience through understanding the costs of outage. Some commercial and industrial customers, for example, experience direct and obvious costs through lost output or interruptions to processes that provide revenue as well as maintain worker safety and corporate reputation. If the magnitude and frequency of these losses exceeds the cost of resilience investments, rational customers will make those expenditures. Indeed, Navigant Research expects commercial and industrial (C&I) customers to massively increase spending on microgrids, growing from $200 million in 2020 to nearly $1.5 billion in 2029 (Forni, Asmus, & Willette, 2019).[2] However, not all customers can accurately assess their own willingness to pay for resilience for a number of reasons: they may not have an understanding of the costs of an outage, may lack awareness of the costs of resilience investments, or may over- or underestimate the likelihood and duration of future service disruptions.

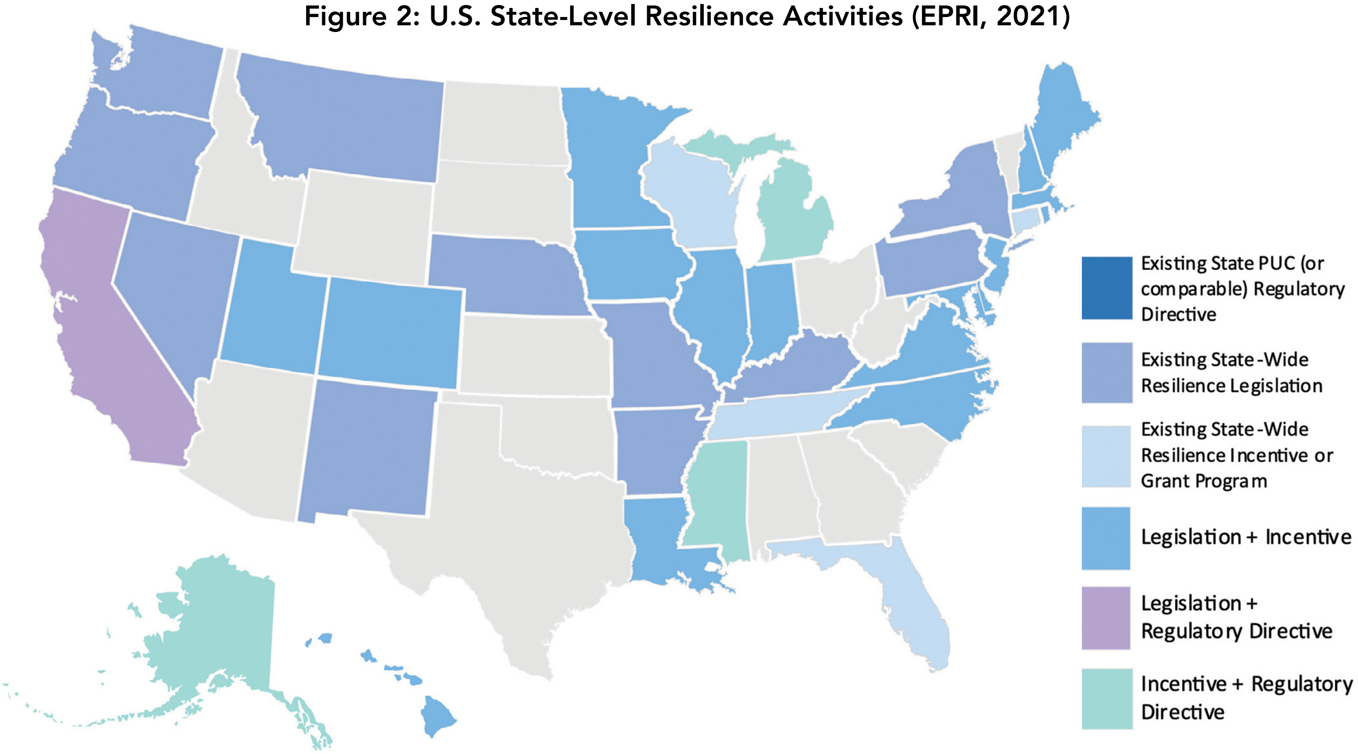
The Electric Power Research Institute (EPRI) notes three broad areas of difficulty in valuing resilience, noting uncertainties and challenges in estimating (a) longer-duration outages, particularly for new threats or for customers with limited experience with long-duration outages, (b) societal costs of widespread, long-duration outages, and (c) scenarios in which more services (e.g., transportation, space heating) shift from reliance on liquid fuels to electricity (EPRI, 2021). All three of these challenges make it difficult to apply cost-benefit analysis to find the right level of investment in microgrids that support community resilience, such as Level 3 community microgrids or even Level 1 or Level 2 microgrids that support public infrastructure (Kallay et al., 2021b).

2 In addition to resilience benefits, customers may also invest in microgrids powered by renewable energy generation and/or energy storage to further address state clean energy goals.

2.2 State-Level Resilience Efforts

Increasingly, PUCs and State Energy Offices appreciate the need to consider a range of resilience investments and are addressing this need through different strategies. EPRI tracks regulatory directives, state legislation, and incentives or grant programs (**Figure 2**).

Figure 2: U.S. State-Level Resilience Activities (EPRI, 2021)



Some states that are facing imminent threats from extreme weather have used microgrids to increase preparedness and resilience to future events, such as in California. Implementing a 2018 law calling on the California Public Utilities Commission (CPUC) to "facilitate the commercialization of microgrids for distribution customers of large electrical corporations" (California Legislature, 2018), the CPUC ordered temporary microgrid deployment at substations and rural communities to improve system resilience and mitigate the effects of wildfire-related power shutoffs (CPUC, 2021). This order is part of an ongoing multi-track resilience and microgrids proceeding, with a neutral third-party review and evaluation of tariffs, rates, rules, incentive programs, and pilot projects anticipated to start in late 2022 or early 2023.

Whereas substation microgrids can be costly, the scale of other types of investments required to increase resilience to wildfires can be enormous compared to business as usual. For example, in July 2021, PG&E proposed a multi-year effort to place 10,000 miles of overhead distribution lines underground to decrease the likelihood of utility infrastructure-caused wildfires, at a cost of up to $40 billion (PG&E, 2021; Penn, 2021). In 2021, Rhode Island and Wisconsin introduced State Energy Office-administered microgrid programs to improve resilience, joining existing programs in Connecticut, Maryland, Massachusetts, New Jersey, and New York. State Energy Office microgrid programs largely aim to improve resilience to hurricanes and severe storms, with several programs launched as elements of state resilience strategies following Hurricane Sandy in 2012.

The Kentucky Office of Energy Policy (OEP) supported a 2021 Commonwealth of Kentucky Regional Microgrids for Resilience Study. The study looked at the resilience value of microgrid islanding capabilities and, when analyzing potential microgrid locations in the state, conducted a load analysis, size breakdown, and cost estimate. While these indicators were used to estimate the cost of a fossil fuel versus renewable microgrid at various critical facilities, the specific value of resilience was not calculated (SEPA, 2021).

The Kentucky OEP was also the first state to use DOE State Energy Program funds to implement the U.S. Green Building Council (USGBC) Performance Excellence in Electricity Renewal (PEER) rating system for energy resilience (Living Standard, 2021). PEER is a certification program that measures power system performance and aims to improve the resilience of electricity infrastructure. Kentucky supported the Nolin Rural Electric Cooperative Cooperation's (Nolin RECC) attainment of PEER certification (PEER, 2018). Nolin RECC operates a microgrid project in conjunction with the Fort Knox Army Base to improve electricity reliability and bring cost savings to this critical location (SEPA, 2021; see **Text Box 2**).

Text Box 2: Using the USGBC PEER Certification Program to Enhance Resiliency

The PEER rating system evaluates power system performance by looking at a project's value when it comes to categories such as reliability and resiliency, grid services, and energy efficiency and environment (PEER, 2021). PEER certification is available for utility and city, campus, or transit projects that have been operational for at least a year. PEER precertification is available for projects still in the design phase or not 100% completed. After a review process, points will be awarded to determine the certification level for the project: PEER Certified, PEER Silver, PEER Gold, or PEER Platinum.

The Nolin Rural Electric Cooperative Corporation (Nolin RECC) was the first electric cooperative in the country to achieve PEER certification. Nolin RECC achieved two separate PEER certifications (PEER Gold and PEER Silver) that demonstrate their commitment to energy system reliability and improved customer service (Holly, 2018). They achieved PEER Gold for their standard service territory by developing an emergency response plan, setting up an Advanced Metering Infrastructure system, and offering free energy audits for customers to determine their energy usage (PEER, 2018). Nolin RECC achieved PEER Silver through a campus-level designation at Fort Knox Military Base. Part of this can be attributed to the combined heat and power microgrid project located at the base, which Fort Knox partnered with Nolin RECC to implement (Fort, 2016). These two designations allow Nolin RECC to focus on specific areas of improvement and to be more strategic when planning future microgrid projects in their service territory.

The barriers to incorporating resilience benefits into decision-making include the lack of standardized or widely accepted valuation practices and the limitations of currently available valuation methods. Despite these limitations, state regulators and energy directors recognize the benefits of incorporating the value of resilience in regulatory and policy processes. In its 2019 Statewide Energy Assessment, for example, the Michigan Public Service Commission wrote: "As utilities and regulators focus on resilience improvements, evaluating expenditures proposed for resilience improvements to ensure they are just and reasonable will be important…The Commission recommends utilities work with Staff and stakeholders to propose a methodology to quantify the value of resilience, particularly related to DERs" (Michigan PSC, 2019). However, states face challenges in taking initial steps towards this goal, and often do not wade deeper than highlighting the need to develop metrics.

The Wisconsin Office of Energy Innovation reviewed microgrid programs supported by State Energy Offices and found fostering local resilience to be a common goal across states. While many programs recognized the resilience benefits of microgrids, few took concrete, quantitative steps towards incorporating this value as a determinant of project funding. Similarly, Wisconsin's initial program memo included reliability and resilience benefits as potential criteria in project applicant scoring, but did not elaborate on how resilience would be reflected in project selection (Wisconsin PSC, 2021a).

Failing to quantify the resilience benefits provided by microgrids and other distribution investments leads to underinvestment in these resources, as concrete costs will always outweigh unquantified benefits. State PUCs and State Energy Offices share jurisdiction and interest in developing valuation methods to account for resilience in decision-making, but they have differing considerations as economic regulators and policymakers, respectively. In the absence of competition among multiple electric distribution companies, PUCs oversee regulated monopoly utilities' expenditures of ratepayer funds to provide services to those ratepayers. As such, PUCs are generally limited in authority to consider the economic impacts of utility investments beyond assuring just and reasonable rates, with some statutorily defined and relatively narrow exceptions (Zitelman & McAdams, 2021). State Energy Offices spend taxpayer money on energy programs that provide public benefits. As State Energy Offices are not primarily focused on maintaining affordable electric rates, they are less constrained in factoring policy goals such as greenhouse gas reductions, economic development, and job creation into energy programs. For both groups of decisionmakers, valuing resilience can aid in coordinating and prioritizing investments to benefit ratepayers, taxpayers, or society at large (Kallay et al., 2021a).

Regulated utilities have proposed a small number of Level 3 (multi-facility) microgrids. NARUC previously reviewed Commission proceedings related to two projects in Maryland and one in Illinois (Rickerson et al., 2019). Maryland regulators rejected both proposals from BG&E and Pepco to place community microgrids into rate base, citing either unquantified or unclear benefits to ratepayers. Pepco used the U.S. Department of Energy's Interruption Cost Estimator (ICE) Calculator to estimate a value of resilience for microgrid participants but acknowledged the inability of the ICE Calculator to estimate damages from long-duration outages (i.e., greater than 16 hours) and to estimate community resilience benefits to customers not directly connected to the microgrid. The Maryland Public Service Commission cited unquantified and uneven benefits to ratepayers in its denial of the project (Maryland PSC, 2015). In contrast, Illinois regulators approved Commonwealth Edison's Bronzeville microgrid proposal, despite a similar lack of quantified resilience benefits (see Text Box 3). The Illinois Commerce Commission cited community learning benefits in approving the proposed project (ICC, 2018).

Text Box 3: Bronzeville Community Microgrid (BCM)

In February 2018, the Illinois Commerce Commission (ICC) approved the use of $12.6 million in ratepayer funds to support a community microgrid in the Bronzeville area of Chicago. Solar PV, battery storage, diesel, and controllable natural gas generation provided power to police department headquarters and other public buildings. Commonwealth Edison (ComEd) stated the microgrid would provide a "resilient oasis" for customers in the surrounding community, defining resilience as "the ability to prepare for and mitigate major extreme events and disasters...also the capacity of individuals, institutions, businesses, and systems to sustain and recover from chronic stresses and acute disturbances." ComEd did not attempt to quantify the value of resilience in its request to use ratepayer funds to support a portion of the costs of BCM, but positioned the project as an opportunity to test, inform, and validate 58 metrics reflecting the resilience of the energy system, critical infrastructure, and community to be used in future regulatory proceedings, and agreed to submit annual progress reports to the ICC (ICC, 2018). In its initial metrics cost/benefit report, submitted in December 2020, ComEd stated that it continued to gather data on resilience benefits provided by BCM for residential and non-residential customers within the project footprint, the surrounding population, society at large, and ComEd as a utility, and noted ongoing work with Lawrence Berkeley National Laboratory to develop valuation tools, discussed in Section 3.

Notably, microgrids can provide additional value beyond local resilience that can significantly mitigate costs borne by customers. Through business model innovations and access to markets, microgrids can provide services beyond local resilience through "value stacking" with multiple revenue and benefit streams (NREL & SEPA, 2020). As demonstrated by several recent military microgrids, microgrids can provide cost-effective grid services and other benefits that have enabled regulators to approve cost recovery from ratepayers (Rickerson et al., 2021). **Table 1** provides examples of military installations where microgrids have been approved, including the relevant proceeding number, the type of generation used in the project, and the benefits noted by the regulators. Regulators have considered and approved utility investments in military microgrids that both support national security and create broader ratepayer and societal benefits. However, without a robust resilience valuation method to factor into decision-making, regulators considering both military and civilian microgrids have been hesitant to pass costs to ratepayers based on resilience benefits alone (Kalley et al., 2021b and Rickerson, Gillis, & Bulkeley, 2019).

States have also overseen the use of taxpayer resources to support microgrid grant and loan programs facilitated by State Energy Offices and state infrastructure and green banks (Cramer, 2021). Programs have generally not required applicants to include a value of resilience in requests for support on microgrids, with some exceptions. The Maryland Energy Administration's (MEA's) Resilient Maryland grant program explicitly recognizes resilience as a scoring criteria worth 20 percent of an applicant's overall score. MEA guidelines encourage applicants to include DERs that enable projects to island during an outage and prioritize critical loads to maximize the project's power duration during an outage (MEA, 2021). The New York State Energy Research and Development Authority (NYSERDA) NY Prize Program, for example, required a benefit-cost analysis for each of the microgrid feasibility studies. As part of the analysis, applicants were asked to calculate a major power outage benefit, which combined results from the ICE Calculator (Section 3.1.1) with FEMA estimates for the value of avoided mortality, injury, and property damage provided by emergency services (Rickerson et al., 2019). The NYSERDA methodology is discussed in Section 3.1.4.

Table 1. Military Microgrids and Ratepayer Benefits

Installation (State)	Commission (Proceeding No.)	Energy System	Benefits	Year in Service
Marine Corps Air Station Yuma (Arizona)	Arizona Corporation Commission (Docket No. E-01345A-16-0036)	25 MW diesel generation	• Frequency regulation	2016
Schofield Barracks (Hawaii)	Hawaii Public Utilities Commission (Docket No. 2014-0113)	50 MW biofuel generation	• Black start • Increase operational flexibility and reliability • Enable older asset retirement • Renewable energy integration	2018
Naval Construction Battalion Center Gulfport (Mississippi)	Mississippi Public Service Commission (Docket No. 2015-UA-65)	4.3 MW PV Battery storage Diesel generation	• Fuel diversity • Downward pressure on electricity rates • Carbon compliance cost hedge	2021
Pacific Missile Range Facility Barking Sands (Hawaii)	Hawaii Public Utilities Commission (Docket No. 2017-0443)	14 MW PV 70 MWh battery	• Reasonable PPA price • Firm capacity • Meets RPS	2021

3. New Approaches to Valuing Resilience

A study authored by Converge Strategies, LLC (CSL) for NARUC in April 2019 found a range of different methods for valuing resilience, most of which estimate the avoided costs of power interruptions. Many of these methods have been applied in academic analyses, but few have been used to directly inform state regulatory or policy decision-making. A growing number of regulatory proceedings broadly acknowledge the importance of valuing resilience. The Michigan PSC's State Energy Assessment in 2019, for example, recommended that "the value of resilience...should be considered in future investment decisions related to energy infrastructure in future cases (MI PSC, 2019, p. 109)." The CPUC similarly noted that "quantifying resilience value is critical for investment decision making, rate-making and emergency planning as we address the vulnerability and changing nature of our energy system (CPUC, 2020, p. 51 in Attachment 2)." As discussed in Section 2, some state regulators have considered the value of resilience specifically for microgrids as part of formal regulatory proceedings, but they have not used a quantitative value of resilience as part of their decision-making.

One of the barriers to valuing resilience is deciding on which method to use. There are a broad range of tools and methods, each of which have their benefits and challenges. NARUC characterizes the different types of tools and methods in two categories: bottom-up approaches and economy-wide approaches (Rickerson et

Table 2. New and Pending Resilience Valuation Approaches

Method/Tool	Developers	Advantages and New Additions	Available
Interruption Cost Estimator 2.0 Tool	• Lawrence Berkeley National Laboratory • Edison Electric Institute	• Updated calculations of power interruption costs. • New willingness-to-pay surveys that will populate the tool with more recent data and more geographic specificity for power interruption cost estimates. • New data on customer responses to longer-duration power interruptions.	Expected 2023
Customer Damage Function Calculator Tool	• National Renewable Energy Laboratory	• Helps individual facilities (or groups of similar facilities) calculate power interruption costs, based on the specific losses that they project will occur. • Guided questions lead facilities through their own assessments. • Graphical summary of initial damage costs, and costs over time.	2021
Social Burden Method	• Sandia National Laboratories • University of Buffalo	• Provides a metric for the social burden of power outages that emphasizes the needs of communities during power outages, instead of emphasizing protecting critical infrastructure for its own sake. • Adopts a more neutral treatment of the willingness to pay vs. the ability to pay for resilience.	Pilot 2021-2022
FEMA Benefit-Cost Analysis Tool	• Federal Emergency Management Agency	• Provides quantitative values for lost emergency services, such as police, fire, and emergency medical response. • New pre-calculated values specifically for hospitals published in 2021. • The use of FEMA values aligns with the application requirements of FEMA grant programs.	2021
Power Outage Economics Tool (POET)	• Lawrence Berkeley National Laboratory • ComEd	• Estimates the economic impacts of longer-duration power outages. • Takes into account how utility customers adapt their behavior during longer duration power interruptions. • Uses surveys of utility customers to collect data on how they would actually behave during a power outage.	Pilot 2021-2022

al., 2019). Bottom-up approaches assess the value of resilience based on customer behavior or site-specific factors, whereas economy-wide approaches measure how power interruptions affect economic performance in one or more sectors across a defined region. During the past several years, U.S. national laboratories and other stakeholders have advanced and improved both bottom-up and economy-wide approaches. For this report, NARUC and CSL reviewed recent and ongoing efforts to quantify the value of avoided power interruptions through regulatory review, literature review, and interviews with experts. This section summarizes the findings of this review and highlights some of the promising new practices that are being developed to address the limitations of current methods.

Table 2 summarizes several of the recently released or forthcoming value or resilience tools and methods. The table summarizes the advances and advantages represented by each tool and method, as well as whether the tools are currently available or under development. It is important to note that the outputs generated by each of these tools will be useful to different audiences in different ways. State energy offices, for example, may use the outputs from these approaches to evaluate the cost-effectiveness of microgrid programs, incentive levels for specific classes of customers, and/or the cost-benefit of specific microgrid projects. State regulators may use the outputs of these approaches to evaluate the reasonableness of proposed utility investments in microgrid programs or projects.

Some of the methods and tools calculate numbers related to the value of avoiding power outages for utility customers, which may be useful to both State Energy Officers and regulators. Some of the methods and tools, however, calculate economic damages expressed in terms of, for example, lost output, earnings, and jobs. As explored in recent NARUC research, some regulators can consider economic benefits as part of their decision making, whereas regulators in some states are not statutorily allowed to do so (Zitelman & McAdams, 2021).

3.1 Bottom-Up Approaches

Bottom-up approaches to quantifying the value of avoided power interruptions include stated preference and revealed preference methods. The most common stated preference method uses surveys that ask respondents to share the dollar amount that hypothetically represents their willingness-to-pay for better service or a willingness-to-accept a payment for less reliable service. Revealed preference methods use real-word data to infer a valuation based on the costs incurred or experienced during a power interruption. This section focuses on recent advances related to survey-based methods, such as the U.S. DOE's ICE Calculator, the Customer Damage Function (CDF) Calculator, and social burden metrics that seek to more accurately reflect community needs during power outages. This section also reviews updates to the damage cost method used by the Federal Emergency Management Agency (FEMA).

3.1.1 U.S. DOE Interruption Cost Estimation (ICE) Calculator Tool

The ICE Calculator is a free, publicly available tool that is considered an industry standard for estimating costs of shorter duration (≤24 hours) power interruptions. The ICE Calculator is based on aggregated customer interruption cost survey data from 34 studies of 105,000 electricity customers, completed between 1989 and 2012 (Sullivan et al., 2015; 2018). Policy makers, utilities, and researchers use the ICE Calculator to analyze and justify a broad range of programs and investments (LBNL, 2015a; 2015b). In 2020, for example, the CPUC (2020), cited the use of the ICE Calculator in relation to the PSPS, and RMI used the ICE Calculator for a statewide analysis of how resilient solar and storage in California could mitigate wildfire-related outages (Dyson & Li, 2020). In Michigan, Consumers Energy included ICE Calculator outputs in a benefit-cost analysis framework for its 2021 Electric Distribution Infrastructure Investment Plan (Consumers Energy, 2021). Although it is a powerful and flexible tool, the ICE Calculator has several limitations:

1. **Specific use cases:** The ICE Calculator provides dollar values associated with power outages for three customer classes: residential, small commercial and industrial (C&I), and medium and large C&I. These

categories do not differentiate by specific industry sectors. As a result, the ICE Calculator results may not accurately reflect the actual avoided outage costs of specific building types, such as data centers.

2. **Geographic coverage:** The ICE Calculator is based on surveys conducted within the service territories of 10 utilities primarily on the West Coast and in the Southeast. As a result, the data are not "statistically representative for all regions of the U.S." (LBNL, 2021).

3. **Data vintage:** Some of the survey data on which the model relies are more than 20 years old and do not reflect some major changes in end use (e.g., remote work from home for residential customers, digital controls for large manufacturing customers).

4. **Outage scale and duration:** The ICE Calculator is intended to estimate the direct costs of power outages that are 24 hours or less in duration, and is not appropriate for estimating the costs of widespread and longer-duration power interruptions

In August 2020, Lawrence Berkeley National Laboratory (LBNL) and the Edison Electric Institute (EEI) launched the ICE Calculator 2.0 initiative to update the underlying survey data, thus addressing the issues of geographic coverage, data vintage, and outage duration (Larsen, 2021). LBNL will conduct new surveys within the service territories of participating EEI member (investor-owned, PUC-regulated) utilities. The goal is to conduct surveys in at least 20 utility distribution service territories across each of the nine U.S. Census subregions. The research team intends to ask questions as part of the national survey to understand how business and residential customers across different regions respond when confronted with longer duration outages (> 24 hours). LBNL expects to complete most surveys by the end of 2022 and to release an updated and upgraded version of the ICE Calculator in 2023.

3.1.2 Customer Damage Function (CDF) Calculator Tool

The CDF Calculator was developed by NREL, with funding from the U.S. DOE's Federal Energy Management Program (NREL, 2021). The CDF Calculator is intended to serve as a resource for facilities to understand the costs incurred during a grid outage. The Calculator provides facilities with step-by-step guidance for estimating their own interruption costs, rather than using outage data aggregated into broad customer categories. The Calculator prompts users with questions about the initial costs, spoilage costs, and incremental costs they experience during an outage, and how those costs vary over time. Initial costs occur immediately when power is lost (e.g., damage to machinery), spoilage costs include one-time losses such as rotten food or steel cooling during manufacturing, and incremental costs accumulate for each hour that power is off (e.g., lost staff productivity or lost revenue). The Calculator graphically shows outage costs as a function of outage duration. This information is intended to help facilities estimate their value of resilience as the potential avoided costs associated with resilience investments. The CDF Calculator outputs allow sites to conduct cost benefit analyses for resilience upgrades, such as calculating the resilience benefits of a microgrid system, providing justifications for investments for enhancing energy security, and informing decision-making based on the cost of inaction.

3.1.3 Social Burden Method

One weakness of survey valuation approaches is that, depending on the method used to qualify the answers, the answers given by customers may be more reflective of their ability to pay than their willingness to pay for resilience. In other words, these methodologies may not accurately account for wealth disparities and the importance of electricity to human health and safety, potentially resulting in investments being disproportionally located in higher-income neighborhoods that can express a higher ability to pay for resilience. Subsequent outages would thus have a more detrimental effect on those in lower-income neighborhoods. The social burden method uses a "capabilities" method for defining and valuing critical infrastructure outside of customer willingness to pay, which focuses on the services each critical infrastructure provides (e.g., refrigeration for storing food and medicine), rather than a static de facto valuation of the infrastructure itself (Day et al., 2016). This approach deemphasizes protecting critical infrastructure for its own sake and focuses instead on maintaining the delivery of the services considered most valuable to society, even if only part of the system can function or if the infrastructure systems are used in unconventional ways (Clark et al., 2018). With the capabilities method in mind, Sandia National Laboratories (Sandia) and its partners at the University of Buffalo developed a metric for the social burden of power outages. This method better includes the needs and goals of communities within infrastructure planning with a more neutral treatment of ability to pay for resilience. Sandia and the University of Buffalo have applied the social burden of power outages method in two projects to date.

In the earliest application, Sandia applied social burden to a process for siting and sizing microgrids across Puerto Rico as a major piece of U.S. DOE's investment recommendations following hurricanes Irma and Maria (Jeffers et al., 2018). More recently, through the U.S. DOE Grid Modernization Lab Consortium (GMLC) "Designing Resilient Communities" project, Sandia and the University of Buffalo teamed up to combine survey-driven and mode-driven approaches to using the social burden metric to site microgrids for community resilience. Sandia and the University of Buffalo conducted surveys of utility customers in the Caño Martín Peña communities of Puerto Rico, to assess and rank the critical services that were most difficult to obtain during Hurricane Maria. The surveys used the time and the cost to replace the lost services as proxies for the "social burden" imposed by the power outages.

Research is ongoing, and the initial findings indicate that the most valuable disrupted activities were storing and obtaining food and medicine, and the service with the greatest well-being impact was refrigeration (Peterson et al., 2021). Sandia used the community research to build and calibrate models of the food, medicine, health care, and water systems, and used the results to develop a quantitative social burden metric as well as an associated computational model to calculate this metric for outages of specified extents and durations. This metric was then used to identify and quantitatively optimize potential microgrid locations that could reduce the social burden of power interruptions for Puerto Ricans (Jeffers et al., 2021).

3.1.4 FEMA Benefit-Cost Analysis Toolkit

The Federal Emergency Management Agency (FEMA) provides a broad range of grants to support pre- and post-emergency and disaster investments in infrastructure, facilities, planning, and research under its Hazard Mitigation Assistance (HMA) programs. Some of the FEMA HMA programs, such as the Hazard Mitigation Grant Program and the Building Resilient Infrastructure and Communities (BRIC) Program can provide funding for back-up power systems, including microgrids (Cramer, 2021).

FEMA requires grant applicants to demonstrate project cost-effectiveness by completing a benefit-cost analysis using the FEMA Benefit-Cost Analysis Toolkit calculator (FEMA, 2021a). The Toolkit calculations automatically include "loss of service" values for facilities such as fire stations, police stations, and hospitals. Based on factors such as the number of people served by the facility, and the distance between the facility and alternative facilities that could provide the same service, the Toolkit assigns additional benefits to the project (FEMA, 2009). The benefits are based on pre-calculated

Text Box 4: NY Prize Resilience Valuation

NYSERDA's NY Prize project awarded funding for microgrid feasibility studies to 83 communities. The communities completed a benefit-cost analysis of the proposed microgrids as part of the studies. As part of the analysis, communities were asked to calculate the benefits of averting a major power outage using results from the ICE Calculator (Section 3.1.1) to estimate the value of avoided power interruptions for commercial and industrial customers. The NY Prize benefit-cost model also calculates the benefit of sustaining emergency services for facilities such as fire stations, police stations, and hospitals (Section 3.1.4). For community microgrids that support both private sector loads and public sector services, the NY Prize method uses a unique combined approach, adding together the values generated by the ICE Calculator with the FEMA values to capture a broader value of resilience reflective of customers and society.

values (e.g., for loss of life, for direct financial losses to property) (FEMA, 2011). Some states have used the FEMA loss of service values as art of their valuation of avoided power outages. NYSERDA's NY Prize microgrid program, for example, included the loss of served values as part of project feasibility analyses (see **Text Box 4**).

In 2021, FEMA released new guidance specifically for calculating the benefit of hospital generator projects. Hospitals with emergency departments can use a pre-calculated benefit to demonstrate cost-effectiveness in lieu of completing the full benefit-cost analysis. The pre-calculated benefit is $6.95 per hospital building square foot in urban areas and $12.62 per square foot in rural areas (FEMA, 2021a). The rural value is greater than the urban value, which reflects the greater average distance to the next nearest hospital in rural areas. If the total cost of the back-up power system is less than the total pre-calculated value, FEMA considers the project to be cost-effective. Just as with the loss of service values, states may opt to incorporate FEMA's pre-calculated values for specific facility types into their value of resilience calculations.

3.2 Economy-Wide Approaches

There are several different types of economy-wide approaches for estimating the economic impacts of power outages (Sanstad, 2016)—or the value of avoiding them in the first place. These approaches can estimate the broader direct and indirect impacts on regional economies using mathematical descriptions to represent and simulate the behavioral responses of consumers and producers to changes in prices, regulations, and external shocks in interrelated markets. Unlike customer interruption cost surveys, regional economic models are well-suited for outages longer than 24 hours since: (1) they can reflect the non-linear impacts that can occur as the effects of power interruptions cascade across sectors and (2) they do not rely on the customer's experience (or lack of experience) with widespread and long-duration outages.

NARUC's 2019 publication, *The Value of Resilience for Distributed Energy Resources: An Overview of Current Analytical Practices*, reviewed four distinct economy-wide approaches that had been used to calculate the value of avoided power interruptions. Three of the four economy-wide methods—computational general equilibrium (CGE) models, macro-econometric methods, and input-output models—measure economic output, employment, and/or financial flows and transfers associated with power outages within a specified geographic area. At the time the report was written, only input-output modeling had been used to analyze resilient DER investment as part of New York State's NY Prize Program. **Text Box 5** summarizes the approach taken in New York, and the findings of a study to compare bottom-up and economy-wide approaches.

Since the publication of the 2019 NARUC value of resilience report, researchers and utilities have been leading an effort to use bottom-up methods in tandem with CGE models to value avoided power interruptions. Historically, bottom-up, survey-based methods and economy-wide approaches have been viewed as belonging to separate and distinct schools of thought (Larsen et al., 2019). LBNL recently developed a new hybrid valuation method that combines the advantages of both approaches into a single framework (Baik et al., 2021). This section

Text Box 5: NYSERDA Comparison of Bottom-Up and Economy-Wide Approaches

NYSERDA also commissioned a separate input-output modeling study of one of the NY Prize communities to quantify the economic losses that the proposed microgrid could avoid. One of the goals of the study was to compare the results of the economy-wide, input-output analysis with the combined bottom-up approach contained within the NY Prize benefit-cost model. The study found that the results of the economy-wide and benefit-cost model approaches were close: the ICE Calculator and emergency services calculation resulted in a combined value of $9.7 million to avoid a one-day outage; the economic analysis found a regional impact of $5 million in sales and $3.1 million in regional GDP from a one-day outage. The study also found, however, that "the regional economic benefits are distinct from, and not a substitute for or add to, the resiliency benefit values provided" by the benefit-cost model (IEc, 2018, p. 19).

provides a high-level description of the hybrid approach and an overview of its application for microgrid evaluation in Chicago.

3.2.1 Hybrid Valuation Approach

The foundation of the hybrid approach is a computational general equilibrium (CGE) model. CGE models are able to reflect responses to disruptions over time, and can be used, for example, to model the impact of how utility customers adapt their behavior during longer duration power interruptions. A disadvantage of CGE, however, is that the parameters in the model that reflect consumer behavior are not well-grounded in empirical data. The hybrid approach seeks to address this limitation by using surveys to assess residential and C&I utility customers' adaptive behaviors during power interruptions. These results can then be used to calibrate the CGE to better estimate regional economic costs (Baik et al., 2021), although PUCs and State Energy Offices have not yet used the hybrid approach in practice.

3.2.2 Power Outage Economics Tool (POET) Pilot

ComEd is currently working with LBNL to demonstrate a hybrid valuation approach under an initiative called the Power Outage Economics Tool (POET) (Aguilar et al., 2021). As discussed in Section 2, ComEd developed a set of 58 resilience metrics relevant to microgrid development as part of its involvement in the Bronzeville microgrid. The ICC approved the microgrid as a pilot and did not weigh a specific value of resilience as part of its decision making. Under POET, LBNL and its partners are surveying customers within ComEd's service territory to assess, among other things, the costs faced by residential and non-residential customers during longer-duration, widespread power outages. The results of the survey will then be used to calibrate a regional economic model that can estimate the direct and indirect costs of a power outage originating from within ComEd's service territory (Aguilar et al., 2021). The model will be able to characterize the economic impacts of an outage not only within the Chicago area, but also within the state and across the country in places where the Chicago economy has significant linkages.

POET would also enable ComEd and stakeholders to assess how additional grid investments or expanded microgrid capacity might avoid future economic losses. As part of the POET effort, LBNL is building a simple-to-use, online tool to analyze the impacts of interruptions within ComEd's service territory. The successful demonstration of the POET concept—along with information collected as part of the ICE Calculator 2.0 initiative—could facilitate expansion of this tool's capabilities to other service territories.

3.3 Remaining Gaps

Growing Field of Research: Although several of these approaches are not yet finalized for immediate use in a regulatory proceeding or state program, they offer valuable opportunities for collaboration in shaping resilience valuation approaches that meet the needs of state decision-makers. State energy offices may find the social burden and POET initiatives to be especially relevant to their missions, as these approaches reflect economic growth and community needs. Developing and producing these approaches is a time- and resource-intensive process, and State Energy Offices, regulators, utilities, and other stakeholders will need to invest their own time and effort in adopting, applying, and improving these approaches to reflect state needs. Providing feedback from real-world applications to continually improve valuation approaches is critical.

Data Availability: The ability to reflect the costs of long-duration outages resulting from HILF events remains difficult due to limited customer experiences and lack of data captured from past events. As HILF events such as Winter Storm Uri and Hurricane Ida continue to occur, contributors to resilience valuation approaches should consider the use of surveys to gather data from customers on the economic impacts of outages exceeding 24 hours in duration. Improved ability to quantify the impacts of long-duration outages is highly important to State Energy Offices and regulators as they consider resilience investments.

Scope of Benefits: Quantifying non-energy societal benefits, such as reductions in mortality, crime, or property damage, as well as community equity benefits are weaknesses for most of the valuation methods in progress (Baik et al., 2021). Moreover, even if quantified, it is unclear how some of these benefits could be factored by State Energy Offices and PUCs into cost-benefit analysis of proposed microgrid investments. Tools to estimate social and equity benefits are likely to be more useful to more granular decision-makers, including individual facility owners and non-governmental organizations, in guiding microgrid investments. Efforts to define and incorporate social equity and energy justice into State Energy Office and PUC processes are in progress in a small number of states, including Washington, Massachusetts, Minnesota, and California. As energy offices and regulators begin to articulate how equity considerations may help to guide future decisions, resilience metrics can be adapted or developed to reflect these aspects.

4. State Actions to Facilitate Resilient Microgrid Investments

While valuing resilience is often imprecise and difficult given current tools and methods, some approaches in development offer hope. Improving how PUCs and State Energy Offices value resilience will lead to more investments in resilience technologies such as microgrids and better outcomes for ratepayers, taxpayers, and society. With this goal in mind, PUCs and State Energy Offices in several states have taken important steps forward by establishing policies that address resilience considerations, approving specific resilience projects, managing resilience programs, and incorporating resilience objectives into ongoing electricity planning or energy assessment programs. Strengthening resilience for the electricity system in the states more broadly is often a joint effort by state legislatures, State Energy Offices, and PUCs. The development of the microgrid tariffs in Hawaii and California (Section 4.1.2), for example, stemmed from resilience bills passed by the legislatures. Through forums such as the NARUC-NASEO MSWG, State Energy Offices and PUCs exchange ideas and learn from other states' examples to consider additional resilience needs. That cooperation often translates into legislative actions, regulations, and state programs and policies.

Key examples of PUC actions are summarized in Section 4.1, with State Energy Office examples following in Section 4.2. These states have laid the groundwork to use future resilience valuation tools and methods to improve the use of ratepayer and taxpayer funds for resilience.

4.1 Regulatory Actions

NARUC has tracked microgrids in commission proceedings since 2019:

- In fall 2021, NARUC released a report focusing specifically on military microgrids (Rickerson et al., 2021). The report found that regulators approved military microgrids when the projects have created clear ratepayer benefits.
- NARUC has also tracked the progress of civilian microgrids in regulatory proceedings. A handful of individual microgrid proposals using ratepayer funding have been approved as pilots by PUCs, with regulators either (a) citing other project benefits to ratepayers (i.e., peak demand savings, frequency regulation, peak capacity, renewable generation) and/or (b) expressing caution about approving similar future projects without more explicit quantification of resilience benefits to customers.

Several regulatory proceedings have demonstrated these principles in practice, illustrated by examples below.

4.1.1 Regulatory Decisions on Microgrid Investments

Duke Energy Hot Springs: In May 2019, the North Carolina Utilities Commission (NCUC) approved Duke Energy's request for a microgrid consisting of a 2-MW solar installation and a 4-MW battery storage facility in Hot Springs, North Carolina, a rural community located at the end of a 10-mile feeder line prone to outages (NCUC, 2019). Duke Energy claimed the project would improve reliability in Hot Springs and provide "energy and additional bulk system benefits for all customers," including frequency and voltage regulation, ramping support, and peak capacity. The NCUC approved the project as a pilot, noting interest in quantifying system benefits:

> "Though it is not clear that the Hot Springs Microgrid is the most cost effective way to address reliability and service quality issues at Hot Springs, the overall public convenience and necessity would be served by granting the certificate for the solar facility and approving the Hot Springs Microgrid as a pilot project. The system benefits from the Hot Springs Microgrid are material but are difficult to quantify accurately without real world experience in DEP's service territory. DEP will gain valuable experience by operating the Hot Springs Microgrid, and this experience and data collection and analysis will be beneficial in future cost-benefit analyses of projects with that proposed to include an energy storage component" (NCUC, 2019).

The project began construction in summer 2019 and started operating in September 2020. Along with other Duke Energy projects, results will feed into a DOE-funded effort to document resilience investments led by the Energy Group of the North Carolina Department of Environmental Quality, the North Carolina Clean Energy Technology Center at North Carolina State University, and the Energy Production and Infrastructure Center at the University of North Carolina – Charlotte, with technical support from the utility (Abdelrazek, Whisenant, & Mazzola, 2019).

Marcus Garvey Apartments: In 2014, the New York Public Service Commission (PSC) approved an application from Consolidated Edison (ConEd) to develop non-wires solutions for Brooklyn and Queens customers, setting aside up to $200 million in ratepayer funds in 2014 to support a range of investments to lower demand in outage-prone areas (NY PSC, 2014). Under this Brooklyn Queens Demand Management (BQDM) program, ConEd proposed 1.1 MW of solar PV, 300 kW / 1.2 of MWh battery storage, and 400 kW of natural gas fuel cells to be installed on a set of affordable housing apartment buildings. The solar and storage assets operate during blue sky conditions to decrease peak demand and further ConEd's renewable generation procurement goals. During an outage, all resources would power offices, security, and an emergency shelter for the apartments (Kallay et al., 2021c). Resilience benefits were not quantified. However, because the project met the needs of the BQDM program, the PSC approved the use of ratepayer funding to support the project, along with other revenue streams from the solar, storage, and fuel cell resources. The project began operating in April 2017 and earns nearly $136,000 each year in demand response revenues from ConEd and the New York Independent System Operator (ACEEE, n.d.).

4.1.2 New/Emerging Microgrid Tariffs

While methods to value resilience continue to develop, PUCs are creating pathways to enable resilience investments by regulated utilities. In California and Hawaii, PUCs approved microgrid tariffs for investor-owned utilities in response to state legislation.

California: Senate Bill (SB) 1339 led to the CPUC's initiation of a multi-track rulemaking to facilitate the deployment of microgrids while avoiding cost-shifting (CPUC, 2021). In January 2021, the CPUC voted to order California IOUs to:

1. Allow microgrids to serve critical customers on adjacent parcels (up to 10 projects per utility)
2. Form new microgrid tariffs
3. Develop a Microgrid Incentive Program
4. Develop pathways to approve low-cost, reliable electrical isolation methods (CPUC, 2021)

PG&E developed a community (front-of-meter) microgrid enablement tariff (CMET), authorized by the CPUC in June 2020, and the CPUC finalized a behind-the-meter microgrid tariff. The front-of-meter tariff supports microgrids up to 20 MW connected to one or more critical facilities and at least one additional customer. Projects must be located in high fire threat districts as defined by the CPUC in a 2017 decision (CPUC, 2017), areas affected by past PSPS outages, or other outage-prone areas. In October 2021, CPUC staff accepted modifications to the CMET proposed by PG&E, including expanded eligibility criteria to make the tariff available to a broader set of resilience projects (Randolph, 2021).

The CPUC's behind-the-meter tariff creates regulatory identification of microgrids in utility tariffs, establishes a statutorily defined microgrid entity, and makes existing net metering (NEM) tariffs available to combined resources meeting the SB 1339 definition of a microgrid. This approach uses existing NEM rules to compensate the use of battery storage and renewable generation in microgrids (Tse & Steingass, 2021). In a future phase, CPUC intends to develop a multi-property, multi-customer microgrid tariff to facilitate the development of Level 3 microgrids.

Hawaii: In May 2021, Hawaii regulators approved a microgrid services tariff (Hawaii PUC, 2021) in response to Act 200, outlining rules for customer microgrids, where customers own all generation, storage, distribution, and related infrastructure to supply their own energy needs, and hybrid microgrids, in which customers provide some or all of their own energy through customer-owned generation while using some utility-owned distribution infrastructure to provide power (HECO, 2021). In approving the tariff for hybrid microgrids, the PUC cited improved ability for customers to use utility infrastructure as an important benefit and predicted the tariff would lower deployment costs (Okabe, 2021). In a future proceeding, the PUC will consider compensation streams for nonemergency services provided by microgrids.

Regulatory staff in California and Hawaii noted that the approved tariffs do not incorporate a value of resilience, citing shortcomings of currently available quantification approaches and lack of stakeholder consensus on which method to use. Future rulemakings could adopt or modify one or more of the new approaches detailed in Section 3.

Where regulators have not approved statewide tariffs, utilities are experimenting with offering "resilience as a service" programs for regulatory approval, developing pathways for customers to voluntarily pay for microgrids and other resilience investments that the utility would ultimately own and operate. These approaches adopt the power purchase agreement model popular in the solar industry by making resilience available to customers willing and able to pay a premium for added infrastructure. This approach recognizes customers' ability to assess their own value of resilience and avoids the need to pass costs of resilience investments on to non-participating customers through rate base.

Wisconsin: Northern States Power Company (NSPW), a subsidiary of Xcel Energy operating in Wisconsin, submitted a request in December 2020 to the Wisconsin PSC seeking regulatory approval for a resilience as a service (RaaS) pilot program enabling investments in microgrids (specifically, on-site generation, battery storage, and control equipment) for participating customers. Citing customers' desire for increased resilience, the pilot calls for NSPW ownership, installation, operation, and maintenance of behind-the-meter energy storage and generation assets. NSPW proposed an initial limit of 30 MW of storage and generation resources under the program, owned by the company for ten years before transfer to the customer. During the 10-year period, customers would pay a resilience charge for NSPW-owned storage and generation assets providing dispatchable power to customers during grid outages. Storage and generation assets may deliver multiple benefits to participating customers beyond back-up power including peak demand reduction, energy arbitrage, reduced energy purchases, and frequency/voltage regulation (Xcel Energy, 2020). The program is structured to solely support behind-the-meter assets and excludes projects that serve customers across multiple meters. NSPW cites "community critical infrastructure support" as a benefit of the program; however, limited applicability to Level 1 and Level 2 microgrids hinders the development of "town center" microgrids across multiple meters. In July 2021, the Wisconsin PSC approved the proposal in Docket 4220-TE-106 (Wisconsin PSC, 2021b).

4.2 Policy Actions

There are several specific policy actions that State Energy Offices have taken to spur investment in resilient microgrids and to ensure that all customers are getting access to the potential benefits of microgrids, including electricity cost savings, peak power curtailment, and renewable energy. Renewable energy microgrids improve air quality, boost grid efficiency, and help states reach their decarbonization goals by increasing the distribution system to incorporate more distributed energy resources. State Energy Offices can implement policies, advise governors and legislators, invest in technological research and development, conduct feasibility studies, develop supportive programs, and facilitate investments through various financing mechanisms. These tools are particularly relevant as states look for ways to modernize and upgrade their electric grid to make it more resilient and reliable. It is especially important for states to attempt to value the resilience benefits of microgrids when considering what policies, programs, and projects to develop and support. Several actions are outlined below with examples from Massachusetts, Connecticut, Minnesota, Wisconsin, Oregon, Puerto Rico, New Jersey, North Carolina, and New Mexico.

State Energy Offices are responsible for developing comprehensive state energy plans that look at energy supply, existing policies, and challenges and opportunities around new and emerging technologies (NASEO, n.d.). State Energy Offices also often spearhead the development of state energy security plans that focus on planning for and responding to energy disruptions and other energy emergencies. Information that is included in a state energy plan or energy security plan may be elevated to higher levels of state government and can support legislative action.

For example, the **Massachusetts** Department of Energy Resources (DOER) released a comprehensive energy plan in 2018 that included a goal for the state to "promote microgrids to provide greater overall grid resiliency and reduce transmission and distribution costs from building out the grid to meet new demand" (Massachusetts DOER, 2018). In 2018, Massachusetts DOER was given authority by the governor to establish a Clean Peak Energy Standard that provides new incentives for microgrids and additional sources of revenue for local communities (Maloney, 2019). In addition, the Massachusetts state legislature funds the Massachusetts Clean Energy Center (MassCEC), which supported 14 feasibility assessments of microgrids across the state at hospitals, emergency centers, affordable housing complexes, wastewater treatment facilities, and other critical infrastructure locations for increased energy resilience in a Community Microgrids Program (MassCEC, n.d.). The MassCEC Clean Energy and Resiliency (CLEAR) Program is the successor to the Community Microgrids Program and kicked off in September 2020 (MassCEC, n.d.). Although the MassCEC is an independent state agency, DOER serves on the board of directors and provides designation to MassCEC for verification of renewable energy credits (MassCEC, n.d.).

Valuing the resilience benefits of microgrids will further spur investment in these advanced technologies. The **Connecticut** Department of Energy and Environmental Protection (DEEP) state energy plan supports the integration of microgrids to meet resilience goals in Connecticut and in support of the state energy security plan. The plan specifically references DEEP efforts to "continue outreach on the value...of community microgrids" (Connecticut DEEP, 2018). DEEP will do so by advocating for supportive legislation, reaching out to municipal employees and officials, and providing funds for the development of microgrids (Connecticut DEEP, 2018). Although placing a value on resilience benefits is challenging, a recent agreement between San Diego Gas & Electric and Marine Corps Air Station Miramar demonstrates the potential benefit when that value is recognized. The agreement includes a Summer Generation Availability Incentive that requires the air station to provide the utility with 6 MW of generation from their microgrid during weather emergencies (Cohn, 2021). The air station would be paid for by the benefit the microgrid provides to the greater electric grid and the utility's customer base (Cohn, 2021). State Energy Offices can look to develop similar policies in their states and formulate programming that includes financial incentives for microgrids based on their resiliency benefits to customers not directly connected to the microgrids.

In August 2019, after a multi-year, multi-stakeholder grid modernization initiative in **Washington, DC** known as Modernizing the Energy Delivery System for Increased Sustainability (MEDSIS), the District of Columbia Public Service Commission launched a PowerPath DC governance board with participation from the District Department of Energy and Environment and other stakeholders (DC PSC, 2019). Using $21 million in funding from the Pepco-Exelon merger, the governance board was charged with overseeing innovative pilot projects aligned with the PSC's vision for grid modernization. As of September 2021, the PowerPath governance board was still selecting projects for funding under the program. In January 2020, as another result of the MEDSIS proceeding, the PSC opened a proceeding on microgrids "to further investigate microgrid ownership and operation structures, business models and value propositions, benefits and costs of microgrids [including factors such as safety, reliability, and resiliency], the different microgrid variances which lead to appropriate microgrid classifications and regulatory treatments" (DC PSC, 2020).

One initial step that can be helpful in valuing resilience benefits is by developing state-wide definitions of the terms "microgrid" and "resilience." State Energy Offices, including the **Minnesota** Department of Commerce's (DOC's) Energy Division, are developing statewide, universal definitions of microgrids, as doing so would better enable project development and make policy language more consistent (Minnesota DOC, 2018). In California, legislation passed in 2018 that directs the CPUC and **California** Energy Commission (CEC) to further develop supportive microgrid policies and defined a microgrid as an:

> "Interconnected system of loads and energy resources, including, but not limited to, distributed energy resources, energy storage, demand response tools, or other management, forecasting, and analytical tools, appropriately sized to meet customer needs, within a clearly defined electrical boundary that can act as a single, controllable entity, and can connect to, disconnect from, or run in parallel with, larger portions of the electrical grid, or can be managed and isolated to withstand larger disturbances and maintain electrical supply to connected critical infrastructure" (California Legislature, 2018).

Beyond looking for ways to value resilience benefits, State Energy Offices can develop programming and utilize funds, including State Energy Program (SEP) funds from the U.S. DOE, that encourage specific investment in resilient microgrids in their states and regions. The bipartisan Infrastructure Investment and Jobs Act (IIJA) was signed into law in November 2021 and includes $500 million in additional funding for the SEP. State Energy Offices will be able to use these funds to continue and begin valuable work on energy system resilience efforts that include microgrids. One example of SEP funds being used for resilient microgrids was in **Wisconsin**. The Wisconsin Office of Energy Innovation (OEI) recently began a Critical Infrastructure Microgrids and Community Resilience Center (CIMCRC) pilot grant program. The strategic objectives of the program center around energy security and clean energy equity, with funding from the first round of applications awarded to 15 recipients, including tribal governments, utilities, the University of Wisconsin system, municipalities, and nonprofit groups. In the second round, SEP-funded feasibility studies will be conducted to determine the applicability of resilient microgrids at these critical infrastructure locations (Wisconsin PSC, 2021a).

As states design policies that facilitate upgrades to the electric grid, **Oregon**, Puerto Rico, and New Jersey provide examples for how State Energy Offices can consider the role resilient microgrids can play in cutting costs and minimizing the need for expanded transmission and distribution capacity. Oregon's Biennial Energy Report was published in 2020 and includes a section on resilient microgrids. In June 2021, the Oregon state legislature passed HB 2021 that included requirements for the Oregon Department of Energy to convene a working group to look at small-scale and community-based renewable energy projects (defined in the bill to include microgrids) and their impacts on local energy resiliency (Oregon Legislative Assembly, 2021).

Another example is **Puerto Rico,** which seeks to improve and upgrade its electric grid. To work toward this goal, the Puerto Rico Department of Economic Development and Commerce, Energy Policy Program, was given sole responsibility for developing a microgrid plan for the territory (McConnell, 2016). The island is prioritizing resilient grid modernization efforts to better withstand natural and manmade disasters.

In New Jersey, the **New Jersey** Board of Public Utilities (NJBPU) facilitated a Microgrid Feasibility Study and published a report that included information on the importance of microgrids for resiliency, specifically in the aftermath of storms such as Hurricane Sandy. The study determined that a town center microgrid can "provide enhanced energy resiliency for critical customers at the local level as well as enhanced reliability and efficiency for usage of the distribution system grid" (NJBPU, 2016), as well as enhanced energy efficiency and renewable energy generation. Thirteen communities received grants to study the possibility of microgrids for their area. The majority of the microgrids in operation in New Jersey have been funded through NJBPU's Clean Energy Program or the New Jersey Energy Resilience Bank, which implemented several microgrid projects for resilience purposes: two at hospitals and one at a wastewater treatment plant (NJBPU, 2016).

One programmatic area for State Energy Offices to focus on is developing funding and financing mechanisms that support research, development, and deployment of resilient microgrids. Microgrid financing policies and programs need to be well defined and structured to include resiliency benefits (Cramer, 2021). Potential financing mechanisms, outlined more fully in NASEO and NARUC's paper *Private, State, and Federal Funding and Financing Options to Enable Resilient, Affordable, and Clean Microgrids* include:

- Energy-as-a-Service
- Energy Savings Performance Contracts
- Commercial Property Assessed Clean Energy (C-PACE)
- State Energy Revolving Loan Funds
- Green Bonds
- Competitive Grants

Recent legislation passed in **North Carolina** authorized the North Carolina Department of Environmental Quality's Energy Group, to oversee the statewide C-PACE program and run the Energy Resilient Communities Fund. The Energy Resilient Communities Fund provides technical assistance for clean energy microgrids, conducts community outreach and stakeholder engagement, and provides communities with opportunities to develop and construct microgrids that support critical infrastructure (North Carolina General Assembly, 2021).

Policy actions are especially helpful when looking to ensure resilience planning includes a focus on equity. Resilient microgrids can be particularly beneficial to disadvantaged and energy-insecure communities. For example, the **New Mexico** Energy Conservation and Management Division (ECMD) within the New Mexico Energy, Minerals, and Natural Resources Department (the State Energy Office) formed a Grid Modernization Advisory Group which looked at low- and moderate-income (LMI) programs to modernize the electric grid. As a result, ECMD recommended creating a legal and financial incentive for rural LMI community microgrids, while also acknowledging the challenge in doing so. A state-run Green Bank was another suggested solution (New Mexico, 2021). The NYSERDA NY Prize outlined earlier encouraged applications from low-and-moderate income communities with proposals outlining the specific benefits to the community (New York, n.d.). Valuing the resiliency of microgrids for low- and moderate-income communities would be an additional opportunity to spur investment and accelerate policy implementation.

The MSWG allows state energy officials to share ideas on policy frameworks and how to structure policy recommendations to remove barriers and foster growth of resilient microgrids. As states look for ways to implement resilient microgrids in their communities, working groups or other collaborative efforts can provide opportunities for states to consider regional approaches in valuing resilience for microgrids, especially as utilities span across multiple states.

5. Considerations for State Energy Offices and PUCs to Move Forward

Understanding when a microgrid is the appropriate tool to enhance resilience and reduce risks is an important initial consideration. When a microgrid is the most suitable solution, valuing the resilience benefits becomes an important focal point for project development. As valuation methods continue to evolve, State Energy Offices and PUCs can take a number of actions to further consider resilience benefits in microgrid investments and other decision-making processes more broadly:

- Use an existing method, recognizing the shortcomings of current options, and consider qualitative methods: Current quantitative methods fail to capture one or more of a range of important factors in valuing resilience. PUCs/State Energy Offices can consider applying a current method to a proceeding, program, or investment, noting that certain benefits could be captured qualitatively to enable some level of consideration, or otherwise would be excluded from the estimate.
- Wait for new approaches to emerge: PUCs/State Energy Offices may delay decision-making until new approaches have been finalized and pilot these methods in different jurisdictions. National Labs and other researchers developing tools and methods welcome feedback, so that weaknesses can be identified and addressed in future iterations.
- Support/encourage utilities to propose valuation methods: utilities may be hesitant to propose a novel valuation method in a regulatory proceeding or program absent explicit direction from regulators/energy offices. Similarly, PUCs/State Energy Offices are hesitant to mandate the use of a particular method given that no single tool is widely accepted nor appropriate for all scenarios and jurisdictions. Utilities and PUCs/State Energy Offices may consider informal, information-gathering/knowledge-sharing proceedings such as investigatory dockets or technical workshops to candidly discuss jurisdictional challenges, strengths and weaknesses of currently available approaches and collective next steps.
- Gather data from the performance of existing microgrids during adverse events to inform valuation efforts: several new approaches rely on real-world performance data to estimate resilience benefits during outages. PUCs and State Energy Offices can consider gathering this data from operating projects, in partnership with utilities or non-utility asset owners/operators and project customers and working with National Labs or other partners to inform future valuation efforts.
- Initiate formal or informal proceedings to hear from stakeholders on how to better define and incorporate resilience into PUC and State Energy Office decision-making: resilience is a reflection of community impacts and benefits, and utilities may not have a complete understanding of these local impacts. PUCs and State Energy Offices could invite community organizations, local governments, individual customers, and others to share how they value and might monetize resilience.

NARUC and NASEO continue to promote sharing of knowledge across states and innovative approaches to common challenges in forums such as the NASEO-NARUC Microgrids State Working Group. Future research may provide updates on resilient microgrid approaches in progress and on lessons learned from initial deployments.

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1101 Vermont Ave, NW • Suite 200 • Washington, DC 20005
www.naruc.org • (202) 898-2200