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National Association of Regulatory Utility Commissioners

The Value of Resilience for Distributed Energy Resources: An Overview of Current Analytical Practices

Prepared for The National Association of Regulatory Utility Commissioners

Prepared by Converge Strategies, LLC

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CONVERGE STRATEGIES

About the Solar Energy Innovation Network

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This paper is written as an input to a broader project by the National Association of Regulatory Utility Commissioners (NARUC) under the Solar Energy Innovation Network (SEIN). NARUC's SEIN project focuses on the value of resilience and its use in state policymaking. NARUC has previously explored the topic of resilience as it relates to electricity regulation (Keogh & Cody, 2013). NARUC has also explored opportunities for improved electric grid resilience in the face of "black sky" hazards that can cause long-duration power interruptions (Stockton, 2014). In parallel, NARUC has developed a manual for state utility regulators on rate design and compensation models for distributed energy resources (DERs) (NARUC, 2016). NARUC's SEIN research builds on these previous efforts by investigating whether and how current state DER policies support resilience objectives. The overall goal of the NARUC SEIN project is to provide state regulators with guidance for taking resilience into account when evaluating investments in DERs.

This report was prepared by Converge Strategies, LLC (CSL), a consulting firm working at the intersection of resilience, advanced energy, and national security. CSL was founded in 2017 and has offices in Boston and Washington, D.C. CSL connects rapidly emerging technologies to the resilience objectives of the military, utilities, and state and local governments. www.convergestrategies.com.

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Acronyms

BCA	Benefit-Cost Analysis
BGE	Baltimore Gas and Electric
CAIDI	Customer Average Interruption Duration Index
CDF	Customer Damage Function
CHP	Combined Heat and Power
ComEd	Commonwealth Edison
CPUC	California Public Utilities Commission
CUNY	City University of New York
DER	Distributed Energy Resource
DG	Distributed Generation
DoD	Department of Defense
DOE	Department of Energy
DR	Demand Response
EE	Energy Efficiency
EPRI	Electric Power Research Institute
ERA	Energy Resilience Assessment
EV	Electric Vehicle
FEMA	Federal Energy Management Agency
ICC	Illinois Commerce Commission
ICE	Interruption Cost Estimate
IDER	Integrated Distributed Energy Resources
IEc	Industrial Economics, Inc.
IEEE	Institute of Electrical and Electronics Engineers
IOU	Investor-Owned Utility
LBNL	Lawrence Berkeley National Laboratory
MIT	Massachusetts Institute of Technology
MW	Megawatt
NARUC	National Association of Regulatory Utility Commissioners
NERC	North American Electric Reliability Council
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
NYSERDA	New York State Energy Research and Development Authority
O&M	Operations and Maintenance
OSD	Office of the Secretary of Defense
Pepco	Potomac Electric Power Company
PSC	Public Service Commission
PSE&G	Public Service Electric and Gas
PV	Photovoltaic
REV	Reforming the Energy Vision
SAIDI	System Average Interruption Duration Index

Executive Summary

Recent extreme weather events, natural disasters, and cyber incursions have brought the vulnerability of the electric system into sharp focus. These events have demonstrated that planning for long-duration power interruptions caused by high-impact, low-probability events will require new approaches to power system resilience above and beyond previous hardening efforts. At the same time, the rapid growth and declining costs of distributed energy resources (DERs) such as microgrids, solar photovoltaics, and batteries have introduced new technology options for energy resilience. Consequently, state policymakers across the country have established electricity resilience policies and programs, with several states focusing specifically on resilient DERs as part of clean energy programs and grid modernization efforts.

Although it is clear that DERs offer resilience benefits, it is unclear how to determine the value of those benefits. Identifying appropriate methodologies to calculate the value of resilience will be an important step toward ensuring that resilient DERs are considered alongside alternatives and integrated into future energy infrastructure and investment planning efforts. This paper reviews current practices for calculating the value of resilience with a focus on valuing resilient DERs installed within the distribution system. It examines both regulatory decision-making and non-regulatory cost-benefit analyses in order to determine if, and how, a value of resilience was calculated and applied. The paper is designed to address questions that utility regulators have identified as being of interest. The questions are listed below, along with the conclusions reached in this report.

Have regulators identified and utilized a value of resilience in regulatory decisions related to resilient DERs?
No. A review of regulatory proceedings was conducted to find instances in which regulators have considered investments in resilient DERs. Three regulatory proceedings—two in Maryland and one in Illinois—were reviewed in detail. In each of these proceedings, resilience was identified as an important potential benefit of DERs, but no specific value of resilience was determined. The regulatory proceedings present qualitative arguments for and against resilience investments, but they do not establish a precedent for quantifying and monetizing resilience.

Is the value of resilience being used to analyze resilient DERs in venues other than regulatory proceedings?
Yes. Decision-makers and analysts have used a variety of methods to quantify the value of resilience for DERs outside of regulatory proceedings. This report examines four case studies in which a value of resilience was incorporated into decision-making—three case studies in New York and one focused on the military. The report reviews the context of the resilience investment, valuation methods used, and results of each analysis.

What are the different methods to value energy resilience?
There are a number of approaches to valuing avoided power interruptions, which is currently the standard proxy for quantifying energy resilience. This report identifies two broad categories of analysis (economy-wide vs. bottom-up). Each category encompasses a variety of data collection approaches (e.g., stated preference vs. revealed preference approaches) and quantitative tools (e.g., ICE calculator, FEMA BCA, and IMPLAN). The four case studies conducted for this report correspond to four different specific methods that have been used to analyze the resilience value of DER: contingent valuation, the defensive behavior method, the damage cost method, and input-output modeling.

What are the pros and cons of different methods used to value resilience?
There is a large body of academic and technical literature on the value of non-market goods. This report does not comprehensively re-examine the pros and cons of different valuation methods. The report focuses specifically on the methods that have been used to analyze the energy resilience value of DERs. The different methods are then evaluated according to usefulness to regulators. The four criteria used in the evaluation include the method's ease of use, scope of outputs, geographic scalability, and power interruption duration analysis capability **(ES-Figure 1)**.

Can regulators adopt or improve value of resilience methods to support their decisions?
Some of the valuation methodologies examined in this report may be useful in regulatory decision-making, but none of the methods reviewed met all four criteria for regulator usefulness and usability. No single method is capable of capturing all regulatory concerns regarding the resilience value of DERs.

ES-Figure 1. Pros and Cons of Selected Resilience Valuation Methodologies

Case Study	Method (Model)	Duration	Scalability	Ease of Use	Outputs
NYC Solar+Storage	Contingent valuation (ICE Calcuator)	🔴	🟢	🟡	🟡
Buffalo Medical Microgrid (NY Prize Stage 1)	Damage Cost (FEMA BCA)	🟡	🟢	🟡	🟡
Rockwell Center Microgrid (NY Prize Stage 2)	Input-output model (IMPLAN)	🟡	🟡	🟡	🟡
Military Microgrids	Defensive Behavior (Generator cost)	🔴	🔴	🟢	🟡

GREEN: The method meets the criteria; i.e., the method can be used to analyze long-term power interruptions, it is readily scalable to different geographic levels, it is relatively easy to use, or its outputs can inform regulatory decisions related to resilience investments.

RED: The method does not meet the criteria; i.e., the method cannot readily analyze long-term interruption durations, it cannot be applied to different geographic scales, it is difficult or costly to use, or its outputs are less relevant to regulatory decision making.

YELLOW: There are pros and cons in terms of how the method relates to the criteria.

Given the lack of precedent from regulatory proceedings and the pros and cons of the models used outside of regulatory proceedings, regulators have several options when attempting to evaluate resilient DER investments:

- Omit consideration of the value of resilience in cost-benefit analysis.
- Utilize decision-making approaches that do not require a resilience benefit to be quantified, such as cost-effectiveness analysis.
- Adopt one of the methods examined in the case studies.
- Adapt other methods that have been used to value avoided power interruptions, but have not yet been used to quantify the resilience value of DERs.
- Actively engage with the ongoing research efforts focused on new approaches to valuation.

Each of these options has its own sets of tradeoffs and potential limitations. The difficulties involved in valuing resilience relate directly to the challenges inherent in analyzing high-impact, low-probability power interruption events. Regulators seeking to evaluate resilience investments will need to grapple with these challenges against the backdrop of increasingly severe threats to the electricity grid.

1. Introduction

During the past two decades, electric utilities have made significant investments in infrastructure hardening following storms such as Hurricane Katrina (2005), Hurricane Ike (2008), and Superstorm Sandy (2012) (Carey, 2014; EEI, 2014). However, recent events such as Hurricane Maria (RPRAC, 2018), Russian cyber incursions against U.S. critical infrastructure (NCCIC, 2018), and record fires in the Western United States (Arango & Medina, 2018; Sterling, 2018) have brought the continued vulnerability of the electric system into sharp focus. These events have demonstrated that planning for long-duration power interruptions caused by high-impact, low-probability events will require new approaches to power system resilience above and beyond previous hardening efforts (National Academies, 2017; Preston et al., 2016). While resilience investments have often been made reactively, the growing risk of high-impact, low-probability events and "black sky hazards[1]" suggests the need to embrace a more proactive planning approach–one that anticipates future threats and invests in new solutions well in advance.

The rapid growth and declining costs of distributed energy resources (DERs), such as microgrids, solar photovoltaics (PV), and batteries, have introduced new technology options for energy resilience. Back-up power systems such as diesel generators or uninterruptible power systems can only supply power for a limited time before they run out of fuel (Energetic Incorporated et al., 2009; Phillips et al., 2016). Conventional back-up systems also typically operate only during power interruptions. New technologies such as resilient solar systems (see Text Box 1) offer distinct advantages over diesel generation, including emissions-free generation, an unlimited fuel supply, and the ability to generate savings and revenue streams when not serving in an emergency power role (Mullendore & Milford, 2015). Although variable energy sources such as solar can also create grid integration challenges,[2] the pairing of variable generation with storage can help alleviate these concerns (Hirsch et al., 2018). This report focuses primarily on opportunities to deploy microgrids and resilient solar (collectively referred to in this paper as "resilient DERs") for critical infrastructure and at critical facilities.

The practice of integrating resilient DERs into resilience planning is still at an early stage. Although it is clear that DERs can offer resilience benefits, it is unclear how to determine the value of those benefits. Identifying appropriate methodologies to calculate the value of resilience will be an important step toward ensuring that resilient DERs are considered alongside alternatives and integrated into future energy infrastructure and investment planning efforts (National Academies, 2017). This paper reviews current practices for calculating the value of resilience with a specific focus on resilient DERs installed within the distribution system.[3]

Text Box 1. Defining Resilient Distributed Energy Resources (DERs)

NARUC (2016) defines a DER as: "a resource sited close to customers that can provide all or some of their immediate electric and power needs and can also be used by the system to either reduce demand (such as energy efficiency) or provide supply to satisfy the energy, capacity, or ancillary service needs of the distribution grid. The resources, if providing electricity or thermal energy, are small in scale, connected to the distribution system, and close to load. Examples of different types of DER include solar photovoltaic (PV), wind, combined heat and power (CHP), energy storage, demand response (DR), electric vehicles (EVs), microgrids, and energy efficiency (EE)."

Although a broad range of DERs can be configured to contribute to resilience objectives, this report focuses primarily on microgrids and on resilient solar—both defined below—which are collectively referred to as "resilient DERs."

- Microgrids are defined as "an integrated energy system consisting of interconnected loads and energy resources which, as an integrated system, can island from the local utility grid and function as a stand-alone system (Judson et al., 2016)."
- Resilient solar is defined as "solar PV systems which can operate during electrical outages, provide emergency power to facilities, as well as provide electricity under normal conditions. The term 'resilient solar' includes technologies such as a solar PV System paired with: 1) battery backup… 2) auxiliary generation such as a diesel generator to reduce fuel needs or a combined heat and power system, 3) an inverter with emergency 'daylight' power outlet (Case et al., 2017)."

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1 According to Stockton (2014), black sky hazards are described as "extraordinary and hazardous catastrophes utterly unlike the blue sky days during which utilities typically operate" "where more than 90% of a utility's customers experience outages of more than 25 days." Black sky events can be triggered by "coordinated cyber, physical, and blended attacks; the electromagnetic pulse effects created by the high-altitude detonation of a nuclear weapon; and major natural disasters like earthquakes, tsunamis, large hurricanes, pandemics, and geomagnetic disturbances (GMD) caused by solar weather."

2 Variable resources such as solar PV may pose integration challenges at the bulk power and distribution grid levels. Issues related to grid integration of variable resources are beyond the scope of this report and can be found in other reports (e.g., Bird et al., 2013; Palmintier et al., 2016; Hirsch et al., 2018).

3 The focus on resilient DER deployment is related to, but distinct from, research into value-based planning for generation, transmission and distribution, and operations (Sullivan et al., 2018). Whereas this paper focuses on smaller-scale generation and storage resources installed in specific locations, value-based planning has focused on costs and benefits of system-wide investments such as hardening distribution infrastructure through undergrounding (Larsen, 2016).

At present, there are no standardized approaches for policy makers or energy project developers to identify and value energy resilience investments at the state, local, or individual facility levels. This lack of standard practice is further complicated by the existence of numerous and ongoing grid resilience discussions focused at different levels of governance (Unel & Zevin, 2018). At the federal level, there continues to be significant debate regarding how best to target resilience investments as a matter of national policy (Palmer et al., 2018; Silverstein et al., 2018). At the same time, state and local governments across the country are exploring energy resilience (NGA, 2016; Sanders & Milford, 2015), whereas institutions such as the U.S. Department of Defense (DoD) are working to assure energy supply to specific critical facilities and loads (Judson et al., 2016; Narayanan et al., 2017; Samaras & Willis, 2013). The utility industry is engaged in resilience investment planning as well (EPRI, 2016); several utility companies have partnered with the U.S. Department of Energy (DOE) specifically on resilience strategies that address the impacts of climate change (U.S. DOE, 2016). Although these ongoing discussions are inter-related, there are currently few practical connection or translation points between them. The field of energy resilience remains highly dynamic and complex.

This paper does not attempt to summarize the energy resilience landscape. It instead focuses on questions related to resilient DER that utility regulators have identified[4] as being of interest:

- Have regulators identified and utilized a value of resilience in regulatory decisions related to resilient DERs?
- Is the value of resilience being used to analyze resilient DER in venues other than regulatory proceedings?
- What are the different methods to value energy resilience?
- What are the pros and cons of different methods used to value resilience?
- Can regulators adopt or improve value of resilience methods to support their decisions?

This paper is structured as follows:

- Section 2 reviews the definitions of resilience and reliability and provides context on state programs to promote resilient DERs;
- Section 3 reviews recent regulatory proceedings that have considered the resilience benefit of DERs;
- Section 4 summarizes and compares the different quantitative methodologies that have been used to characterize the resilience value of DERs and presents case studies of their use outside of regulatory proceedings; and
- Section 5 presents conclusions and recommends next steps.

2. Resilience, Reliability, and State Policy

The concept of reliability is familiar to state regulators, and reliability standards are used to support regulatory decision making across the country. Resilience[5] is closely related to reliability, but the concepts are not identical. This section defines resilience for the purpose of this report and differentiates it from reliability.

2.1. The Definition of Resilience

Many different definitions of the term "resilience" can be drawn from a wide range of disciplines (Martin-Breen & Anderies, 2011). Divergent definitions exist even within the field of power system resilience (Sanstad, 2016; Taft, 2017; IEEE, 2018). This paper uses the definition developed by 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).

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4 These questions were reviewed and refined with state regulators, commission staff, and industry experts from around the country during workshops in 2018 focusing on the "Intersection of Resilience and DERs" hosted by NARUC on August 14 in Scottsdale, Aiz., by PJM on September 27 in Audubon, Pa., and jointly by NARUC and PJM on November 14 in Orlando, Fla.

5 The term resilience is used interchangeably with the term resiliency in the literature. This study uses the term "resilience" unless quoting from a source that specifically uses the term resiliency.

2.2. Resilience vs. reliability

The concepts of power system reliability and resilience are related but distinct in how they are defined and measured. Electric reliability refers to the ability of the power system to "maintain the delivery of electric services to customers in the face of routine uncertainty in operating conditions" (Anderson et al., 2017).[6] At the distribution level, reliability is typically measured and evaluated with indicators such as the System Average Interruption Duration Index (SAIDI), which presents the average power interruption duration for each customer served. State regulators use indicators such as SAIDI to set and track reliability standards, and to penalize or reward utilities for reliability performance.

A major distinction between resilience and reliability is the scale and duration of the power interruptions contemplated. Reliability focuses on preventing disruptions that are "more common, local, and smaller in scale and scope," whereas resilience "addresses high-impact events, the consequences of which can be geographically and temporally widespread" (EPRI, 2016, p. 45). In many states, reliability metrics, such as SAIDI, are used to measure day-to-day reliability performance, and they explicitly exclude major interruption events from their datasets in order to avoid skewing the measurement. As a result, traditional reliability metrics are insufficient for characterizing resilience (Keogh & Cody, 2013).[7] There are a number of organizations that are investigating appropriate metrics for resilience (Murphy et al., 2018), but industry-wide standards do not exist, and there are few examples of resilience metrics use cases (Anderson et al., 2017).

A second distinction between resilience and reliability is that reliability focuses primarily on power interruption prevention, whereas resilience focuses on preserving system function during the period post-event as well. As summarized by the National Academies of Sciences, Engineering and Medicine (National Academies) in *Enhancing the Resilience of the Nation's Electricity System*,

> Resilience is not the same 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 Academies, 2017, p. 10)[8]

The distinctions between resilience and reliability have been delineated in the literature, but they are only beginning to transition from academia into the regulatory process. A recent survey of several state regulatory commissions by Lawrence Berkeley National Laboratory (LBNL), for example, found that the commissions surveyed have not historically distinguished between reliability and resilience during general rate cases or during proceedings dedicated to power interruptions (LaCommare et al., 2017). A notable exception is the Public Service Electric & Gas Company's (PSE&G) Energy Strong Program proceeding in New Jersey following Superstorm Sandy. The New Jersey Board of Public Utilities considered whether and why additional investments in grid hardening were required above and beyond conventional reliability measures. The Board approved an investment of more than $1 billion, with costs to be recovered by PSE&G through a dedicated Energy Strong Adjustment Mechanism. PSE&G is required to report quarterly to the Board on Customer Average Interruption Duration Index (CAIDI) Major Event performance at the circuit, operating area, and system-wide levels (New Jersey Board of Public Utilities, 2014). The Maryland Public Service Commission has also created specific resilience surcharges for two investor-owned utilities (IOUs), and several states have highlighted resilience as a theme in recent distribution system planning proceedings (Homer et al., 2017).

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6 There are differences in the way that reliability is analyzed and measured at the bulk power and distribution system levels (Beasley & Greenwald, 2018); this paper focuses on utility distribution systems.

7 The IEEE (2012) has established voluntary guidance (IEEE Standard 1366) on how to define and track major power interruption events, and a growing number of states are now requiring utilities to track a separate indicator that tracks major events. This practice is not yet standard nationwide (Stockton, 2014; Larsen et al., 2016).

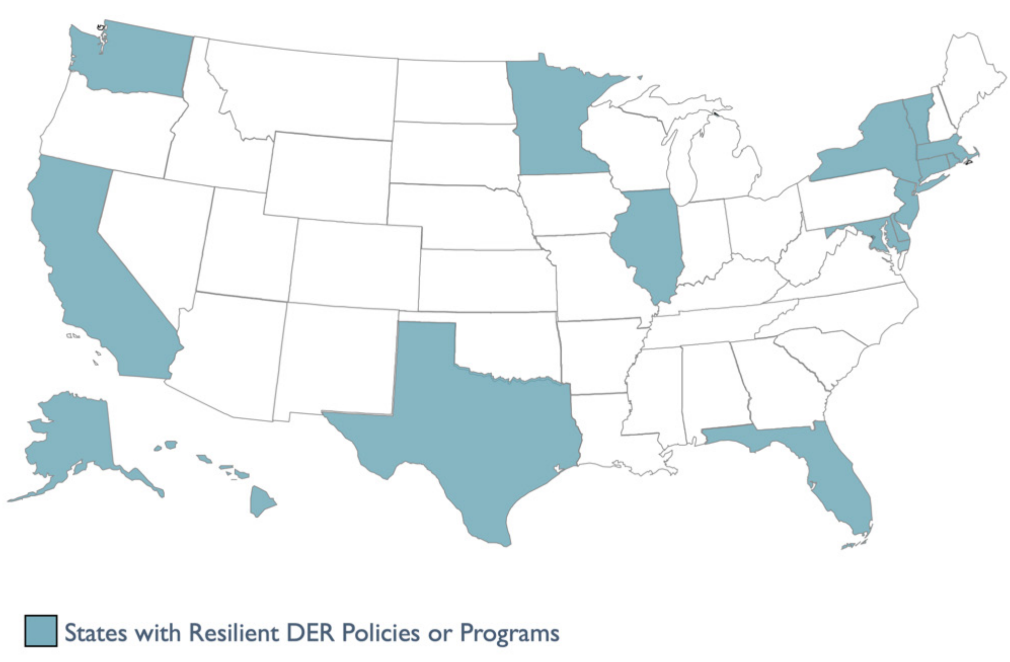
8 There is debate about whether recovery and restoration should be included in the definition of resilience of whether doing so "conflates resilience with reliability." Taft (2017:2) argues that attempts to define and measure resilience should focus on power system architecture and should not combine "grid characteristics with utility response to external events."

2.3. Resilient DERs in state electricity policy making

Resilience is not yet a common or well-defined concept in formal utility regulatory proceedings. State policymakers across the country, however, are moving ahead with electricity resilience policies and programs, with several states focusing specifically on resilient DERs as part of clean energy programs or grid modernization efforts (Olinsky-Paul, 2015). New York State's Reforming the Energy Vision (REV) proceeding, for example, explicitly links the issue of resilience with considerations of DER expansion (NY DPS, 2014). The California Public Utilities Commission (CPUC) recently mandated that IOUs in the state pursue at least one pilot for DERs to demonstrate distribution grid services—including "resiliency (microgrid) services" under the Integrated Distributed Energy Resources (IDER) proceeding (CPUC, 2016, p. 6).[9] The use of DERs for resilience is also a prominent focus of power system reconstruction efforts in Puerto Rico (Siemens, 2018; Toussie et al., 2017). As state-level resilient DER programs expand and mature, regulators in a growing number of states may be required to more frequently consider the intersection of resilience and DERs.

As discussed in Section 1, this paper focuses on resilient solar and microgrids. The number of public sector programs dedicated specifically to resilient solar has been limited to state and local efforts in 16 states: PSE&G is pursuing a resilient solar pilot in New Jersey (Powers & Sherman, 2018); Delaware introduced a solar resilience pilot in 2016 (DESEU, 2015); Florida has installed solar and storage on schools through the SunSmart E-Shelter Program (FSEC, 2018); and both New York City and San Francisco have published resilient solar roadmaps (Best et al., 2017; Case et al., 2017a). A number of states have commissioned formal studies of microgrids (Burr et al., 2013; Celtic Energy et al., 2017; NJBPU, 2016; NYSERDA, 2014; MDRMTF, 2014) and a growing number of states have established policies or programs that support microgrid deployment. **Figure 1** contains an illustrative snapshot of recent resilient DER policy and program development at the state level. As a result of these policies (and other drivers), U.S. resilient DER installations are projected to grow substantially during the next five years.[10]

Figure 1. Resilient DER policies and programs at the state level in the United States.



Source: Olinksy-Paul (2015); Cook et al. (2018); Shea (2016); Converge Strategies research

9 Pacific Gas & Electric Company (PG&E) has indicated that it is studying the feasibility of an IDER Incentive Pilot for resiliency (PG&E, 2018).

10 For example, GTM Research projects that total U.S. microgrid capacity will expand to 7.1 gigawatts by 2023 (Metelitsa, 2018) and that annual storage installations will reach 3.9 GW in the same year (GTM Research, 2018).

The experience of each of these states was reviewed to determine the extent to which state regulators considered value of resilience during the course of formal proceedings. The next section provides overviews of regulatory proceedings in which utility regulators evaluated proposed microgrid investments in Maryland and Illinois.

3. Recent experience with microgrids in regulatory proceedings

Over the past four years, there have been several prominent cases in which utilities have proposed microgrid investments to state public utility commissions. This Section summarizes three recent cases where requests to recover the costs of microgrid investments from ratepayers were considered by state public utility commissions—two in Maryland and one in Illinois—and examines whether or not state regulators considered a value of resilience in their analysis. The proposals are discussed chronologically in the order in which they were filed. **A review of these proceedings illustrates that the Commissions did not consider a specific value for resilience in their decision making and instead focused on other quantified benefits.** The regulatory decisions in each of the three cases were driven by factors other than resilience. A summary of these proposals can be found in **Table 1**.

Table 1. Regulatory Proceedings Regarding Proposed Microgrid Investments by Utilities

Utility	Baltimore Gas & Electric	Commonwealth Edison	Pepco
Proposed Microgrid Location	Columbia, MD (Kings Contrivance) Baltimore, MD (Edmonson Village)	Chicago, IL (Bronzeville)	Largo, MD Rockville, MD
Total Cost	$16.2 million	$12.6 million	$63.7 million
Technologies Included:	**Columbia, MD:** Natural gas (2 MW) **Baltimore, MD:** Natural gas (3 MW)	**Phase 1:** Solar PV (0.75 MW) Battery storage (0.5 MW) Diesel (3 MW) **Phase 2:** Controllable generation (7 MW) (most likely natural gas)	**Largo, MD:** Natural gas (5.6 MW) Solar PV (1.18 MW) Battery storage (1.85 MW) **Rockville, MD:** Natural gas (6.6 MW) Solar PV (0.86 MW) Battery storage (0.25 MW)
Resilience Analysis	Resilience acknowledged as a distinct benefit, but not quantified or valued.	Resilience acknowledged as a distinct benefit, but not quantified or valued.	Pepco calculated "resiliency savings" for microgrid participants using the Interruption Cost Estimate (ICE) tool. The PSC determined that a value for community resilience could not be quantified.
Approved by Regulators?	No	Yes	No
Reasons for Decision	- Reliance on single fuel - Renewables/storage not incorporated - Unequal distribution of benefits to ratepayers. - The concept of a "major event" was not defined	- Community learning benefits justified socialization of costs across ratepayers	- Resilience benefits not quantified - Grants and other funding mechanisms to support project not pursued - Unequal distribution of benefits to ratepayers.

3.1. Baltimore Gas & Electric Company
Maryland Public Service Commission: Case No. 9416

Summary

On December 18, 2015, Baltimore Gas & Electric Company (BGE) filed a proposal for two community microgrid pilots, one in the Kings Contrivance area of Columbia, Md., and the other in Baltimore City at Edmonson Village. The Maryland Public Service Commission (PSC) denied the proposal in an order issued on July 19, 2016 (Maryland PSC, 2016). Although the PSC mentioned resilience as a benefit of community microgrids, the value of resilience was not quantified during the proceedings. The information contained in this section is drawn from PSC Order 87669 unless otherwise noted (Maryland PSC, 2016).

Technology and Costs

BGE's proposed microgrids would have been powered by two natural gas generators – a 2 MW, $7 million microgrid system at Kings Contrivance, and a 3 MW, $9.2 million system at Edmonson Village. BGE proposed to recover costs through a monthly surcharge on its 1.25 million electricity customers – $0.04 per residential customer per month in the first year and $0.13 per month in the second year, continuing until the microgrid generation assets fully depreciated.[11]

Resilience Considerations

Resilience was repeatedly identified as a benefit of the proposed microgrids, but neither BGE nor the PSC offered a definition of resilience. BGE and the PSC frequently referred to the value of maintaining power in the microgrid footprint during interruptions in the distribution system. BGE identified "avoided customer interruption" as a benefit from community microgrids but did not attempt to calculate its value (Maryland PSC, 2016, pp. 8–9). BGE argued that any resilience benefits of the microgrid would extend to non-microgrid customers throughout the service territory because local residents could travel to use microgrid-supported services during a power interruption.

The Maryland PSC questioned many of the resilience benefits that BGE claimed the microgrids would provide to surrounding communities. PSC staff argued that conditions underlying major interruption events could prevent ratepayers from traveling to the microgrid area, which would diminish the microgrid's value during a power interruption. Furthermore, PSC staff observed that the microgrids might not have sufficient capacity to support the sudden influx of demand. The staff also noted that critical services such as hospitals, police stations, and fire department buildings already had emergency backup power systems, which diminished the benefits that a microgrid could offer. Finally, the staff took issue with the generation plan, which relied on natural gas and did not include renewable generation or storage options. The staff pointed out that the lack of fuel diversity would erode the resilience objectives.

Other Considerations

BGE argued that, in addition to resilience benefits, the projects would serve the public interest by a) improving power quality, system balancing, and voltage regulation; b) reducing peak demand; c) participating in the PJM market[12]; and d) reducing system upgrade costs (BGE, 2015).

Although the PSC acknowledged these benefits, it raised concerns about the generators' ability to participate in the PJM market. The staff also noted that BGE had failed to integrate "forward-looking generation and storage concepts to test whether these elements could work in Maryland and be replicated in future microgrid projects." Consequently, the PSC did not find a clear benefit to all ratepayers that was sufficient enough to justify recovering costs via a mandatory surcharge.

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11 See https://www.bge.com/AboutUs/Pages/default.aspx.

12 The microgrid could capture additional revenue streams by bidding into PJM's energy, capacity, and ancillary service markets.

3.2. Commonwealth Edison

Illinois Commerce Commission: Docket 17-0331

Summary

On July 28, 2017, Commonwealth Edison (ComEd) filed a proposal for a two-phase microgrid project in the Bronzeville neighborhood of Chicago with 7.75 MW generating capacity and an unspecified amount of energy storage. The Illinois Commerce Commission (ICC) approved the proposal in an order issued on February 28, 2018 (ICC, 2018). The microgrid will serve customers that provide critical public services, including the Chicago Police Department headquarters. A value of resilience was not quantified during the proceeding, but ComEd did propose resilience metrics that it will validate and record during the course of the project. ComEd plans to use these metrics to learn about the "impact of increased resiliency on economic development," among other benefits (ICC, 2018, p. 3). The information contained in this section is drawn from the ICC order dated February 28, 2018, unless otherwise noted.

Technology and costs

The 10-year project (starting in 2019) consists of two phases:

1. Phase I will cover 10 city blocks serving 490 customers with 2.5 MW load at a total cost of $12.6 million. Phase I will be supported by a $4 million DOE SHINES[13] grant, which requires a focus on integrating renewable energy sources and energy storage into the microgrid. Phase I will include at least 0.75 MW of solar PV and 0.5 MW of battery storage with a 4-hour duration (equivalent to 2 MWh). ComEd may also integrate 3 MW of existing mobile diesel generators for testing purposes (ComEd, 2017).

2. In Phase II, the project will expand to include an additional three blocks, 570 customers, 4.5 MW of load, and 7 MW of "controllable" generation resources (ComEd, 2017).[14] The microgrid will also be able to connect to and coordinate with the existing nearby Illinois Institute of Technology microgrid. Research and testing of appropriate microgrid control technology will be supported by a $1.2 million DOE research and development grant (ComEd 2017; ICC, 2018). ComEd estimates that Phase II will cost $17 million (ComEd, 2017).

The microgrid investment costs will be recovered through a surcharge on all 3.9 million ComEd ratepayers' bills. The surcharge will be approximately $0.11 per month for the 10-year project duration.

Resilience Considerations

ComEd defined 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" (ICC, 2018, p. 22).[15] ComEd stated that the microgrid would serve as a "resilient oasis" for the local community during power interruptions (ICC, 2018, p. 22). However, the value of resilience was not quantified by ComEd or by ICC staff, nor did it directly inform the ICC's decision.[16]

ComEd did propose using the microgrid pilot to validate resilience metrics that will serve as the foundation for a future resilience valuation methodology. The company suggested 28 metrics based on existing industry best practices and recent academic literature. The metrics will measure energy system resilience and performance,

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13 Sustainable and Holistic Integration of Energy Storage and Solar PV.

14 As noted in the ICC ruling: "ComEd explains the permanent DER installed in Phase II must be controllable–they must be capable of supplying the entire load of the Project area in an islanding event, the timing of which may not align with solar PV generation. ComEd notes parties have stated that solar PV can become controllable by being paired with battery storage. While that may be true, ComEd anticipates that obtaining sufficient solar PV and battery storage to supply the entire Project area will be significantly more expensive than other DER options." (ICC, 2018: 42)

15 Other stakeholders submitted nuanced or alternative definitions of resilience. The Illinois Attorney General's Office, for example, defined resilience as "rapid recovery of a power source" (ICC, 2018, p. 75).

16 Although ComEd and ICC staff did not attempt to quantify resilience, an intervenor representing the Environmental Law and Policy Center applied the LBNL Interruption Cost Estimate (ICE) tool to calculate that a 43-minute reduction in annual system "down time" would deliver a "reliability benefit" of between $82,000 and $112,000 per year (ICC, 2018, p. 66). A more detailed discussion of the ICE calculator methodology is included in Section 4.2.1 of this report.

community resilience, and critical infrastructure resilience. The company will issue its first metrics-driven report on the status of the microgrid project in 2020.[17]

The Illinois Attorney General's Office and other intervenors raised a range of concerns about the project, some of which questioned the resilience benefits (ICC, 2018). Examples of the intervenors' discussion points related to resilience included:

- There is no need for the project because the area already benefits from reliable service.
- ComEd should be able to estimate or predict the benefits of "grid security and reliability" based on existing knowledge; since they did not, it is unclear if the benefits outweigh the project costs (ICC, 2018, p. 43).
- The Chicago Police Department headquarters already has backup power capability, limiting the project's added value as backup to a critical service.
- The microgrid area does not include significant public or critical services beyond the Chicago Police Department headquarters.

Other Considerations

ComEd argued that the project would support electricity delivery services and provide lessons regarding the value and use of microgrids. It also argued that the microgrid could provide the utility with experience in using DERs to support the distribution grid. The ICC concluded that a quantitative cost–benefit analysis was not necessary because the microgrid project provides lessons that are valuable for all customers and sufficient to justify cost recovery from ratepayers.

The ICC's decision to forgo a cost-benefit analysis was met with resistance from the Illinois Attorney General's Office, which argued that the project will provide limited learning opportunities. The AG's office specifically noted:

- It is unknown if and when islanding will occur, so the learning opportunities will be limited by circumstance.
- The project will give preferential treatment to the 1,060 microgrid customers, violating the Illinois Public Utilities Act, which states that public utilities may not grant preference or advantage to any customer, nor establish or maintain an "unreasonable" difference in services or facilities between localities (ICC, 2018, p. 37).
- The project violates the Illinois Public Utilities Act least-cost requirement (Section 8-401) because it is not the least expensive way to achieve reliability (ICC, 2018, p. 39).[18]

3.3. Potomac Electric Power Company
Maryland Public Service Commission: Case No. 9361

Summary

On September 25, 2017, Potomac Electric Power Company (Pepco) filed a proposal for two community microgrids—one in Largo, Md., and one in Rockville, Md. Pepco filed an updated proposal on February 15, 2018, proposing 6.78 MW of generating capacity with 1.6 MW of storage for Largo, and 7.46 MW of generating capacity with 0.25 MW of storage for Rockville, Md. Both proposals were filed as a condition of Pepco's 2016 merger with Exelon Corporation (Maryland PSC, 2015). On September 17, 2018, the Maryland PSC denied Pepco's proposal,

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17 In response to the Maryland PSC's decision in the BGE case, ComEd noted the importance of developing metrics "that ComEd, the Commission, the industry, and other stakeholders can apply when considering future distribution system advancements, distributed generation, and microgrid projects" (ComEd, 2017, p. 13). According to the Commission, "these metrics include 28 energy system resilience metrics, 15 community resilience metrics, and 13 critical infrastructure resilience metrics" (ICC, 2018, p. 68). The ICC order required ComEd to use these metrics throughout the pilot program and to issue a metric-driven report in 2020. The metrics can be found in ComEd Exhibit 3.01, attached to ComEd's testimony filed July 28, 2017 (https://www.icc.illinois.gov/docket/files.aspx?no=17-0331&docId=255296).

18 The Illinois Attorney General (AG) observed that ComEd was already "in the midst of extensive modernization of its distribution system" in order to "underground residential cable and mainline cable system replacement and repair, storm hardening, distribution automation, and cyber-secure communications." The AG noted that this effort "improves reliability and resilience throughout the distribution grid without the need to locate new energy resources, paid for by the public and utilized only in the most extreme circumstances to serve a very small subset of customers." The AG also argued that "ComEd provided no analysis of the cost or feasibility of any alternative or less costly methods to achieve its goals," and therefore concluded "that a project that provides reliability and resiliency at double the cost of distribution infrastructure modernization and duplicates existing energy resources is not least-cost." (IC, 2018, p. 39-40)

citing concerns over the impact on residential rates, a lack of cost-sharing by the beneficiary counties, Pepco's failure to apply to various grant programs, and Pepco's inability to quantify the community and distribution system resilience benefits of the program.

Technology and costs

1. The Largo microgrid would have covered the County Administration Building, a pharmacy, a gas station, a grocery store, the Prince George's Regional Medical Center, and a separate medical facility. The microgrid would have consisted of 1.175 MW of PV and 5.6 MW of natural gas generating capacity, along with 1.6 MW of battery storage with 2-hour duration (equivalent to 3.2 MWh). The entire system was estimated to cost $26.2 million.
2. The Rockville microgrid would have covered grocery stores, gas stations, a pharmacy, a fire station, and local government buildings. The microgrid would have consisted of 0.86 MW of PV and 6.6 MW of natural gas generating capacity with 0.25 MW of battery storage with 2-hour duration (equivalent to 0.5 MWh). The entire system was estimated to cost $37.2 million.

Pepco proposed to recover the costs for both microgrids from all Maryland Pepco customers through distribution rates, with a $0.36 monthly bill increase on a levelized basis for the typical residential customer. The rate recovery would have taken place over a 20-year period, based on the microgrids' minimum operational lifetime (Pepco, 2018a).

Resilience Considerations

According to Pepco, resilience would have been the primary benefit of the microgrid pilots. Pepco defined resilience as "the ability of the distribution system to withstand and recover from a destructive event" (Pepco, 2017, p. 11). Commission staff adopted the same definition in its analysis (Staff of the Maryland PSC, 2018, p. 3). Pepco did not calculate a value of community resilience[19] in its proposal, citing the lack of a standardized industry methodology for determining community benefits.[20] However, the company did use the ICE Calculator to estimate two benefits for customers connected to the microgrid—"outage avoidance benefits to microgrid participants" ($7.6 million) and "resiliency savings" ($8.3 million).

Maryland PSC staff agreed that the ICE calculator was an "appropriate tool to evaluate [the] microgrid proposals" because it is "accepted and used by electric reliability planners at utilities and government organizations across the nation for estimating interruption costs to customers, or societal costs, associated with reliability improvements in the United States." (Staff of the Maryland PSC, 2018a, p. 7). Because both of Pepco's savings estimations were computed with the ICE Calculator, the staff found that they represented only reliability benefits that "exclusively apply to the microgrid participants, not the thousands of customers who may indirectly benefit from the microgrids" (Staff of the Maryland PSC, 2018a). In other words, the staff found that neither value represented the full value of resilience, despite the name "resiliency savings." The staff opted to use the higher "resiliency savings" estimate in its cost-benefit analysis only because that estimate provided independent values for each microgrid, not because it believed that the figure more accurately estimated the value of resilience.

Pepco defended its inability to quantify community resilience benefits, likening the microgrids to an insurance policy. "Like other forms of insurance," Pepco wrote, "it has minimal value when not needed, but extraordinary value when used that greatly exceeds its cost." Pepco went on to suggest that the microgrids "represent a public good," the value of which is difficult to calculate and "nearly impossible to assign in terms of cost allocation" (Pepco, 2018b, p. 9).

In its September 17 order, the Maryland PSC denied Pepco's proposal, in part, because of its failure to quantify community resilience benefits. The PSC noted that Pepco had proposed to use the program to collect data that

19 Community resilience benefits refer to the benefits that accrue to customers that are not directly connected to the microgrid, such as access to services located within the area served by the microgird.

20 "The Company is unaware of an existing methodology for appropriately quantifying the financial benefits associated with microgrid availability during [outages]" (Pepco, 2017, p. 55)

would later facilitate quantifying these benefits. However, the PSC determined that it could not speculate on their value, especially given the Commission staff's unfavorable cost-benefit analysis.

Other Considerations

The PSC staff concluded that the costs for both projects outweighed their quantifiable benefits, even after accounting for the "resiliency savings" estimate.[21] The Commission staff further found that microgrid customers would disproportionately benefit from the project, and that customers who are closer to the microgrid area would experience greater benefits than those located farther away (Staff of the Maryland PSC, 2018a).

The PSC did reiterate its position that "public purpose microgrids have the potential to serve the community by providing electricity for public purposes during periods of extended grid outages" (Maryland PSC Order 88836, 2018, p. 24). It went on to clarify, however, that the costs of microgrids should not be borne solely by the ratepayers, but instead should be financed, at least in part, "through a combination of Participant contributions, government grant programs, and funding arrangements with the Counties or private market participants" (Maryland PSC, 2018, p. 24).

3.4 Findings regarding regulatory proceedings

The proceedings summarized reveal several trends in regulatory decision making related to ratepayer-funded microgrids:

- *A limited track record with mixed results.* Microgrid investment proposals have met with mixed success in regulatory proceedings thus far. In two out of three of the cases, the commissions rejected utility proposals. In Maryland, PSC staff conducted cost-benefit analyses for both BGE and Pepco's proposed microgrid investments and concluded that the investments could not be justified based on the quantified benefits. In the ComEd Bronzeville case, the ICC determined that unquantified community learning benefits were sufficient to make a cost-benefit analysis unnecessary, although intervenors made arguments that the microgrid would not be cost-effective.
- *Resilience is not quantified or valued in a way that impacts decision making.* Resilience is consistently identified as an important but intangible benefit of microgrid development. Resilience is unquantified in the formal regulatory proceedings surveyed.
- *Ratepayer-funded microgrids raise questions of equity.* Ratepayer equity proved to be an important consideration for all three proposals. In Maryland, the PSC determined that ratepayers closer to microgrid sites benefit disproportionately when compared to those further away. Consequently, the PSC found that rate charges spread equally across all ratepayers would not be appropriate, especially in the absence of cost-sharing by the beneficiary counties. Conversely, the Illinois Commerce Commission found that community learning benefits were shared equally by all ratepayers in the region. As a result, the ICC approved ComEd's proposal without a formal cost-benefit analysis. These results highlight uncertainties as to whether the resilience provided by DER investments represents a public or private good.
- *Commissions take the resource mix of proposed microgrids into account.* Both the ICC and the Maryland PSC valued the integration of DERs over conventional resources. In the BGE case, the Maryland PSC denied the proposal in part because of its failure to incorporate renewables and battery storage into the resource mix. The Maryland PSC later praised Pepco's proposal for its efforts to incorporate those resources. The ICC approved ComEd's proposal, in part, because its resource mix—which included both solar and natural gas—contributed to the unquantified community learning benefits.

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21 Quantifiable benefits included only ICE calculated values for microgrid participants; it did not include community resilience benefits.

4. Recent approaches to valuing resilience for DERs

The value of resilience has played a limited and largely qualitative role in the regulatory proceedings reviewed in Section 3. As discussed in Section 2, however, a number of states, cities, and institutions are actively exploring the use of DERs for resilience outside of regulatory venues. This section reviews approaches to the value of resilience outside of formal regulatory proceedings. The analytical processes used in states, cities, and institutions to identify cases where the value of resilience has been calculated and applied to resilient DERs. In jurisdictions where a value of resilience was analyzed, the extent to which the analytical method could be applied (or adapted) within the regulatory context was reviewed. The criteria used to review the applicability of the methods for regulators include:

1. **Power interruption duration.** As discussed in Section 2.2, interruption duration is one of the concepts distinguishing resilience from reliability. Some methods do not include a time element, or assume that the relationship between power interruption duration and cost is linear. In reality, power interruption costs may increase exponentially under the longer-term interruptions contemplated by resilience. Although many of the direct costs of power interruptions are incurred by consumers upfront, the indirect costs of an interruption on the wider economy can grow and spread over time.
2. **Scalability.** Regulators may need to evaluate resilience investments at multiple geographic scales, ranging from a specific critical location to an entire utility service territory—or they may need to evaluate the benefits of a statewide policy. Some valuation methods are flexibly scalable to different levels of analysis; other methods are designed with a specific scale in mind and are difficult to adapt for other purposes. A related issue is whether the methods contemplate direct or indirect impacts. A method that considers only the direct costs and benefits to a specific location may not sufficiently reflect the spillover effects that a longer-term power interruption can have on society.
3. **Ease of use.** Regulators need to make decisions in a transparent manner—often with limited budgets and within tight timelines. These parameters place a premium on replicable methods that employ low cost tools, readily available datasets, and accessible models. Some of the resilience valuation methods are comparatively simple, whereas others are data intensive, require highly customized solutions that take months to develop, and/or are difficult for stakeholders to access or understand.
4. **Scope of outputs**. Regulators may need to take different values into account in their decision making, depending upon factors such as state law, regulatory precedent, or standard practice. Some states may consider only the costs and benefits experienced by the utility system, whereas other states may consider the costs and benefits experienced by society as a whole (Woolf et al., 2017).[22] The different valuation methods produce different outputs. Some methods generate values based on indicators (e.g., employment) that may or may not be germane to state regulators, depending on the costs tests they use.

Section 4.1 briefly summarizes the different approaches to valuing avoided power interruptions that underpin value of resilience calculations. Section 4.2 presents case studies of the different methods that have been applied to calculating the value of resilience for DERs, including the context in which the method was used, the outputs generated, and the manner in which the outputs were incorporated into broader analyses. The case studies also situate the method within the broader valuation approach they employ. The case studies do not seek to comprehensively compare different economic valuation approaches; the objective of the case studies is to compare specific use cases through the lens of the four criteria discussed previously. The case studies also do not comment on whether the methods used were a good "fit" for their intended purpose; rather, they explore the extent to which methods used for non-regulatory purposes could be adapted to the regulatory context.

22 New York State Department of Public Service (2015) staff, for example, categorized the costs and benefits of the Reforming the Energy Vision proceeding according to whether they were relevant to the Rate Impact Measure (RIM), Utility Cost Test (UCT), or Societal Cost Test (SCT). Under the heading of "Reliability/Resiliency" benefits, staff categorized Net Avoided Restoration Costs as relevant to RIM, UCT, and SCT and Net Avoided Outage Costs as relevant only to the SCT.

4.1. Avoided power interruption valuation methods

There are numerous approaches for valuing nonmarket goods and resources (e.g., Champ et al., 2013). There is also extensive existing literature spanning several decades that describes and compares methods for valuing power interruption costs (Burns & Gross, 1990; Larsen, 2016); several recent papers focus specifically on longer-duration power interruptions (Roark, 2018; Sanstad, 2016). This paper does not attempt to revisit the literature on power interruption valuation in depth. Instead, this section provides short descriptions of the different methods to ground the terminology used in the Section 4.2 case studies.[23] This section broadly categorizes the different methods by whether they are bottom-up approaches, which assess the value of resilience based on customer preferences or behavior; or economy-wide models, which measure how power interruptions affects economic performance.

Bottom-up approaches.[24] Bottom-up approaches can be divided into stated or revealed preference methods.

- ***Stated preference methods*** use surveys or interviews to directly ask customers about their intended (or actual) behavior (Brown, 2003). Contingent valuation is a type of stated preference approach that is commonly used to elicit values for non-market goods; for example, the value to customers of avoided power interruptions (Woo & Pupp, 1992).[25] These surveys often ask respondents to give a hypothetical willingness-to-pay for better service or a willingness-to-accept[26] a payment for less reliable service (Caves et al., 1990; Schröder & Kuckshinrichs, 2015). For example, utility customers may be asked how much they would pay to avoid a power interruption or to be guaranteed a higher level of supply security. Stated preference approaches also include methods such as conjoint analysis[27] and discrete choice experiments (DCE), which attempt to elicit value by asking respondents to choose between different options (EPRI, 2017).[28] The ICE Calculator, developed by Lawrence Berkeley National Laboratory, is based on data gathered using the contingent valuation method (Section 4.2.1).
- ***Revealed preference methods***[29] use real-world data (e.g., purchasing behavior) to infer a valuation of non-market goods (Boyle, 2003). Defensive behavior and damage cost methods are examples of revealed preference approaches that have been used to establish the value of avoiding power interruptions. Defensive behavior methods identify the amount that customers have paid to avoid the negative consequences of a power interruption. The costs of purchasing and maintaining a back-up diesel generator, for example, could represent the value of avoiding power interruptions according to the defensive behavior method. Damage cost methods calculate the actual costs that may be experienced by different groups (e.g., customers) during a power interruption (Dickie, 2003).[30] The Federal Emergency Management Agency (FEMA) integrates the damage costs of increased injuries and lives lost from degraded critical services during power interruptions into its Benefit-Cost Analysis (BCA) tool (Section 4.2.2).

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23 The paper highlights where alternative terminology is used within recent U.S. literature for the same methods or categories. The paper does not highlight alternative terminology or categorizations used in older studies from the U.S. (e.g., Burns & Gross, 1990) or from studies outside the U.S. (e.g., Ajodhia, 2006; Schröder & Kuckshinrichs, 2015).

24 Bottom-up approaches are also referred to as microeconomic approaches (Roark, 2018).

25 Avoided power interruption costs are also referred to as Customer Interruption Costs; i.e., "the economic cost that customers incur when they experience an interruption in electricity service." It is also referred to as the value of lost load (Sullivan et al., 2018, p. 1).

26 Willingness-to-accept would require questions about how much money customers would need to be offered to accept reduced security of supply. In theory, willingness-to-pay and willingness-to-accept should be equivalent or at least relatively close to one another (Shogren et al., 1994). In practice, willingness-to-accept values tend to be significantly higher than willingness-to-pay (Horowitz & McConnell, 2002).

27 Conjoint analysis is a method of determining how consumers value certain attributes when choosing between similar products or services; in other words, it shows "what a consumer really wants in a product or service." A more thorough discussion of conjoint analysis can be found in Green and Wind (1975).

28 The precise definitions and the differences between conjoint analysis and DCE have been the subject of debate in the literature (see, e.g., Louviere et al., 2010)

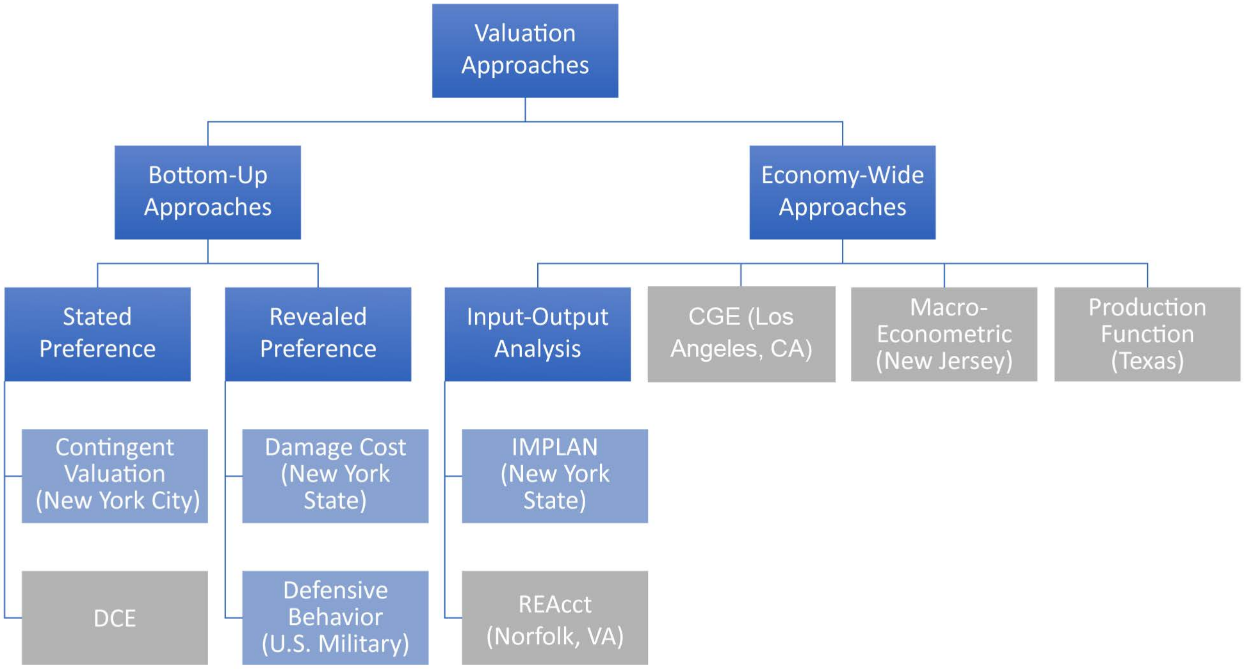
29 Revealed preference methods are also referred to as "market-based methods" (Sullivan et al., 2018) because value can be assessed based on the cost of purchased goods and services.

30 There are a broad range of approaches to calculating damage costs. Some approaches project hypothetical future costs, whereas others attempt to assess actual damage costs after the fact. Ex post approaches include conducting case studies of actual blackouts or analyzing insurance claims data post-interruption. A discussion on the pros and cons of these different approaches can be found in other reports (Sullivan et al., 2018; Mills and Jones, 2016; LEI, 2013).

Economy-wide approaches. Economy-wide approaches[31] analyze the effects of power interruptions on regional economies using indicators such as economic output and employment. Some economy-wide approaches rely on models that reflect the financial flows and transfers within a geographic area. These models include, for example, input-output models such as IMPLAN and REAcct (Vargas & Ehlen, 2013), computational general equilibrium (CGE) models (Sue Wing & Rose, 2018), and macro-econometric methods (Greenberg et al., 2007).[32] There are also economy-wide approaches that do not rely on complex models. Production function approaches,[33] for example, calculate the relationship between indicators such as energy consumption and gross domestic product (GDP) (de Nooij et al., 2007; Leahy & Tol, 2011).

Interviews and a literature survey were conducted to identify locations where the methods described were used to calculate a value of resilience for DER resources in the United States. These examples are highlighted in light blue and correspond to one of the case studies in Section 4.2. It is noteworthy that efforts to quantify the value of resilient DER have been concentrated in New York. The light grey cells indicate that the method has been used to calculate power interruption costs in the United States,[34] but has not been applied to analyze resilient DER. The light grey examples were not included as case studies in this paper, but they are summarized in other studies (Greenberg et al., 2007; Jeffers et al., 2016; LEI, 2013; Rose et al., 2007).

Figure 2. Methods used to calculate the value of avoided power interruptions and the value of resilient DER in different locations in the United States



31 These models are also collectively referred to as macroeconomic (EPRI, 2017), but Sanstad (2016) makes a case for why the term "economy-wide" may be a more appropriate characterization. Other authors group similar concepts as "regional economic modeling" (Sullivan et al., 2018).

32 LBNL summarizes and compares these different models in a recent study (Sanstad, 2016).

33 Also referred to as a "proxy" or "macroeconomic measures" methods (DOE, 2017)

34 The exception to this is DCE. Sullivan et al. (2018) identify instances where DCE has been used outside the U.S. (Belgium, Cyprus, Israel, and Sweden), but not in the U.S.

4.2. Case studies

This Section provides detailed case studies of how the power interruption valuation methods described in Section 4.1 have been used to calculate a value of resilience for DERs in the United States. Each case study includes: a) background and context for the study, b) the valuation method used, c) the outcomes of the analysis, and d) the method's applicability to regulators, using the criteria described in Section 4. These case studies represent efforts to calculate the value of resilience as a benefit that can be compared against the costs of the DER investments–e.g., through a cost-benefit analysis. There are alternative approaches to evaluating investments in resilient DERs that do not require benefits to be quantified, such as cost effectiveness assessments. Cost effectiveness assessments compare the costs of different alternatives to achieve a single quantified (but not monetized) outcome—e.g., the costs of the different technologies that could be used to provide back-up power for a two-day power interruption. Cost effectiveness assessments can be used when "social benefits are difficult to monetize (Boardman et al., 2001, p. 437)."

Table 2 contains an overview of the case studies and a summary of how the methods relate to the criteria introduced at the beginning of Section 4. The criteria summary is color coded in the following manner:

GREEN: The method meets the criteria; i.e., the method can be used to analyze long-term power interruptions, it is readily scalable to different geographic levels, it is relatively easy to use, or its outputs can inform regulatory decisions related to resilience investments.

RED: The method does not meet the criteria; i.e., the method cannot readily analyze long-term interruption durations, it cannot be applied to different geographic scales, it is difficult or costly to use, or its outputs are less relevant to regulatory decision making.

YELLOW: There are pros and cons in terms of how the method relates to the criteria.

It is important to note that the color coding is illustrative and is not intended as a definitive judgment on the fundamental merits of the different methods. The methods are useful for different purposes and in different contexts. Regulators should consider which methods are applicable for the unique contexts of their states.

Table 2. Detailed pros and cons of selected resilience valuation methodologies

Case Study	Method	Tool	Duration	Scalability	Ease of Use	Scope of Outputs
Solar + storage for critical infrastructure (Section 4.2.1)	Stated preference: Contingent valuation	ICE Calculator	• U.S. data sets are for interruption durations < 1 day • Limited customer experience with black sky events	Scalable from facility to national level	• ICE calculator available online • New surveys are resource intensive	• Well established in regulation • Does not consider spillover effects
The value of microgrids for critical services (Section 4.2.2)	Revealed preference: Damage cost	IEc Model (FEMA BCA tool)	• Can account for longer duration interruptions • Difficult to account for non-linear effects of long-term power interruptions	Scalable to different geographic levels	• Depends on damage metric used • FEMA BCA tool available online	• Depends on damage metric • Value of critical services may not be in-scope for regulators
Microgrids for community economic security (Section 4.2.3)	Input-output analysis	IMPLAN	• Can analyze long-term disruptions • Static models do not fully capture long-term shocks	• Effective for regional analysis • Difficult to scale to facility level	• IMPLAN commercially available • Other economy-wide approaches are more complex	Economic indicators may not be in regulatory scope
Microgrids for military bases (Section 4.2.4)	Revealed preference: Defensive behavior	Generator cost calculation	Most resilience measures are not purchased for long duration power interruptions	Difficult to scale to larger geographies	Market data is available	• Directly related to energy investment • Does not consider spillover effects

4.2.1. Solar and storage for critical infrastructure
ICE Calculator: Stated preference – Contingent valuation

Background

In October 2012, Superstorm Sandy made landfall near Atlantic City, N.J., causing widespread damage along significant portions of the East Coast. In New York City alone, Sandy caused an estimated $19 billion in damages and left 1.5 million customers without power (City of New York, 2013; New York City Office of the Mayor, 2012). During the decade prior to the storm, New York City had experienced a dramatic increase in installed rooftop solar PV. However, almost none of the installed PV systems were configured to provide back-up power in the event of a power interruption (Case, 2017b).[35] Following Superstorm Sandy, the City University of New York (CUNY) launched the Smart Distributed Generation (DG) Hub "to develop a strategic pathway to a more resilient distributed energy system."[36] A key focus of the Smart DG Hub was the development of a resilient solar roadmap, which outlined strategies to support the installation of solar and storage systems citywide (Case et al., 2017b). CUNY partnered with the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) to conduct a feasibility study of solar and storage systems installed on critical infrastructure in New York City. NREL and CUNY analyzed the technical and economic viability of PV and battery systems on three critical infrastructure sites in New York City.[37] These included a coastal school that serves as a storm shelter, a fire station, and a senior center that provides cooling services during heat emergencies. NREL worked with city agencies to identify the critical loads in each building and then used the REOpt model[38] to find the combinations of PV, batteries, and diesel generators that would supply the critical load at lowest cost under different scenarios. The results of this study indicated that the "inclusion of the cost of power interruptions can have a large impact on the economic viability of a resiliency solution" (Anderson et al., 2016).

Method Used

NREL integrated a value of resilience into its economic analysis of the three sites. NREL used the Interruption Cost Estimate (ICE) Calculator tool,[39] developed by LBNL. The ICE Calculator estimates the avoided cost of power interruptions for specific customer types in different parts of the country and for different durations (i.e., the "customer damage function" or CDF[40]). The CDF values are developed from a meta-analysis of 34 different survey datasets collected by 10 utilities across the country from 1989-2012 (Sullivan et al., 2009; Sullivan et al., 2015).[41] The surveys employed a contingent valuation approach to assess customer willingness-to-pay for avoiding power interruptions as it relates to grid reliability.

Outcomes

A "value of resiliency" was calculated for each of the three cases on a $/hour/year basis using the ICE calculator. Annual short and long-duration power interruption costs for each facility were then calculated by multiplying the $/hour/year value of resilience by the power interruption duration, assuming a 2-hour short duration and 22-hour long duration interruption for buildings located on the network grid (i.e. the fire station) and a 7-hour short duration and 50-hour long duration interruption for buildings on the radial grid (i.e., the school and the senior center (Anderson et al., 2016) (**Table 3**)).[42] These values were then incorporated into a cost-benefit analysis of PV and battery investments as an additional quantitative benefit.

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35 As described in Mullendore & Milford (2015): "the majority of PV systems currently installed are grid-tied…for safety reasons, these systems are configured to shut down when the grid goes down; if they did not, they could send power back up grid distribution lines undergoing repair, endangering utility line workers. (p. 3)"

36 See https://nysolarmap.com/solarplusstorage/.

37 A similar approach has been used to analyze facilities in Anaheim, CA (NREL, 2018) and NREL and CUNY have since built on this analysis to explore how the insurance industry might monetize the value of resilience (Anderson et al., 2018).

38 REopt is "NREL's software modeling platform for energy system integration and optimization." See Simpkins et al. (2014).

39 See https://icecalculator.com/home.

40 An in-depth discussion of CDF can be found in Sullivan et al. (2009).

41 As described in Sullivan et al. (2015: iv), "Once the datasets from the various studies were combined, a two-part regression model was used to estimate customer damage functions that can be generally applied to calculate customer interruption costs per event by season, time of day, day of week, and geographical regions within the U.S. for industrial, commercial, and residential customers."

42 Power interruption durations in this study were taken from average annual power interruption durations for radial and network customers in New York City. The school shelter and fire stations were connected to a radial system, whereas the senior center was connected to a network system. This explains the difference in power interruption durations. A discussion of the difference between the two systems can be found in footnote 8 in Anderson et al. (2016).

Table 3. Value of Resiliency for New York City Facilities

Site	Value of Resiliency Provided ($/hour/year)	Annual Cost of Short Duration Power interruption (7 hours; 2 hours for Fire Station)	Annual Cost of Long Duration Power interruption (51 hours; 22 hours for Fire Station)
School shelter	$69	$500	$33,515
Fire station	$917	$11,824	$20,071
Senior center	$32	$232	$11,632

Adapted from Anderson et al. (2016).

Evaluation

Power Interruption Duration. The ICE Calculator does not currently reflect "resilience-scale" power interruption durations. The ICE Calculator outputs are based on surveys of the willingness-to-pay to avoid power interruptions of up to 16 hours in length.[43] This duration is too short for resilience analysis. As recommended in a recent NARUC report, resilience to "black sky" events could entail power interruptions of 25 days or more (Stockton, 2014). New contingent valuation surveys could be designed to ask customers to contemplate longer-term duration interruptions (Caves et al., 1990; Schröder & Kuckshinrichs, 2015). However, most customers in the United States—apart from Puerto Rico and the U.S. Virgin Islands—have not experienced long-term interruptions on which they could base their value assessments and may have trouble accurately assessing their willingness-to-pay to avoid such scenarios (Sullivan et al., 2018; Atkinson et al., 2012).

Scalability. The ICE Calculator—and the results from contingent valuation surveys more generally—can be used to support analysis for an individual facility or for larger geographic areas.[44] Contingent valuation approaches are also particularly useful for residential customers, for which other valuation techniques fall short (Larsen et al., 2018).

Ease of Use. The ICE Calculator is a powerful and comparatively easy-to-use model. Regulatory staff have employed the ICE Calculator both in the microgrid proceedings discussed in Section 2 and in cases considering power interruptions more broadly (LaCommare et al., 2017). However, the cost of designing and implementing a new survey (e.g., to assess interruptions longer than 24 hours) is resource intensive and "can cost $1 million or more for a large service territory and take more than a year to complete (Roark, 2018)." Designing a survey that elicits useful responses is also difficult; survey question structure can influence respondents' answers and some surveys suffer from asking the "wrong" questions (Bateman, 2011; Brown, 2003; de Nooij et al., 2007).

Scope of Outputs. Willingness-to-pay outputs can be used in a broad range of regulatory contexts. Contingent valuation approaches typically address only direct costs to customers since designing a survey to assess indirect costs would require complex design that could be confusing for respondents (Sullivan et al., 2018; Atkinson, 2012). LBNL comments that the ICE calculator estimates "are not appropriate for resiliency planning… For resiliency considerations that involve planning for long duration power interruptions of 24 hours or more, the nature of costs change and the indirect, spillover effects to the greater economy must be considered (Sullivan et al. (2015: xiv)."

43 "This meta-study focuses on the direct costs that customers experience as a result of relatively short power interruptions of up to 24 hours at most. In fact, the final models and results that are presented...truncate the estimates at 16 hours, due to the relatively few number of observations beyond 12 hours (scenarios of more than 12 hours account for around 2% to 3% of observations for all customer classes)." (Sullivan et al., 2015, p. 17)

44 It is also possible to scale the results from contingent valuation studies up to apply to larger geographies and this has been done in studies outside of the United States. For example, the State of Victoria in Australia scaled results from contingent valuation surveys to determine a state level value of lost load (CRA International, 2008). Results from Victoria were then used to develop a national value of lost load for Australia (Hoch & James, 2011).

4.2.2. The value of microgrids for critical services
FEMA BCA: Revealed preference - Damage cost

Background

The NY Prize Community Grid Competition (NY Prize), developed and conducted by the New York State Energy Research and Development Authority (NYSERDA) in partnership with the New York Governor's Office of Storm Recovery, promotes designing and building community microgrids to improve local electrical distribution system performance and resilience. In Stage 1 of the NY Prize, funding for 83 communities was provided to conduct engineering assessments to evaluate the feasibility of microgrid implementation.[45] Many of the proposed microgrids aimed to improve resilience against the effects of severe weather events (BNL, 2017). All of the feasibility studies included a cost-benefit analysis using a model developed by Industrial Economics, Inc. (IEc), which draws on several different valuation methods (BNL, 2017).

Of the 83 communities, 11 were selected to move onto Stage 2 of the NY Prize and received additional funds to conduct comprehensive engineering, financial and commercial assessments of the proposed microgrids. NYSERDA will provide additional support for microgrid project implementation under Stage 3 of the program.

This report examines the Buffalo Niagara Medical Campus microgrid proposal, which was selected for support under Stage 2 of NY Prize committee for Stage 2 analysis. The proposed microgrid would cover nine health care, life science research, and education facilities on the Buffalo Niagara Medical Campus. The campus facilities include:

- The Roswell Park Cancer Institute, comprised of six buildings;
- Kaleida Health, which includes the Buffalo General Medical Center, Gates Vascular Institute, Buffalo Clinical and Translation Research Center, and Women & Children's Hospital;
- The University at Buffalo School of Medicine; and
- Cleveland Biolabs

The proposal emphasized the importance of enabling the Roswell Park Cancer Institute and Kaleida Health facilities to maintain 100 percent service quality during extended interruptions. The microgrid would integrate both existing and new distributed generation assets at those facilities, including diesel generators, battery storage, and renewables. The proposal also suggests integrating larger generation assets in the future, as well as including the nearby Fruit Belt neighborhood in the microgrid.

Analysis Method Used

The IEc model includes an estimate of the benefits for avoiding major power interruptions, which it breaks into two categories: the benefits of maintaining commercial and industrial (C&I) services and the benefits of maintaining critical services (IEc, 2016). The IEc model uses the ICE Calculator to quantify the C&I services component of the benefit calculation (see Section 4.2.1). To determine the benefit of maintaining critical services, the model uses the Federal Emergency Management Agency (FEMA) Benefit–Cost Analysis (BCA) approach, which incorporates a damage cost methodology (FEMA, 2011). FEMA developed this methodology in order to conduct cost-benefit analyses for its Hazard Mitigation Grant Program. The methodology uses location-specific information—such as the size of the population served and the power interruption duration at that location—as well as some standardized equations to estimate the costs of degraded fire, police, and emergency services (IEc, 2016).[46] The costs associated with critical services are based on assumptions about the value of lives saved and injuries prevented.

Outcomes

The IEc model estimated the 20-year net present value (NPV) of the microgrid's capital expenditures at $35 million, with annualized operations and maintenance costs of $1.37 million and annualized fuel costs of $8.34 million. The

45 See https://www.nyserda.ny.gov/All-Programs/Programs/NY-Prize/Opportunity-Zones-Map.

46 The FEMA BCA also includes a version of a production function method to calculate reduced economic activity in the case of lost electric, water, or wastewater services.

model showed that there would need to be at least 7 hours of interruption each year for the microgrid's benefits to exceed its costs. Benefits were calculated for a variety of categories (for example, "avoided emissions damages" and "reliability improvements"); this study focuses specifically on "Major Power Outage Benefits." The 20-year NPV of these benefits, assuming just seven (7) hours of interruption annually, was estimated to be $22.4 million ($1.98 million annualized).[47] These benefits include the value of healthcare services that would otherwise have been diminished (calculated using the FEMA BCA methodology), as well as saved operating costs from diesel generators. The FEMA BCA portion of the analysis relied on several damage functions, which estimated the impacts of the interruption on survival probability, additional travel time to hospitals, patient waiting time, and cardiac arrest fatality rates.

Evaluation

Interruption Duration. Damage cost methods can be designed to consider power interruptions at different timescales. Many damage cost methods, however, rely on relatively simple indicators that may not capture the full range of damages that would result from significant power interruption events. The damage costs calculated by the FEMA BCA methodology are linear and would not reflect the compounding impacts of long-duration power interruptions.

Scalability. Damage cost methods can be scaled up from the level of the individual customer to larger geographic areas. The scalability of the damage cost method will also depend on the assumptions made about the types of damages included in scope. Under the FEMA BCA methodology, for example, the damage cost will vary depending on whether one assumes that the next closest alternative emergency room is 2, 10, or 50 miles away if the nearest hospital loses power.

Ease of Use. Damage cost methods are relatively easy to apply and are less costly than surveys to develop and administer (Dickie, 2003). The FEMA BCA framework, for example, uses ready-made software that has been deployed by the federal government and is available online. Damage cost methods can also be comparatively straightforward to explain to a lay audience. However, damage cost estimates are sensitive to inputs, some of which may be controversial—such as the value of a human life (van Parijs, 1992).

Scope of Outputs. The basis for damage cost assessments can vary, and this may impact the methods' applicability to regulatory decision making. Damage cost assessments that consider the direct power interruption-related costs incurred by customers, for example, may be directly relevant to commissions across a broad range of states. NARUC, for example, has published a study with the MD PSC in which damage costs from power interruptions are estimated for different customer types (Burlingame & Walton, 2013). Outputs such as the value of critical services, however, may only formally factor into decisions in states where regulators are able to consider a broad range of benefits in their analysis.

4.2.3. Microgrids for community economic security
IMPLAN: Economy-wide approaches – Input-output analysis

Background

During Stage 2 of the NY Prize program, NYSERDA commissioned a pilot study from IEc to evaluate the Village of Rockville Centre community microgrid using an input-output model (IEc, 2018).[48] IEc drew inspiration from an Electric Power Research Institute (EPRI) report that identified regional economic impact modeling as a method to measure the value of avoided power interruptions (EPRI, 2017; IEc, 2018). The pilot study assessed the economic activity within the area served by the microgrid and how the microgrid would affect economic activity in the case of a major power interruption.

47 The 20-year NPV of Major Power Outage Benefits increases as the annual power interruption duration increases. For example, the avoided interruption benefits for an annual 24-hour power interruption total $65.6 million (over 20 years); the benefit of avoiding an annual seven-day power interruption total $438.6 million (over 20 years).

48 IEc built the cost-benefit analysis tool used to analyze the microgrids during Stage 1 of the NY Prize competition under contract to NYSERDA. IEc was also contracted to perform the input-analysis on a pilot basis as part of Stage 2.

The Village of Rockville Centre community microgrid was one of 11 projects to advance to Stage 2 in the NY Prize program. The proposed microgrid will include up to 0.7 MW solar PV, 6 – 12 MW dual-fuel or gas-fired generation, and the possibility for energy storage, demand-side management, and a combined heat and power (CHP) plant. It will serve 2,900 residents and 34 critical facilities (NYSERDA, 2017). Overall project costs are estimated at $14.76 million, in addition to $96,500 in annual operations and maintenance, offset by $2,653,100 in annual revenue (RRT SIGMA Engineering & Ove Arup and Partners, PC, 2016).

Method Used

Input-output analyses are economy-wide models that show how processes binding the regional economy are affected by a shock, policy, or change of economic circumstances (Larsen et al., 2018). An input-output model can quantify (often disproportionate) changes that one economic sector can have on the entire regional economy. The model does so by translating changes in productivity in one sector to changes in demand in the regional economy. An input-output analysis can represent all inter-industry relationships or flows in an economy; namely, how outputs of some industries are used as inputs to others (Sanstad, 2016). IEc used IMPLAN—a commercially available input-output tool with historical datasets that allows users to model economic impacts (Sanstad, 2016).

Outcomes

To conduct the input-output analysis, IEc collected information about industry sector and facility outputs within the microgrid footprint. As there was limited detailed information available, the analysis used assumptions based on county-level data available in the IMPLAN database, as well as from the U.S. Census Bureau. The IMPLAN analysis for Stage 2 found that a one-day power interruption in the area served by the Village of Rockville Centre microgrid would cause $5 million in lost sales, $3.1 million in lost regional GDP, and lost labor income equivalent to sustaining 32.1 average annual jobs. By contrast, the IEc cost-benefit model that was used to analyze the microgrid for the Village of Rockville Centre in Stage 1 of NY Prize calculated that the value of avoiding a 1-day power interruption would be $9.7 million (Flight, 2018; RRT SIGMA Engineering & Ove Arup and Partners, PC, 2016). IEc and other authors recommend that regional economic benefits should be considered separately from, and should not be added to or substituted for, the results of bottom-up analyses such as the cost-benefit analysis conducted in Stage 1. Instead, the input-output analysis results give a different perspective on the benefits of a regional microgrid (IEc, 2018; Larsen et al., 2018).

Evaluation

Interruption Duration. Input-output models have advantages over bottom-up methods in estimating the impacts of longer-term duration interruptions (Sullivan et al., 2018). The IEc analysis, for example, examined effects of power interruption scenarios up to seven days, including additional impacts on labor income at the county and state levels. The authors point out, however, that IMPLAN is a static model, meaning that impacts are attributable to one moment in time and do not reflect longer term adjustments that may occur in the economy (IEc, 2018). IMPLAN assumes fixed coefficients determining the input-output relations between industries, so any valuation resulting from the input-output method remains tied to the moment when such relationships were accurate (Larsen et al., 2018; Sanstad, 2016). Put another way, models such as IMPLAN cannot effectively reflect the full economic disequilibrium that may result from a long-term power interruption.

Scalability. Input-output models can analyze economic impacts at multiple scales. Resilient DER systems, however, may be small scale and in place at a single facility. Input-output models may not be sufficiently granular to calculate a meaningful economic impact from smaller-scale resilient DER systems. Input-output methods are also best used for microgrids serving many commercial and industrial facilities, since the analysis is based on market transactions.

Ease of Use. The IMPLAN model is commercially available and is used frequently at the state level for public policy analysis. The economic outputs produced (e.g., jobs) are also familiar to a broad range of stakeholders. Input-output models are comparatively easy to use and less expensive than other methods (Larsen et al., 2018; Sanstad, 2016). In New York, however, the IEc project team recommended that IMPLAN analyses be reserved for the final of pool microgrids chosen for NY Prize Stage 3 because of the level of effort required, rather than deployed broadly for projects in earlier stages of project development (IEc, 2018).

Scope of Outputs. Input-output models generate results that reflect economic impacts, such as jobs and earnings, but do not produce outputs that are directly related to utility customer preferences or behaviors. Depending on the state, economic impacts may or may not be within the scope of regulatory decision making.

4.2.4 Microgrids for military bases
Generator Cost: Revealed preference – Defensive behavior

Background

The US Department of Defense (DoD) and the military services are increasingly focusing on domestic energy resilience in order to assure national defense (Rickerson et al., 2018). Historically, DoD's energy resilience efforts have focused on mitigating short-term power interruptions. Recent threat analyses have indicated an increasing risk of regional prolonged power disruptions from extreme weather and determined adversaries (CNA, 2015). DoD has been steadily updating its policies to place a greater emphasis on critical infrastructure protection.

- The Office of the Secretary of Defense (OSD) established policy that requires military bases to assess their critical infrastructure vulnerabilities and to deploy energy efficiency, distributed generation, and/or renewable energy sources to enhance energy resilience as needed (DoD, 2009; DoD, 2014). DoD is also requiring the development of Installation Energy Plans that identify the critical mission operations on military bases that require a continuous supply of energy (Office of the Assistant Secretary of Defense, 2016).
- The Army has issued an energy and water security policy for its installations, requiring that critical missions be provided with their required energy and water for 14 days, and the Air Force has issued a policy that critical infrastructure be able to function independent of the grid for at least seven days (Secretary of the Air Force, 2016; Secretary of the Army, 2017). The Department of the Navy's Energy Security Framework also requires backup power for up to 7 days, depending on the type of facility (Tetatzin, 2017).
- The 2019 National Defense Authorization Act (NDAA) amended the Energy Policy of the Department of Defense[49] to include additional energy resilience requirements. These included establishing specific resilience metrics, conducting energy system readiness assessments, reporting on resilience initiatives, and prioritizing resilience in energy procurement contracts (Public Law No. 115-232, 2018).[50]

The DoD does not currently have a standard method for calculating the value of energy resilience. The Office of the Secretary of Defense (OSD) commissioned the development of the Energy Resilience Assessment (ERA) simulation tool from MIT Lincoln Laboratory. The OSD ERA tool estimates the cost and capability of existing systems to avoid power interruptions of different durations and then compares those results against alternative infrastructure combinations (e.g., microgrids with centralized generation, solar PV and storage, fuel cells, etc.). The ERA tool is a form of cost effectiveness assessment—it compares the costs of different strategies to avoid an assumed power interruption, rather than comparing the cost of those strategies to a quantified benefit for power interruption avoidance. The ERA tool will be utilized by projects applying for funding through the DoD Energy Resilience and Conservation Investment Program (ERCIP) starting in 2019 (Office of the Assistant Secretary of Defense, 2017).

Although the military does not have an official cost-benefit analysis approach for resilience, entities outside the DoD have attempted to determine a military value of avoided power interruptions. NREL, for example, has conducted contingent valuation surveys focusing on the value of avoided power interruptions at military bases (Giraldez et al., 2012). This section focuses on a report commissioned by the Pew Charitable Trusts that analyzes the business case for deploying microgrids for energy resilience at domestic military installations (Marquesee et al., 2017).

Method Used

The Pew study analyzes scenarios in which small-scale diesel generators connected to individual buildings at military bases in different parts of the country are replaced by large-scale diesel generators installed as part of a microgrid.

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49 10 US Code § 2911, see https://www.law.cornell.edu/uscode/text/10/2911.

50 For example, Section 312 – "Further improvements to energy security and resilience" available at https://www.congress.gov/bill/115th-congress/house-bill/5515/text.

The Pew study argues that attempts to identify a value for resilience are "misguided." [51] Since DoD requires the installation of a standalone diesel generator at every building that houses a critical load, the study argues, the cost of a standalone diesel generator (including up-front capital, O&M, and incremental fuel costs) should "represent the value (price) that DoD…places on energy security" (Marquesee et al., 2017, p. 36). The study further argues that "the value of energy security should be determined by the least-cost method of providing that security"—i.e., of avoiding damage from the power interruption in the first place. "Currently, standalone generators represent that least cost method" (Marquesee et al., 2017, p. 36). This approach to valuation can be viewed as a form of defensive behavior methodology (Dickie, 2003). The defensive behavior method assumes that electricity users act rationally and insure themselves against damages caused by power interruptions when it is economical to do so. Customers purchase back-up generators until the expected marginal cost of additional back-up power equals the expected marginal cost of a power interruption (Caves et al., 1990). Other studies have also used the cost of back-up power to value avoided power interruptions (Matsukawa & Fujii, 1994). Although the Pew Center report asserts the comparative advantages of the defensive behavior method, the method has both strengths and weaknesses, which are discussed in subsequent text.

Outcomes

The Pew study estimates that the 20-year cost to protect a kilowatt of load using standalone diesel generators is between $80 and $85 per kilowatt per year. This cost is then compared to the lifecycle cost of the diesel microgrid. The report concludes that diesel generator-based microgrids are more cost-effective on a lifecycle basis than standalone generators.[52]

Evaluation

Power Interruption Duration. Defensive behavior methods can be scaled up to reflect longer duration power interruptions. When using the cost of diesel generation as a proxy, for example, long-term fuel supplies, maintenance costs, and storage facilities can be built into the cost assumptions. It is important to identify the assumptions involved in defensive behavior calculations. Many resilience measures are not purchased for long duration power interruptions (Phillips et al., 2016). The cost of a diesel generator with a short-term fuel supply would not be an appropriate proxy for a long-term duration power interruption—particularly since diesel fuel supplies may be disrupted during longer-term power interruptions (Stockton et al., 2016).

Scalability. Defensive behavior methodologies cannot effectively be scaled up to the level of an entire economy (Schröder & Kuckshinrichs, 2015). The U.S. DOE states that scaling up the defensive behavior method "would require that voluntary adoption of diesel generators is sufficiently common to allow for a statistically significant estimate of customers' valuation of outage (DOE, 2017, p. 201)." This may not be the case in areas with relatively high reliability on "blue sky" days where customers will not typically make security of supply investments, as is the case in utility territories across much of the U.S.

Ease of Use. The defensive behavior method does not require survey design and administration and is therefore easier and less costly than stated preference methods (Woo & Pupp, 1992). However, the defensive behavior method may require additional data gathering, such as data on attitudes, beliefs, and perceptions since purchasing decisions are based on a consumer's perceived costs and benefits (Dickie, 2003).

Scope of Outputs. Defensive behavior may reflect the investment decisions for an individual customer to invest in resilience for their own facility. These investments, however, do not reflect the broader spillover effects of long-duration power interruptions that could suggest investment in resilience as a public good.

51 The study authors refer to the value of resilience as the "value of energy security" (Marquesee et al., 2017).

52 The report assumes that 160 small-scale diesel generators connected to individual buildings at a military base are replaced by 12 two-megawatt diesel generators installed within a microgrid. Decreased operations and maintenance expenses are the primary source of savings created by the microgrid. The report also finds that a hybrid diesel and natural gas microgrid would be competitive with small-scale diesel generators in California, but not in other regions of the country.

4.3. Findings regarding DER valuation case studies

The case studies presented above reveal several trends regarding attempts to identify a value of resilience for DER investment:

- Governments and institutions are actively exploring the value of resilience for DER, but no standardized approach has emerged.
- The value of resilience has been used to analyze cost-benefit tradeoffs, but has not been utilized to justify investments in project construction. NYSERDA used the IEc model to evaluate the Stage 1 NY Prize participants and has piloted the use of IMPLAN for one Stage 2 participant – but it is unclear how and whether the value of resilience will be considered in subsequent decision making.
- As summarized at the beginning of this section in **Table 2**, there are tradeoffs for regulators related to each of the approaches used in the case studies. Some of the methods perform well against some of criteria. None of the methods reviewed met all four criteria related to regulator usefulness and usability, however. No one method can be used to analyze long-term power interruptions in a way that produces broadly relevant outputs, while also being readily scalable to different geographic levels and relatively easy to use. Several of the approaches, for example, use readily available models such as the ICE calculator, the FEMA BCA method, or IMPLAN, but these models do not capture aspects of resilience to high impact power interruptions that are important for decision makers to consider. For example, the ICE Calculator can estimate interruption costs for short-duration power interruptions up to 16 hours, but it cannot project ways in which costs may compound as power interruptions stretch from days into weeks.

5. Conclusions and Next Steps

This report examined current regulatory and non-regulatory approaches to using the value of resilience in DER investment decision-making. While there is evidence that resilience is a consideration in both regulatory proceedings and non-regulatory analyses, the report finds no standardized approaches for determining a specific value of resilience when making investment decisions.

The review of regulatory proceedings in Section 3 found that a value of resilience has not been determined or utilized in the analysis of microgrids. The proceedings in Maryland and Illinois do not provide a benchmark or precedent for approaching the value of resilience.

The review of non-regulatory studies in Section 4 found that a value of resilience has been calculated and applied to analyze DER investments in several different contexts and using several different methods. However, none of the four methods analyzed is a strong fit with the criteria used to evaluate their usefulness to regulators and regulatory decision-making.

Given these findings, regulators attempting to analyze investments in resilient DER have several options.

- Do not use a value of resilience in cost-benefit analysis. This was the approach taken by commissions and intervenors in regulatory proceedings in Maryland and Illinois. Some resilient DER projects create benefits beyond resilience that are sufficient on their own to justify investment. This approach, however, undervalues the benefits created by resilient DERs and would constrain investments in projects that do not create sufficient additional benefits to move forward.
- Use an alternative benefit analysis methodology that does not require calculating a specific value of resilience. As shown in regulatory proceeding summaries in Section 3, the need for a value of resilience is driven by the use of cost-benefit analysis to support decision making. Calculating the specific benefit for resilience is difficult. Methods such as cost-effectiveness assessment provide an alternative to cost-benefit analysis when benefits are difficult to monetize. A challenge with using cost-effectiveness assessments, however, is that the resilience objective of the assessment needs to be defined. This would likely require that the

resilience objective be formally established and articulated in policy by a legislature, governor, or other authority. As discussed in Section 4.2.4, the DoD Defense ERA tool is based on cost effectiveness assessment methodology and does not calculate a value of resilience. The tool analyzes the cost effectiveness of energy investments that would meet the resilience requirements articulated in official DoD policies and guidance.

- Adopt one of the methods described in the case studies profiled in Section 4. Although none of these methods meet all four criteria introduced in Section 4, the methods may serve as starting points for regulatory analysis. These models may also perform better if viewed through the lens of alternative criteria customized for specific regulatory contexts.
- Adapt one of the other the methods identified in Section 4.1 for valuing avoided power interruptions. This report focused only on case studies where valuation methods had been used to analyze DER investments. Regulators could consider whether there are other methods that could be used in evaluating resilient DER investments. Each of the other methods has its own tradeoffs that may or may not present advantages over those analyzed in this report.
- Actively engage in research efforts focusing on new approaches to resilience valuation. There are multiple ongoing efforts to advance the "frontiers" of energy resilience valuation. These include, for example, new survey designs to elicit willingness-to-pay values for power interruptions with longer-durations than those used in existing models (Larsen et al., 2018; Sullivan et al., 2018). Regulators could more actively investigate or engage in these processes, although as noted earlier in this report, it may take significant time and resource commitments to develop and deploy new methods and tools.

Each of these options has its own sets of tradeoffs and potential limitations. The difficulties involved in valuing resilience relate directly to the challenges inherent in analyzing high impact, low probability power interruption events. The lack of prior experience with high-impact, low-probability events means that the likelihood and scale of potential disruption is difficult to imagine. This means that justifying the high costs of mitigation to ratepayers can be challenging. Regulators seeking to build resilience will need to continue to grapple with these issues against the backdrop of increasingly severe threats to the electricity grid.

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