# Valuing Distributed Energy Resources: Combined Heat and Power and the Modern Grid

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April 2018

An ACEEE White Paper



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## Acknowledgments

This paper is based on research, outreach, and writing undertaken as part of a 2016 project to engage the financial and insurance industries in valuing combined heat and power's resiliency and reliability benefits. We thank the New York State Energy Research and Development Authority (NYSERDA) for its support of CHP research. ACEEE drew upon the many publications and the work funded by NYSERDA in the writing of this paper. The authors gratefully acknowledge internal reviewers, colleagues, and sponsors who supported this study. Internal reviewers included Maggie Molina, Steve Nadel, Neal Elliot, and Ethan Rogers. We would also like to thank Fred Grossberg for developmental editing and managing the editorial process; Keri Schreiner, Sean O'Brien, and Roxanna Usher for copy editing; Eric Schwass for graphics support; and Dawn Selak, Maxine Chikumbo, and Wendy Koch for their help in launching this paper.

## Executive Summary

In 2017, many large-scale natural disasters hit the United States and affected our power systems. In the wake of storms such as hurricanes Harvey, Irma, and Maria and forest fires in California and across the west, decision makers have begun to rethink the design and management of the nation's energy infrastructure. They also have an opportunity to evaluate investment decisions that affect infrastructure performance, both on a daily basis and under stress.

This paper is designed to help facilities, communities, utilities, and customers affected by poor energy resiliency better assess the costs of disruptive events and the value of mitigation strategy benefits. They cannot make these assessments without accurate information about the reliability and resiliency of various energy systems. Despite the many definitions of reliability and resiliency, however, no clear framework or set of metrics exists to evaluate investments in these assets.

This study defines energy system resiliency and explores the ways in which utilities, insurance companies, cities, investors, and energy users are valuing (or not valuing) energy systems' abilities to withstand high-consequence events. We identify which data are available to determine a system's resiliency and suggest ways to collect new information. These data will support informed investment decisions that more accurately reflect the resiliency benefits of various energy resources.

Our focus is on energy-efficient combined heat and power (CHP) systems. We suggest a path forward for properly valuing CHP's resiliency benefits, including a proposed framework for measuring the resiliency value of distributed energy resources.

### *METRIC DEFINITIONS*

Energy resiliency, reliability, and power quality are critical indicators of energy system performance. In facilities such as hospitals, poor performance on these metrics can lead to lives lost; it can also lead to huge economic and data losses for data centers, manufacturing centers, and other businesses.

*Power quality* measures the degree to which an electricity supply maintains its voltage and frequency and is free of distortions. *Resiliency* can be measured in many ways, and no widely accepted standard currently exists. Here, we define energy resiliency as an energy system's ability to withstand "high-consequence, low-probability" events and to regain normal operational activity after such events occur.[1] Such events are rare, potentially devastating, and poorly prepared for. Resiliency also describes how quickly a system can recover from these events and fully restore service, as well as its ability to isolate certain critical facilities and insulate them from the full brunt of service disruption.[2] This definition of resiliency can be applied to a facility, an energy system, a city, or even a region.

[1] J. Watson et al., *Conceptual Framework for Developing Resilience Metrics for the Electricity, Oil, and Gas Sectors in the United States* (Albuquerque: Sandia National Laboratory, 2015).

[2] A. Chittum, *Valuing Resiliency: How Should We Measure Risk Reduction?* (Washington, DC: ACEEE, 2016).

*Reliability* describes the degree to which an energy resource is available. It includes measurements of the seconds, minutes, hours, or days that a customer is unable to obtain full service. Whereas resiliency describes a system's ability to withstand infrequent but devastating major events, reliability describes the system's ability to weather "low-consequence, high probability" events (Watson et al. 2015). Individual facilities may experience poor energy reliability as short, sub-hour power outages that occur several times a year and that the utility quickly resolves.[3] However, for sensitive customers such as hospitals, data centers, research facilities, and others requiring constant power to accomplish their mission, these short outages can be very costly.

Several studies offer clear assessments of the scale of economic loss due to poor energy performance. The most conservative estimate finds that poor energy reliability and power quality costs the United States $79 billion a year.[4] Most of the economy-wide assessments of the cost of poor energy performance are well over $100 billion annually. Energy reliability is worse in the United States than in many other developed countries. To help remedy this situation, stakeholders must be able to measure and manage the downtime costs and resiliency benefits of various energy resources. Doing so will help them optimally allocate scarce resources and create the most resilient systems, thereby reducing costs for everyone.

### *CURRENT RESILIENCY METRICS, DATA, AND GAPS*

Standard ways exist to describe energy reliability, and several commonly used metrics are collected and published for most US utilities, including metrics on the number and length of outages. Data collected by individual CHP facilities and other backup generator systems are also sometimes available. Metrics describing distribution system performance include: System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), and Customer Average Interruption Duration Index (CAIDI).

Tools are also available to calculate economic losses associated with poor system performance. Although these measurements and data are a good starting point for valuing resiliency, gaps remain. Individual facilities and energy system planners need normalized, comparative data to use any of the existing or newly identified data on energy performance. At present, the value one company finds in a proposed investment in onsite CHP may not translate to a company across the street. Beyond better normalization of data, creating more data points altogether will help move the discussion of CHP benefits beyond the anecdotal. Existing data can help these discussions begin, but they are just a starting point.

Some states and jurisdictions are moving forward with resiliency valuation even with imperfect data. Their approaches include offering financial prizes for innovative projects that address reliability concerns in specific geographic locations, the consideration of resiliency metrics in cost-effectiveness testing for different projects, the sale of energy

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[3] J. Watson, *Ibid*.

[4] K. LaCommare and J. Eto, *Cost of Power Interruptions to Electricity Consumers in the United States* (Berkeley, CA: Lawrence Berkeley National Laboratory, 2006).

performance insurance products, and various certifications or rating processes for energy performance.

### *CHP Systems: Performance and Benefits*

CHP systems are onsite resources that generate both heat and power concurrently. CHP is not a single technology but rather an approach to using existing technologies, including those typical of traditional electric generation. In a CHP application, however, the waste heat generated from the electricity production process is captured and used rather than wasted. Because they generate two useful products from one fuel input, CHP systems are a more efficient way to generate energy. CHP is more appropriate for certain applications than for others, however. For example, campuses, larger buildings, and cities (as opposed to rural areas) are typically well suited for CHP systems because they often have natural gas infrastructure and a consistent and adequate thermal demand.

CHP systems are located closer to the consumption site than traditional centralized generation. This improves energy resiliency because power moves over shorter distances, reducing the likelihood that it will be interrupted by tree limbs or debris falling on electric distribution and transmission lines. CHP systems can also ramp up faster than many other types of power generation resources, so they can begin serving loads faster and responding more quickly to changes in grid-supplied power. Further, by directly supplying local loads with power and heat, CHP systems can reduce the strain on nearby parts of the electric distribution grid. This alleviates stress and reduces the chances of individual grid component failure.[5] Further, CHP systems are typically well maintained, since they operate on a near-continuous basis to provide power and heat to connected facilities under normal operating conditions. Some CHP-based energy systems can fully disconnect from the grid and continue to provide power and heating services to some or all of their connected facilities; in that case they are said to be islanding. These systems offer the best resiliency benefits by insulating connected buildings from the surrounding grid's performance and can maintain service even if the grid goes down.

Undoubtedly, the future energy grid will look very different from the one we recognize today. Resources that rely on an extensive and complex transmission and distribution infrastructure are susceptible to catastrophic outages as well as shorter, more frequent disruptions. After Superstorm Sandy, states along the eastern Atlantic Coast began identifying microgrids as pieces of critical resiliency infrastructure.

CHP is the primary driver of most in-place US microgrids today.[6] On the margins, more CHP and CHP-anchored microgrids are being added to the grid, improving energy resiliency and providing additional benefits. However only a portion of the potential has been met: CHP represents only about 8% of installed US electric generating capacity. Our

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[5] A. Chittum and K. Farley, *Utilities and the CHP Value Proposition* (Washington, DC: ACEEE, 2013). A. Moreno-Munoz et al., "Improvement of Power Quality Using Distributed Generation," *International Journal of Electrical Power and Energy Systems* 32 (10), 1069–1076.

[6] E. Wood, *US Microgrid Market Growing Faster Than Previously Thought: New GTM Research* (Microgrid Knowledge, 2006).

electric grid is still fundamentally built around centralized resources. Yet, even though CHP has great untapped potential, most of it will likely be unrealized under current policies and practices. This is partly because many facilities find it difficult to economically justify the investment given that CHP's (possibly large) resiliency benefits are not fully valued in project cost screening.

### *STAKEHOLDERS AND MISALLOCATION OF CAPITAL*

Both micro and macro factors compromise risk profile accounting for energy infrastructure investment decisions. At the micro level, facilities have little data with which to assess the risk associated with poor grid performance. Likewise, facility owners and decision makers have little information to help them determine the degree to which CHP would provide economic benefits over business-as-usual energy resources such as an onsite boiler and a grid connection. At the macro (society/economy-wide) level, the planning mechanisms that utilities use to identify future energy investments do not consider resiliency as a priority. Others with interest in the resiliency of the energy system also lack frameworks with which to value premium resiliency performance.

Stakeholders here include facilities that are often hamstrung by their own internal investment guidelines. For example, a facility or company may have a well-established requirement that investments pay for themselves in three years or less. With no way to monetize the full resiliency value, a CHP project may not pass an initial screening test. Additionally, electric utilities are the largest investors in US energy infrastructure. They assess which types of resources would best meet their future needs through the lens of established tests that delineate the costs and benefits of various investments. However most fail to assess whether more distributed, strategically sited resources would offer consumers better, more cost-effective system resiliency options.

Local resiliency planners and governments recognize that failed critical facilities negatively impact their constituents and communities, as well as burden the remaining facilities. Cities and states may deem facilities that could serve as emergency shelters—such as wastewater treatment plants and public buildings—as critical to resiliency planning and target these facilities as premium energy performance assets.

Although many programs and policies promote CHP and CHP-based microgrids for their resiliency benefits, most do not offer the financial decision-making context required to justify investments in these resources. This is also true for investors and shareholders who are not aware of the degree to which a company exhibits energy vulnerability. Such information is rarely disclosed in publicly facing documents that shareholders use to determine how to value a company.

An asset's value can include losses avoided by its presence over time. A market mechanism usually exists for determining the value of such an asset, and it offers a clear and accepted way to determine that value. However CHP resiliency benefits currently lack an agreed-upon and easily understood mechanism for valuation. Accountants reviewing the financial statements of companies that are investing in CHP or CHP-based microgrids have no established basis on which to determine whether the valuation of resiliency benefits is justified. Similarly, while several major categories of insurance products would be triggered by poor energy resiliency during times of disaster, the insurance industry is not yet reflecting the premium resiliency that CHP provides in its underwriting activities. We conducted interviews with more than a dozen US insurance companies as part of this research and found that none offer products that reflect the reduced risk that a facility using CHP might represent.

### *A Resiliency Valuation Framework: The Distributed Energy Resource Resiliency Value (DERRV)*

Stakeholders need a commonly accepted metric (or set of metrics) to describe the resiliency value of onsite distributed resources for both individual facilities and the grid. To begin a conversation on the topic, we propose a distributed energy resource resiliency value (DERRV) framework. A DERRV could give stakeholders the information needed to make informed decisions about risk calculation, as well as provide company- or facility-specific determinations about impacts and costs.

Existing consensus-based standards and valuation approaches on a variety of environmental and corporate social responsibility issues offer precedents for a standard that might use a DERRV-style metric. Stakeholders could develop a proposed DERRV metric framework, and then begin collecting and organizing the multiple sets of accurate data that DERRV calculations will require. For example, actionable information for the DERRV might include data on the reliability of the grid and backup generators, downtime costs, and CHP and microgrid performance and costs. Although multiple data needs have yet to be met, DERRV developers would not have to meet all of them before improved valuation could occur.

Stakeholders involved in creating a DERRV should include CHP and microgrid developers and equipment manufacturers, industries concerned about energy risk (such as hospitals, data centers, first-responder facilities, and wastewater treatment plants), utilities, city and state policymakers and regulators, insurance companies, and investor representatives and advocates. Each of these stakeholders has much to gain from valuing, and thus increasing, energy system resiliency. Developing a DERRV with broad stakeholder acceptance could underpin the development of a consensus-based standard that would help facilities and communities maximize energy resiliency.

## Introduction

Combined heat and power (CHP) is a century-old technology that has been quietly meeting about 12% of US power needs in recent years and has been serving as a source of resilient energy during severe weather events. During Superstorm Sandy, for example, CHP outperformed traditional centralized generation throughout New Jersey and the rest of the hard-hit Atlantic coast. During the storm, CHP systems stayed online as the grid around them failed. Hospitals, universities, wastewater treatment centers, and high-rise residential buildings fortunate enough to be served by CHP were much more likely to keep the lights, heat, and hot water on for students, residents, and patients. At the same time, neighbors across the street lost power from the grid for days and in some cases even weeks (Chittum 2012). As a result of how CHP systems performed during Superstorm Sandy, the federal government and the most-affected states, including New York, New Jersey, and Connecticut, increased CHP deployment efforts to boost resiliency. However CHP remains a very small component of all new energy resources being built today.

Unreliable power costs the United States at least an estimated $79 billion every year (LaCommare and Eto 2006). Given such costs, it is natural to wonder why more resilient alternatives are not being built across the country, particularly in areas prone to extreme weather events. One answer is that we are not adequately valuing the resiliency of different energy assets when investing in our energy system. If we do not change the way we value energy resiliency, the system and customers will continue to bear the costs.

This paper defines energy system resiliency and explores how utilities, insurance companies, cities, investors, and energy users are valuing (and not valuing) energy systems' abilities to withstand high-consequence events. We identify the data available to determine a system's resiliency. We also suggest ways in which existing and new data can facilitate investment decisions that more accurately reflect various energy resources' resiliency benefits.

We designed this paper to help facilities, communities, utilities, and customers that will be affected by poor energy resiliency better assess the costs of disruptive events and better value the benefits of mitigation strategies. We focus on CHP and suggest a path forward for more properly valuing CHP's premium resiliency benefits. Implementation of our suggestions will yield a more resilient energy system and bring CHP benefits to more energy consumers.

## How Does Our Energy Infrastructure Perform?

Investments in energy infrastructure too often fail to properly value the costs of poor energy resiliency, reliability, and power quality. Of these, resiliency and reliability are most positively impacted by investments in highly reliable onsite energy generation such as CHP. This section defines these terms and highlights the risks and financial costs of poor performance on these metrics.

### *THE VICTIMS OF POOR ENERGY PERFORMANCE*

Sub-optimal energy resiliency and reliability is burdening the entire US economy. When energy infrastructure fails, many sectors directly and indirectly experience economic pain.

These victims include individual facilities, such as manufacturers, laboratories, and data centers, that will fail to meet customer demands or will experience product or equipment damage. Poor performance affects health care systems as well, including hospitals and nursing facilities that may need to reduce the care they provide or rely on other area facilities to maintain patient quality of life. Local economies also suffer, such as when people are out of work; schools are closed; infrastructure such as wastewater treatment centers are disrupted; stores are damaged; and the general flow of goods and services is interrupted. Other areas impacted include investors in grid-related risk sectors (such as the banking, data management, and IT industries) and insurance companies that offer business-continuity insurance and other products that help cover the costs of these kinds of unexpected events. Indeed, weather-related payouts by insurance companies are about $50 billion per year and have been doubling every decade since the 1980s (Mills 2012). While such payouts are not all related to grid performance, they demonstrate how weather-induced damages are increasingly affecting a widening swath of the US economy.

### *What Is Energy Resiliency?*

Resiliency has many different definitions. Here, we define it as the ability of an energy system to withstand "high-consequence, low-probability" events and to regain normal operational activity after such events occur (Watson et al. 2015). These are *black swan* events as described in black swan theory.[7] Black swan events are rare, potentially devastating, and poorly prepared for; they include natural catastrophes, such as hurricanes and ice storms, and human-caused events, such as terrorist acts. Resiliency describes how quickly a system can recover from black swan events and fully restore its services, as well as its ability to isolate certain critical facilities and insulate them from the full brunt of service disruption (Chittum 2016). This resiliency definition is thus broad and can be applied to a facility, an energy system, a city, or even a region. However the term is not typically applied to a single building, but rather to the utility system of its neighborhood or city. It can also include other systems such as transportation, health care, and food systems.

A system's resiliency can be described or measured in many ways, but no widely accepted standard currently exists. In one example, system resiliency can be expressed as the probability that something will happen as a result of a defined threat. To measure a city's resiliency in the face of a particular threat, for instance, stakeholders might aggregate the costs of various outcomes expected to occur due to that threat. They could then describe the probability that those costs will be incurred—for example, electricity service will be disrupted for *X* number of customers, costing *$X.XX* per day due to a Category 4 hurricane with a given trajectory.

#### Risk Metrics for a Nonresilient Energy System

Poor energy resiliency incurs both direct economic loss and broader losses including lost lives, lost confidence in a city or region (which can impact investor behavior), and indirect economic losses. These additional elements can be considered in aggregate to characterize an energy system's resiliency in the face of a threat (Chittum 2016; Watson et al. 2015).

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[7] For more information, see Taleb 2007, xvii.

For example, the impacts experienced and measured due to poor energy resiliency could include the lives lost due to poor, reduced, or challenged emergency services and hospital operations. This could also extend to lives lost (and other negative health impacts) due to loss of heating, cooling, or electricity in homes and areas of refuge during and immediately after the threat. Health metrics may also include the potential impacts of additional local air pollution produced as backup generators suffer performance degradations and other generators run for longer hours per day than typically allowed (Dawson 2012; Kopytoff 2012). System operators or managers may also calculate the costs of energy lost to critical facilities such as wastewater treatment plants, potable water infrastructure, and solid waste management.

Broader metrics may include the degree to which backup generation can operate given extended transportation system failures, which might prevent fuel deliveries, and the degree to which onsite fuel storage can withstand the threat (Lacey 2014). Transportation system losses may also affect the degree to which people can reach their places of employment after the threat, especially if transportation-sector employees are unable to get to work themselves. During Superstorm Sandy, telephone and Internet infrastructure failed significantly, indicating that losses associated with the loss of electricity to cell phone towers or other telephone and Internet infrastructure may be an important resiliency metric (Hamblen 2012). Commercial and retail facilities without reliable backup systems may measure general losses due to power outages. These are some examples of metrics that could be measured; there are many more.

### *WHAT IS ENERGY RELIABILITY?*

Energy reliability describes the degree to which an energy resource is available. It includes measurements of the seconds, minutes, hours, or days that a customer is unable to obtain full service. Whereas resiliency describes a system's ability to withstand the infrequent but devastating major events, reliability describes its ability to weather "low-consequence, high probability" events (Watson et al. 2015). For example, individual facilities may experience poor energy reliability as short, sub-hour power outages that occur several times a year and are quickly resolved. However for sensitive customers—including hospitals, data centers, research facilities, and others for whom constant power is mission critical—these short outages can be very costly.

Energy reliability is most directly affected by local, low-voltage distribution systems, rather than by higher voltage distribution and transmission systems (Rouse and Kelly 2011). Reliability is typically measured in a utility-specific manner, whereas resiliency is often considered for a much broader system and for system users beyond utility customers. As one discussion of the difference between reliability and resiliency noted, "…reliability addresses the ability of a system to accomplish its objective; which says nothing about how the system response may affect the community or other social elements. Again, resilience bridges this gap by extending the system response to a social conclusion" (Watson et al. 2015).

#### Risk Metrics for an Unreliable Energy System

Facilities that are unable to run their businesses or provide designated services in an expected manner have poor energy reliability. This poor reliability has impacts and costs that can be measured across various industries, such as lost revenue at restaurants, hotels, and retail stores that must turn away customers when all or part of their facilities lack power (Bhattacharyya and Cobben 2011). Personnel time needed to address the power outages and to restore normal operations once power returns represent additional costs. Further, hospitals and data centers may incur indirect costs when they switch to backup generation, which may not perform as expected and can sometimes require certain noncritical loads to be turned down or off.

Manufacturing and agricultural facilities may incur costs due to production being slowed down or stopped entirely. This may inhibit the ability to fill orders on time and may leave products, materials, and/or experiments partially damaged or ruined when power fails in the middle of a mechanical process. As with poor power quality (discussed below), outages of even a few minutes can ruin entire runs of manufacturing processes or damage equipment that was not correctly turned off.

## *WHAT IS POWER QUALITY?*

Power quality is a measure of the degree to which a supply of electricity maintains its voltage and frequency and is free of distortions. Power quality is most often impacted by a facility's equipment, but it can be affected by the utility distribution system. Poor power quality delivered by a utility can disturb the operation of certain types of sensitive loads within a facility. In addition, certain types of facility loads can also disturb power quality. Power quality events typically last less than one second and often have no negative consequences. For instance, in a single-family home, lights may flicker momentarily when a vacuum cleaner or hair dryer is turned on. For high-tech manufacturing facilities, an unanticipated split-second variation in power quality can be very costly. Microprocessor-based controls, which run much of the equipment used in manufacturing and health care today, are highly sensitive to power quality variations (Fehr 2016).

### Risks of Poor Power Quality

Poor power quality is typically experienced as a very brief dip in a circuit's voltage. When sensitive equipment is on such a circuit, poor power quality may result in ruined materials when machinery fails or restarts at the wrong production process point; damaged or ruined machinery that is not properly turned off and thus restarts in a detrimental manner when power is restored; and lost data or transactions when poor power quality affects data centers or computers that are in the middle of processing data. Although many companies can easily withstand variations in power quality, companies that require perfect power are becoming aware of the degree to which poor power quality affects their production lines.

## *COSTS OF POOR ENERGY PERFORMANCE*

Several studies offer clear assessments of the scale of economic loss due to poor energy performance. The most conservative of these estimates finds that poor energy reliability and power quality costs the United States $79 billion a year (LaCommare and Eto 2006). Other analyses identify costs in different ways, attempting to describe all the economic costs of an energy system that fails to serve its customers and region both on a regular basis and in the face of a major threat or disaster. Ultimately, poor energy performance costs us all.

Table 1 summarizes some of the more recent and robust assessments of the cost of poor energy resiliency, reliability, and power quality. Most of the economy-wide assessments of the cost of poor energy performance are well over $100 billion annually. Although these assessments rely on different parameters and arrive at different estimates, the magnitude of economic losses due to poor energy performance is clearly in the tens, if not hundreds, of billions of dollars every year.

**Table 1. Recent assessments of the cost of poor energy performance**

| Study author | Parameters | Annual cost |
|---|---|---|
| Galvin Electricity Initiative (Rouse and Kelly 2011) | Cost of losses due to power outages | $150 billion (about 4 cents for every kWh consumed nationwide) |
| Lawrence Berkeley National Laboratory (LaCommare and Eto 2006) | Cost of poor energy reliability and poor power quality | $79 billion |
| Hartford Steam Boiler and Atmospheric and Environmental Research (AER and HSB 2013) | Cost of power outages | $100 billion |
| Executive Office of the President (2013) | Cost of weather-related outages over five minutes | $18–33 billion |
| Institute of Electrical and Electronics Engineers (Bhattacharyya and Cobben 2011) | Cost of poor power quality | $119–188 billion |
| Electric Power Research Institute (EPRI) (Hampson et al. 2013) | Cost of outages to "industrial and digital economy" businesses | $45.7 billion |
| EPRI (Hampson et al. 2013) | Cost of outages to entire US economy | $120–190 billion |
| US Congressional Research Service (Campbell 2012) | Cost of weather-related outages longer than five minutes | $25-70 billion |

Few studies have explicitly assessed the cost of poor power quality. However power quality disruptions are becoming costlier now because machinery is increasingly digitally controlled and thus is more easily interrupted by the briefest disruptions in power quality. Since IEEE's 2011 study (see table 1), the degree to which we rely on digitally controlled machinery has increased; at the same time, facilities with extensive perfect-power requirements are increasingly investing in onsite technologies to help mitigate power quality problems (Bhattacharyya and Cobben 2011).

The data center industry is at the forefront of addressing issues related to poor power quality and unplanned outages. Data centers are increasingly investing in onsite generation as the cost of outages in their industry continues to rise. According to an industry report, one minute of an unplanned outage for a data center cost an average of $8,851 in 2016. The total cost of an average outage is rising, too: to $740,357 per outage in 2016, which is a 32% real increase in the average total outage cost reported in 2010. The primary cause of unplanned outages in these facilities was identified as a failure of the facility's power supply (Ponemom Institute 2016).

Estimates on the amount of downtime in the United States vary; what we do know, however, is that US energy reliability is significantly worse than that of other developed countries. In 2013, the US Executive Office of the President estimated that between 2003 and 2012, there were 679 full outages due to weather events, each of which impacted "at least 50,000 customers" (Executive Office of the President 2013). Carnegie Mellon estimates that, in the United States, "consumers lose power for an average of 214 minutes" per year, varying by region (Kopytoff 2012), while the American Society for Healthcare Engineering's survey of its 1,558 members found that members experienced about one power outage per year from 2011 to 2014 (Winters 2014). One multination assessment found that the average amount of time that US customers lose power each year is approximately 168 minutes, compared to 15 minutes for Danish customers and 32 minutes for Germans. On average, US customers experience 1.25 power system interruptions per year, compared to 0.37 and 0.5 for customers in Denmark and Germany, respectively (CEER 2015; Chittum 2016; EIA 2018).

In a typical example, CenterPoint Energy, a Texas-based utility, reports that its customers experience an average of two outages a year, for an average of approximately three hours total. Customers experience brief (less than five minutes) outages 10 times a year. CenterPoint's customers also experience about 70 voltage sags below 90% annually. Of those, about 23 sags will see voltage fall below 70%, which is "generally considered the threshold for causing motors and other sensitive equipment to drop off-line" (CenterPoint Energy 2014).

With multiple assessments of grid reliability and resilience and multiple approaches to estimating the cost of that unreliability, it is perhaps not surprising that companies and organizations in various utility service territories have a hard time assessing what their utility's reliability performance costs them. It is similarly difficult for them to assess the economic benefits of investing in onsite energy resources to reduce the risk of poor reliability and power quality.

The benefits of investing in onsite energy generation strategies that mitigate the economic pain facilities experience are poorly understood and thus rarely valued properly. These energy assets could cost-effectively meet everyday needs while also providing more resilient and reliable energy resources during catastrophic events. The individuals and organizations discussed above could do a better job of allocating capital to manage the risks of poor energy resiliency.

## Improved Energy Performance with Onsite CHP Generation

### *COMBINED HEAT AND POWER (CHP)*

In most commercial, industrial, and institutional buildings in the United States, heat for space heating and hot water is derived from an onsite boiler, while power for electrical needs is purchased from the grid. The separate generation of these energy resources in two different places is inefficient, as is converting fuel to power at a typical centralized power generation station. Additional losses also occur as that power travels long distances over wires.

In contrast, CHP systems are onsite generation resources that produce both heat and power concurrently. CHP is not a single technology but rather an approach to using existing technologies. CHP systems generate two useful products from one fuel input, making it a much more efficient way to generate necessary energy products. Figure 1 shows an example of a CHP system.

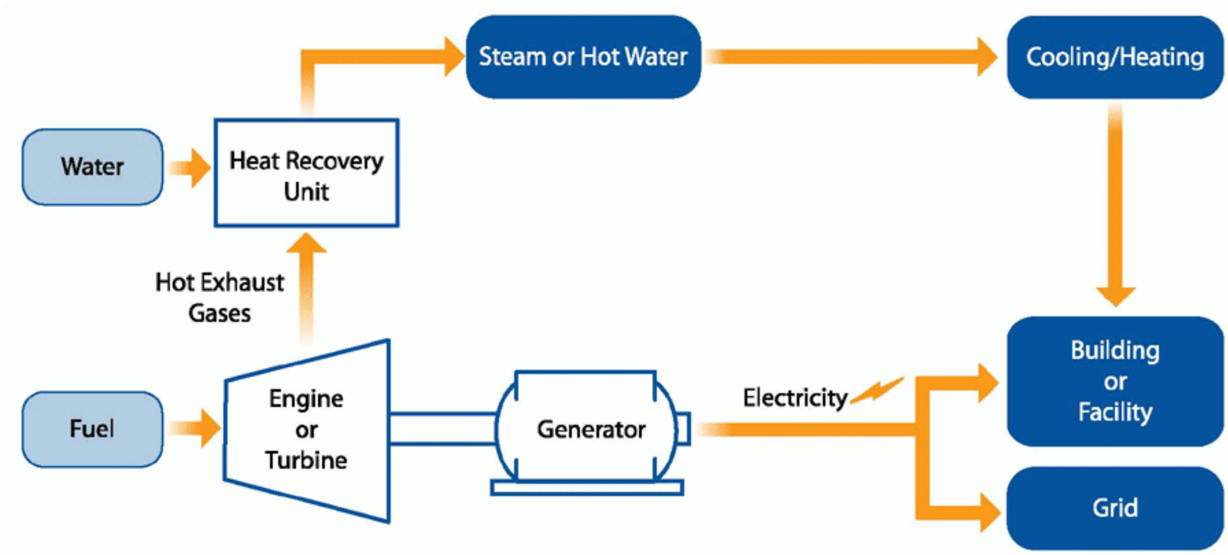


Figure 1. CHP unit using a combustion turbine or reciprocating engine. *Source:* EPA 2018.

CHP uses much of the same technology typical to traditional electric generation. However, in a CHP application, the waste heat generated from the electricity production process is captured and used instead of discarded. Gas turbines are the most common kind of CHP generation, and they are used in traditional centralized generation around the country. In a centralized, electricity-only application, gas turbines run at 30% efficiency. When used in a CHP application that recovers heat and uses it for a productive purpose, gas turbine CHP systems run at approximately 65–70% efficiency (DOE 2018; EIA 2017). This substantial increase in efficiency makes CHP a very cost-effective way to meet onsite energy needs. In terms of size, a CHP system serving a large hospital campus or multiple commercial buildings would be about half the size of a cargo container.

It is important to note that CHP is more suited to certain applications than others. For example, campuses, larger buildings, and cities (rather than rural areas) are typically well suited for CHP systems as they often have natural gas infrastructure and consistent and adequate thermal demand.

### *How Does CHP Improve Resiliency and Reliability?*

In addition to being highly efficient, CHP is also highly reliable. CHP systems are usually located in an individual building and supply it (and sometimes nearby buildings) with power and heat in the form of steam or hot water. CHP systems typically burn natural gas taken directly from the underground gas distribution lines, but buildings connected to CHP systems usually remain connected to the grid for supplemental power needs. However, in the event of a grid disruption, CHP systems can continue operating, continually producing power and steam or hot water for their connected buildings.

CHP systems are located closer to the consumption site than traditional centralized generation. This improves energy resiliency because power moves over shorter distribution lines, which reduces the likelihood that power will be interrupted by tree limbs or debris falling on electric distribution and transmission lines. CHP systems can also ramp up faster than many other power generation resources, allowing them to begin serving loads faster and respond more quickly to changes in grid-supplied power. Further, by directly supplying local loads with power and heat, CHP systems can reduce the strain on nearby parts of the electric distribution grid. This alleviates stress and reduces the chances of individual grid component failure (Chittum and Farley 2013; Moreno-Munoz et al. 2010).

CHP provides additional premium resiliency benefits above and beyond those of standard backup generation. CHP systems are typically well maintained because they operate on a near-continuous basis to provide power and heat to connected facilities under normal operating conditions. In contrast, certain types of backup power supplies are not always reliable during emergencies because they are not maintained while sitting dormant. According to the Electric Power Research Institute, backup generators will fail about 15% of the time. This is not because diesel generators are fundamentally unreliable, but rather because they sit unused so much of their lives. According to one analyst, "If you don't burn diesel fuel sitting in the tank, it will start to degrade and clog the fuel filters. Things that don't get used tend to fail" (Koerth-Baker 2012).

Many backup generators failed during Superstorm Sandy when system components, including fuel storage, were inundated with water (Kopytoff 2012). Backup generators usually rely on some onsite fuel storage designed to meet needs for 24 to 48 hours. Beyond those ranges, they rely on diesel fuel deliveries, which are often disrupted during disasters (Dawson 2012). CHP systems are usually supplied by the underground natural gas network or solid fuel stored onsite.[8] Some CHP systems are designed to run on multiple fuels and can use whichever fuel is available during a disaster.

The CHP systems that offer the most premium resiliency benefits are those that are connected to multiple buildings through a district energy system that can island itself from the grid. A district energy system connects many buildings via pipes and wires that deliver reliable energy resources generated in one main plant. District energy systems can integrate onsite energy storage, such as hot-water tanks, as well as multiple energy generation resources. CHP-based district energy systems are said to be islanding when they fully disconnect from the grid and maintain power and heating services to some or all of their connected facilities. When a CHP or CHP-based district energy system islands itself from the larger grid, it insulates its connected buildings from the surrounding grid's

[8] Most CHP resilience benefits have been documented in areas not subject to seismic hazards, and no existing studies have comprehensively assessed how CHP systems perform during and immediately after earthquakes. Additional research will be required to adequately assess CHP performance in these scenarios.

performance, allowing it to maintain service even if the grid goes down. According to one analysis, investing in the equipment necessary to island adds an additional 5–10% to a CHP project's cost, but many facilities find that the costs are worth it (Hampson and Rackley 2013).[9]

CHP systems can also yield better power quality when compared to the local grid (Darrow et al. 2015; Moreno-Munoz et al. 2010). For companies that need perfect power, such as data centers, this benefit has been very attractive and has driven CHP investment (Gowrishankar, Angelides, and Druckenmiller 2013).

### *THE PERFORMANCE OF CHP SYSTEMS DURING CATASTROPHES*

During Superstorm Sandy and Hurricane Katrina, facilities such as hospitals and wastewater treatment plants with onsite CHP remained operational and online better than counterparts without CHP. The US Department of Energy (DOE) recognized the superior performance of CHP during these disasters and commissioned a study in 2013 to examine CHP performance during Superstorm Sandy. That document reported that, in hard-hit New York State, every CHP project that received incentives from the New York State Energy Research and Development Authority (NYSERDA) and was designed to island stayed online, serving its connected facilities as anticipated during Superstorm Sandy (Hampson et al. 2013).

Table 2 highlights many of the known instances in which CHP provided facilities with reliable heat, electricity, and hot water during Katrina and Sandy.

**Table 2. Known instances of CHP remaining online during major hurricanes**

| Facility name | Location | System size (kW) | Performance of CHP system |
|---|---|---|---|
| 5th Avenue residential high-rise | New York City | 4,000 | Kept the power on for four days while the rest of neighborhood was out; powered elevators, lights, and all apartments (typically 720 residents, but this about doubled as people brought in friends and family) |
| Bergen County Utilities Authority wastewater treatment plant | Bergen County, NJ | 2,800 | Kept wastewater plants functioning during Sandy and processed sewage of 47 municipalities; other cities had to stop using water because of concerns about raw sewage, but Bergen County residents were able to use water as normal both during and immediately after Sandy |
| Central Connecticut Coast YMCA | Connecticut | 110 | Offered respite to people during Sandy |
| Christian Health Care Center | Wyckoff, NJ | 260 | Ran independently of the grid for 97 hours during Sandy, serving a 12-building, 85-acre multiservice health care facility |
| Co-op City residential complex | New York City | 40,000 | Kept heat and lights on for 55,000 residents during Sandy |

[9] The additional islanding cost is based on an analysis of CHP projects funded by the New York State Energy Research and Development Authority (NYSERDA), and is further discussed in Hampson and Rackley 2013.

| Facility name | Location | System size (kW) | Performance of CHP system |
|---|---|---|---|
| Danbury Hospital | Danbury, CT | 4,500 | Kept all 371 hospital beds online during Sandy |
| Greenwich Hospital | Greenwich, CT | 2,500 | Continued normal operations for 7 days during Sandy and admitted 20 additional patients to its 175-bed hospital |
| Louisiana State University | Baton Rouge | 20,000 | Provided most cooling and all heating for LSU during Katrina; housed all admin from University of New Orleans and LSU Medical Center; never lost power or heat |
| Mississippi Baptist Medical Center | Jackson, MS | 4,600 | Met almost 100% of the 624-bed hospital's power, cooling, and hot-water needs during Katrina; operated in island mode for 52 hours as grid went down around it; was able to accept patients from other facilities; provided a headquarters for emergency first responders who needed a place to operate |
| NYU—Washington Square campus | New York City | 13,400 | System kept CHP-connected buildings running |
| Presbyterian Home and Meadow Lake Nursing Home | New Jersey | 360 | Operated in island mode for about a week during Sandy because of grid disruptions; helped local utility re-establish grid service through dual-feed substation setup |
| Princeton University | Princeton | 15,000 | Kept university running off grid for three days during Sandy; provided shelter for staff members impacted by the storm; serviced 150 buildings and approximately 12,000 people each day |
| Public Interest Data Center | New York City | 65 | Supplied own power and cooling for more than two days during Sandy |
| Salem Community College | Carney's Point, NJ | 300 | Powered Red Cross disaster relief shelter for 47.5 hours during Sandy; Davidow Hall served as shelter for 85 people and 12–15 relief workers |
| Sheraton Edison Hotel Raritan Center | New Jersey | 250 | Offered respite to people during Sandy |
| Sikorsky Aircraft Manufacturing Plant | Stratford, CT | 10,000 | Kept manufacturing online and provided 9,000 people/day with charging for cell phones, showers (could be reserved for their families), and hot meals; provided 25,000 people with services (friends and family) |
| South Oaks Hospital | Amityville, NY | 1,250 | Provided services for two weeks during Sandy, relying solely on CHP; served 245-bed hospital and also admitted patients from other sites and offered refrigeration for vital medicines; provided similar services in 2003 blackout |
| Stony Brook University | Stony Brook, NY | 40,000 | Supported 7,000 students on main campus during Sandy while grid went down |
| The College of New Jersey | Ewing, NJ | 5,200 | Operated in island mode for about a week during Sandy because of grid disruptions; helped local utility re-establish grid service through dual-feed substation setup for 39 buildings on 340 acres |

*Sources:* Anderson 2005; R. Araujo, manager, sustainability and environmental, health, and safety programs, Sikorsky Aircraft Corporation, pers. comm., November 2015; Chittum 2012; Hampson et al. 2013; Pentland 2012; Stanley 2012.

Many organizations have taken notice of CHP's reliable performance. In the wake of Sandy, the US Green Building Council's NYC Building Resiliency Task Force examined near-term opportunities to ensure more resilient buildings of all types during the next major weather catastrophe. One of its primary recommendations was to consider building-scale CHP for various building types to create a more reliable energy resource than traditional backup generators (Urban Green Council 2013).

Various arms of the US military have identified CHP and CHP-based microgrids as a critical component of resilient and reliable energy for their installations around the world.[10] In 2016, the secretary of the Army issued a memorandum to some of its most critical commands, including its Medical, Material, Reserve, and Installation Management Commands, as well as the director of the National Guard, announcing an Army-wide goal to double (to 200 megawatts) the amount of CHP installed on Army installations over the next two years. The secretary also requested that each command "develop an overarching CHP deployment strategy…that appropriately considers CHP as a key element of the Energy and Sustainability Strategy and has applicability to all land holding commands" (Fanning 2016). This echoes other efforts to deploy CHP for reliability purposes throughout the Department of Defense and the federal government.[11]

DOE also launched a CHP for Resiliency Accelerator, designed to provide tools and support for cities that want to understand how to deploy CHP for maximum resiliency value. To date, about two dozen partners have joined the Accelerator, and will work to ensure that CHP is considered when doing larger-scale resiliency planning (DOE 2016a).

### *CHP's Role in the Grid of the Future*

Clearly, the future energy grid will look very different from the grid we recognize today. After Superstorm Sandy, states along the eastern Atlantic Coast began identifying microgrids as pieces of critically important resiliency infrastructure. Microgrids are a major trend shaping the future of distributed energy resources, and CHP is the primary driver of most in-place US microgrids today (Wood 2016). Microgrids also typically include some sort of distributed generation such as solar energy and a battery or storage infrastructure.

A *microgrid* is defined in various ways, but it generally comprises some type of distributed energy generation or storage, as well as an electric infrastructure to bring the electricity to connected buildings. For some programs and policies that define microgrids, the ability to island from the grid is a defining characteristic. Some states take that further, as in New Jersey, where the New Jersey Energy Resiliency Bank requires that a microgrid be able to island for five days and exhibit a minimum efficiency of 65% (New Jersey Resiliency Bank 2014). In such cases, CHP is likely needed as few other resource types could meet these requirements.

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[10] Microgrids are electric-only district energy systems that can operate in parallel or fully islanded from the broader electric grid.

[11] For a detailed look at how different defense branches are considering CHP and energy resiliency, refer to the Hard Power effort led by the Pew Charitable Trusts (Pew 2015).

Microgrids are a type of district energy network. These networks can maximize their potential flexibility and benefits by combining energy-efficient buildings, storage, load shedding, and onsite generation. The potential for CHP and CHP-based microgrids to boost nearby resiliency, as well as that of the larger grid in which it sits, is a burgeoning field of scientific research. Because CHP is located near the consumption point, the systems can help mitigate strain on local distribution and even on the transmission system. This benefit is especially valuable when the grid is most strained.

The inclusion of CHP in microgrid settings and in settings where the connected facility can be flexible in its use of CHP-provided energy services is attractive to utilities that need flexible and reliable electricity resources. For example, the CHP system serving the Sikorsky Aircraft facility in Stratford, Connecticut, offers quick load-shedding capabilities to the local utility. This load shedding lets the utility continue its supply to other facilities during times of extreme energy demand (R. Araujo, manager, sustainability and environmental, health, and safety programs, Sikorsky Aircraft Corporation, pers. comm., November 2015). In another example, Florida's Amelia Island is served by a single transmission line. A recently deployed CHP system operated by the local utility provides a more reliable electric generating resource and reduces line losses. Customers now benefit from the redundancy provided by two resources (Chesapeake Utilities Corporation 2018).

## How We Misallocate Energy Capital

While CHP improves energy resiliency and provides tremendous additional benefits, the United States currently has only 82 gigawatts (GW) of CHP capacity installed, or about 8% of installed electric generating capacity. DOE estimates that 240 GW of additional CHP capacity is currently technically possible in existing buildings (Hampson and Wang 2014). Most of that potential will likely go unrealized, however, in part because many facilities find it difficult to economically justify CHP investment as its (possibly very significant) resiliency benefits are not fully valued in project cost screening. CHP requires a significant upfront investment; when considering only the benefits of increased energy efficiency, the return produced can be marginal. Therefore, even though systems can offer continuous benefits for 20 to 30 years, most organizations do not consider them a priority investment.

This challenge reflects a larger issue: the energy resources market has many imperfections. Information is not equally available, for example, and regulations support status quo market structures. Energy infrastructure investors such as utilities often realize greater rewards for conventional investments than they do for investments in energy efficiency and resiliency. So, while CHP might make greater economic sense than conventional resources in a theoretical scenario, it often fails to do so in reality because it is neither fully valued nor encouraged.

When it comes to making decisions about energy infrastructure investment, both micro and macro factors create a poor accounting of full risk profiles. At the micro (facility) level, individual facilities have little data to anchor a risk assessment for poor grid performance. Likewise, scant information is available to help a facility owner or decision maker determine the degree to which CHP would provide economic benefit over business-as-usual energy resources such as an onsite boiler and grid connection. At the macro (society/economy-wide) level, the planning mechanisms that utilities use to identify future energy investments (discussed in more detail below) do not significantly prioritize resiliency. Stakeholders interested in broader energy system resiliency also lack frameworks to adequately value premium resiliency performance.

We now discuss some of the primary stakeholders that currently lack a context in which to appropriately value CHP's resiliency benefits.

### *INDIVIDUAL FACILITIES THAT COULD USE CHP*

Every year, new CHP systems are deployed around the country, primarily for their energy and cost savings. The most common investment calculation a potential CHP-using facility undertakes compares the costs of generating heat onsite and buying power from the grid with the cost of generating both products onsite with CHP. The cost difference is determined, and the facility or company makes an investment decision based upon its established target for return on investment. Where CHP projects are being built, they are justified primarily on the basis of how the system will reduce overall operating costs and emissions, and improve efficiency (Dawson 2012). Resiliency is not often part of the decision-making framework and is rarely part of the financial cost–benefit analysis.

Although CHP systems might make broad economic sense, individual facilities are often hamstrung by their own internal investment guidelines. For example, a facility or company may have a well-established existing requirement that effectively requires investments to pay themselves back in three years or less. Because there is no way to monetize the full resiliency value, a CHP project may not prove its full financial worth for six years. So, even though it provides broad benefit to the facility and society for decades, the CHP project would be incapable of passing an initial screening test.

For example, an agricultural company with multiple facilities in the western United States described an internal assessment that revealed the price the company was paying for very short-duration power outages. The manager responsible for the facility's energy use was interested in considering CHP for its resiliency and reliability benefits, but the CFO was uncomfortable using the estimated costs of outages in investment decision making. In fact no clear guidance exists on how to value avoided downtime (sometimes called uptime) in any sector. Thus the agricultural company effectively used a value of zero for avoided downtime, even though internal leaders recognized that the value was certainly greater than zero (Smock 2013). The new CHP projects did not go forward.

Certain sectors might be better suited than others to consider valuing avoided downtime, and these considerations might look very different from sector to sector. For some, the rare but catastrophic event might be less important than the "death by a thousand cuts" of the frequent, short but highly disruptive outages. Walgreens, for example, aims to maintain business continuity and provide medications and other critical products during disasters. Viewing the ability to withstand major weather events as a competitive advantage, it has incorporated energy resiliency into general facility investment planning (R. Araujo, manager, sustainability and environmental, health, and safety programs, Sikorsky Aircraft Corporation, pers. comm., November 2015).

Today, individual facilities often address the risk that blackouts pose by investing in onsite backup generation because the capital cost of doing so is low. Demand for small electric generators has grown since Sandy. One forecast put the 2018 demand for diesel generators at $41 billion and for small natural gas generators at $10 billion (Lavelle 2013). These house-by-building responses, however, do not address broad societal needs for more resilient energy infrastructure. Further, backup generators can compromise local air quality, require fuel deliveries, and may not be regularly maintained, reducing their reliability (Hampson et al. 2013). Using them does not represent the best use of energy infrastructure dollars.

### *ENERGY RESOURCE PLANNING*

Electric utilities are the largest investors in US energy infrastructure. Through their integrated resource plans (IRPs) and other long-range plans, utilities assess the kinds of resources that would best meet their future needs. However most fail to assess whether more distributed resources, strategically sited, might provide better and more cost-effective system resiliency options for consumers. IRPs and other investment decision-making plans that utilities present to regulators do not typically assess the likelihood of certain distribution resources being challenged by catastrophic weather events. Plans also do not typically assess whether alternative infrastructures, such as CHP and CHP-anchored microgrids, might better mitigate related damages.

Energy resiliency is bigger than a single building or facility. Considering resiliency on a geographic scale that parallels a utility's service territory is one way to think about the broader regional impact of resilient technologies. Utilities are uniquely positioned to invest in strategically sited resiliency infrastructure such as CHP because they can socialize resiliency costs and benefits. Regulators establish frameworks to value the societal costs and benefits of different investments. Utilities can undertake projects with long investment time horizons because utility investors accept lower rates of return in exchange for low risk and routine dividends. Utilities also have a full view of their system and can best target CHP and CHP-based microgrids to areas they deem most vulnerable or challenged.

Utility resource planning is conducted through established cost tests that delineate the specific costs and benefits of different investments. Resources that appear to be the lowest cost over a long period are prioritized. When reliability issues are identified, they are typically addressed by investing in distribution infrastructure, such as new substations or, increasingly, batteries.

CHP and microgrid benefits are most realized at the distribution system level. Distribution assets are the most vulnerable to weather events and have the least amount of redundancy. Additionally, distribution assets that regularly operate at or near peak experience higher line losses than the 7% average assumed by the US Energy Information Administration. As system and components reach their peak, marginal losses for each additional kilowatt (kW) can result in losses of up to 20% (Chittum and Farley 2013). One analysis by Lawrence Berkeley National Laboratory found "that the majority of power outages are…due to events that affect the local low-voltage distribution system" (Rouse and Kelly 2011). Energy resource planning rarely considers or calculates the value of siting CHP in locations where it might alleviate strain and stress on the low-voltage distribution system lines.

In the few cases where IRPs consider CHP, they do so for its baseload kWh contribution as an energy resource. For instance, PacificCorp considers CHP systems as resources for the different territories included in its IRP, but mostly as Qualified Facilities under the federal *Public Utility Regulatory Policy Act of 1978* (PURPA) framework (PacifiCorp 2015).[12] CHP is considered regardless of its location, which ignores its specific geographic benefits to local facilities and the status of the distribution system serving the facility. Incentives for CHP deployment are available for new systems regardless of where they are located or how they help improve grid resiliency. A move to better value CHP's specific locational grid benefits could reduce the reliance on incentives for CHP projects and better allocate funds to the projects that will provide the most benefits to both individual facilities and broader grid systems.

### *LOCAL RESILIENCY PLANNING*

In the past 10 years, resiliency planning at the local level has rightly captured the attention of mayors and other local leaders. Efforts such as the 100 Resilient Cities, pioneered by the Rockefeller Foundation and ICLEI's Resilient Cities forums, have established resiliency as a key consideration for urban planning activities (100 Resilient Cities 2018; ICLEI 2017). The field of resiliency planning is nascent enough, however, that there is no widely accepted approach to valuing increased resiliency. Unlike carbon dioxide ($CO_2$), where widely accepted values and proxies exist for the $CO_2$ reduction benefits of different types of energy resources and policy activities, increased resiliency is hard to clearly quantify.

Many programs and policies encourage CHP and CHP-based microgrids for their resiliency benefits, but most do not offer the financial decision-making context required to make investments in these resources happen. For example, in Pennsylvania, the Public Utility Commission proposed a statement on CHP that encourages utilities to, among other things, "make CHP an integral part of their… resiliency plans" (Pennsylvania PUC 2016). This kind of statement is encouraging, but it will not likely yield the specific consideration of strategically sited CHP in future resource planning until utilities are clear on how they can value those resiliency benefits.

In New Jersey, the Energy Resiliency Bank uses federal Community Development Block Grant funds to support microgrids and distributed resources for resiliency purposes. The funds are designed to strengthen areas damaged by Sandy by encouraging microgrids and other resources that can automatically disconnect from the grid, can serve critical loads for seven days without delivery of fuel, and can start up by themselves should the grid fail. However the grant program does not offer a cost–benefit investment framework in which the resiliency and reliability benefits are ascribed any specific economic value (New Jersey Energy Resilience Bank, 2014).

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[12] PURPA established the category of Qualified Facility (QF) for certain types of distributed generation. In some areas of the country, distributed generation resources can obtain QF status and compel a utility to buy their kWh output. However the price paid for this output is often too low to justify many projects, and it does not account for other benefits that the distributed generation resource might provide.

In Connecticut, the Green Bank and the Department of Energy and Environmental Protection (DEEP) fund energy projects that include CHP upgrades and microgrids. However, when the bank and DEEP assess the assets' estimated financial performance, they do not account for their resiliency benefits. The pro forma analysis considers hard revenues, such as payments for power sold under power purchase agreements and sales of renewable energy credits, but not annual avoided costs of outages. As a condition of funding, the DEEP program requires annual reporting of the number of times a microgrid islanded from the grid and the microgrid's annual savings to users, yet there is no guidance on how those savings should be calculated. The savings are also not included in the overarching project financial analysis.[13] Decisions about investments are based instead on an assessment of how the assets will perform during regular operating conditions.

Local governments recognize that failed critical facilities will negatively impact their constituents and communities and put significant burden on remaining facilities. Cities and states may deem certain facilities that could serve as refuge areas, such as wastewater treatment plants and public buildings, as critical for resiliency planning purposes. Cities may target these facilities for premium energy performance assets. States such as Texas, Louisiana, and Washington now require critical public buildings that are new or being renovated to consider CHP for its resiliency benefits (ACEEE 2017). However these policies do not encourage the economic valuation of this added resiliency.

Unfortunately, there are few efforts to account for the costs a community bears when energy resources do not perform as expected. For instance, when a New York City hospital's backup generation failed during Superstorm Sandy, city emergency vehicles were dispatched to help transfer critically ill patients to other nearby hospitals (CBS News 2012). Costs such as these are not calculated when cities, counties, or states make decisions about energy infrastructure to meet future needs.

### *INVESTORS AND SHAREHOLDERS*

The degree of energy vulnerability is not disclosed in most public-facing documents that shareholders use to determine how to value a company. Although publicly traded companies are supposed to disclose information material to their operations, what they choose to disclose is up to them, and most of their annual reports note in only a broad way that they might be susceptible to natural disasters and power interruptions risk (R. Ament Marquigny, senior counsel, ombudsman operations, U.S. Security & Exchange Commission, pers. comm., February 29, 2016). Such disclosures and discussions are typically found in the Management Discussion & Analysis (MD&A) portion of the 10-K, the annual report that publicly traded companies file with the US Securities and Exchange Commission (SEC) (R. Araujo, manager, sustainability and environmental, health, and safety programs, Sikorsky Aircraft Corporation, pers. comm., November 2015).

There is no legal definition of what is "material" to operations, and companies that do disclose certain risks are not required to discuss what they might be doing to address those

[13] See the Connecticut Department of Energy and Environmental Protection for detailed filings on the DEEP microgrid grant program (CT DEEP 2015).

risks (H. Phadke, research director, Sustainability Accounting Standards Board, pers. comm., November 2015). Thus, companies are on their own to convey to shareholders how certain investments might avoid costs related to downtime. Because there is no industry-wide standard that gives investors a clear idea of valuation of energy resilience, shareholders cannot easily compare how different companies are addressing risks associated with poor energy performance.

Additionally, companies have well-established premium standards, such as Leadership in Energy and Environmental Design (LEED) and the International Organization for Standardization (ISO) certifications, that they may follow in full or for parts of their facilities. LEED reflects exemplary building-scale energy and environmental performance, but does not reflect a valuation of improved energy resiliency. ISO standard certifications include 9001, which reflects systematic quality management within an organization's core business areas, and 50001, which reflects an organization's exemplary management of energy resources.

Empirical evidence shows that adherence to LEED and ISO standards confers actual economic benefits to organizations (USGBC 2015; Yaron and Noel 2013). Establishing these standards allows for clear tracking of the value participating organizations receive, and that value is now better reflected in investor valuations (Yaron and Noel 2013). In the case of ISO standards, an "ISO methodology" was developed to help companies value their efforts to achieve certification (International Organization for Standardization 2014). Still, as we noted earlier, there is presently no widely accepted standard for measuring and valuing a company's energy resiliency.

### *THE ACCOUNTING INDUSTRY*

For the purposes of financial statements, an asset's value depends on the value of cash flows the asset yields over a certain time period, which can also include a valuation of the losses avoided by the asset's presence over time. In financial statements, asset valuation on paper is directly linked to the value of the underlying physical asset in question. Usually, there is a market mechanism for determining the asset's value that offers a clear and widely accepted way to determine a value for that asset class. CHP's resiliency benefits currently lack this widely agreed-upon and easily understood valuation mechanism, in part because the value of resiliency is not traded in any financial market.

"The further you move away from an actively traded asset, the harder it is to justify using a particular value for an asset within standard financial statements," said a member of the Financial Accounting Standards Advisory Council (FASAC), which influences the development of new accounting standards. Further complicating the matter is the fact that resiliency's value is highly dependent on numerous variables that will change from sector to sector and across geographies. "Financial statements do not deal well with things that have means and large standard deviations," explained the FASAC member.

Accountants reviewing the financial statements of companies that are investing in CHP or CHP-based microgrids have no established basis with which to determine whether the valuation of resiliency benefits is justified. A standard way to describe resiliency's value across sectors and geographies could help alleviate this problem.

### *THE INSURANCE INDUSTRY*

If there is one industry that is laser focused on accurately assessing risk, it is the insurance industry. Challenges and risks related to climate change are being directly addressed by many of the largest insurance companies today. A worldwide 2012 study of insurance companies found that about 25% of them were "crafting innovative insurance products" to address the risks presented by climate change, especially catastrophic weather events. Insurance companies recognize that their exposure to climate change-induced losses is rising, and that their product lines must adapt and reflect climate science and adaptation practices (Mills 2012).

Poor energy resiliency in the form of blackouts and long-term outages disrupt almost every part of an economy, and losses extend far beyond a particular outage's duration (Maynard and Beecroft 2015). Recent catastrophic events have resulted in immense payouts far above predicted maximum payout amounts to customers holding both commercial and individual insurance (McHale and Leurig 2012). PSEG, the New Jersey utility roiled by Superstorm Sandy, recently settled a $264 million lawsuit with its insurance company for unpaid coverage for power generator losses during Superstorm Sandy (O'Neill 2015).

Several major insurance product categories are triggered by poor energy resiliency during disasters. These categories include coverage for power plants and utilities with losses related both to damaged equipment and to responding to and repairing the damage. Costs associated with regulatory fines "for failing to provide power" and coverage for a loss of business income (often referred to as "business interruption" insurance) may also be triggered. This can help a company make up for losses associated with many types of disruptions, and it is often linked directly to the financial value of lost or damaged product.[14] Coverage for extra expenses incurred during a business interruption can help cover costs such as for hiring additional staff to make up for a mechanical failure. Liability insurance for a single affected facility might be called upon to cover losses related to the cost for failing "to protect its workforce" or to deal with impacts of a poorly managed "polluting accident" or some other effect of a power failure. Various other types of specialty coverage may also be triggered by specific situations such as "event cancellation" or destruction of shareholder value triggered by poor management, which could be covered under the liability insurance of "directors and officers" (Maynard and Beecroft 2015).

Although insurance companies are aware of the impacts of climate change and the need to make intelligent decisions about appropriate adaptation strategies, they are not yet reflecting the premium resiliency provided by CHP in their underwriting activities. Interviews with more than a dozen US insurance companies conducted as part of our research found that none offer products that explicitly reflect the reduced risk a facility using CHP might represent. In many cases, these individual companies did not know about

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[14] Standard business interruption insurance may not pay on claims related to the grid going down if the facility that is covered did not experience any direct damage (S. Bushnell, president, Stephen Bushnell and Associates, pers. comm., October 2015). However specialty insurance policies and "contingent business interruption" policies often explicitly cover losses related to poor power quality or total power failure, and are typically used in industries where losses due to power failure can be substantial (N. Blaine, senior vice president, Wells Fargo, pers. comm., October 2015; S. Bushnell, president, Stephen Bushnell and Associates, pers. comm., October 2015).

CHP and indicated that it would likely be treated just like any other backup generator, even though CHP has a very different risk profile from a standard backup generator.

To date, insurance experience with distributed generation has largely been with risk exposure when onsite generation equipment, such as photovoltaic panels, fails or causes problems. Insurance companies want to know that onsite generation has been given the dedicated personnel necessary to safely operate the machinery, and that the equipment is going to perform as expected. Onsite fuel storage is also often viewed as a liability (AAIS 2006), though any sort of backup generation is typically viewed as a mark of conscientious building management.

"A firm that has its own power generating capacity is generally considered to be a better risk," explains the American Association of Insurance Services (AAIS). "When you have your own power, even for emergency purposes, it demonstrates that you have taken precautions to maintain operations and limit losses" (AAIS 2006). By maintaining a facility's lights, heat, and operational capabilities, a company may reduce the risk associated with loss of business products. It also reduces the risks associated with the building being vacant, such as the risk of vandalism (AAIS 2006).

The insurance industry has begun to understand that *green* properties are generally less risky to insure. Companies and facilities that monitor and manage their energy use are generally less risky customers. One insurance company, Fulcrum Insurance, offers discounts on insurance products to businesses that are LEED or ENERGY STAR certified, because it has seen evidence that these facilities are less risky overall since more attention is paid to the entire building's operations. For instance, Fulcrum has found that new LED bulbs cause fewer fires and correspond with a safer indoor environment that sees fewer third-party claims (E. Arthur, Fulcrum Insurance, pers. comm., March 2015).

Given the electric grid's cybersecurity risks, some insurance companies are beginning to establish clear ways to estimate downtime at various types of facilities.[15] This could lay the foundation for broader discussions around valuing energy system resiliency and help address the reluctance insurers feel when faced with a new and unfamiliar product class. When something is unfamiliar and insurers do not have the data they need to comfortably analyze risks, they demand higher deductibles and generally set lower limits. It is a cautious industry that requires robust data to make appropriate risk assessments. Presently, the data to fully articulate the premium resiliency benefit CHP and CHP-anchored microgrids offer over both the grid at large and traditional backup generators simply do not exist in a comprehensive way.

## Gaps in Energy Resiliency Data

Each utility service territory has its own energy performance characteristics, as does each CHP system and microgrid. For example, downtime costs affect hospitals very differently than furniture manufacturers. Whether it is a CFO deciding about investing in a single CHP

[15] The Lloyd's of London *Business Blackout* report takes a deep dive into the costs and effects of a cyberattack on the US power sector (Maynard and Beecroft 2015).

system or a state identifying the benefits of encouraging its utilities to invest in multiple CHP-based microgrids, good data are critical for good decision-making. While pockets of good data exist, we do not have the sufficient documentation of CHP performance needed to inform decision making for most applications. We explore the state of actionable data around energy resiliency below, and Appendix A lists specific data sources available for the various data categories.

### *CHP Systems and Microgrid Performance*

CHP systems and CHP-based microgrids have been around long enough that their performance has been monitored extensively. However there are only a handful of new CHP projects in each state every year, and they are typically bespoke solutions for each customer. Performance data have only recently been collected across a wide swath of CHP projects, and they do not reside all in one place.

The insurance industry harbors concerns that available CHP performance data are imprecise because the way programs measure system performance varies from state to state. Further, vendors may claim that a system configuration averages 45% energy savings, but that means that some projects are far more efficient, while others are far less so. According to an insurance industry executive, when customers look at bids for CHP systems, they are driven by cost, so there is concern that corners may be cut, which could impact future performance (D. Tine, product development manager, R. Jones, senior vice president of research and engineering, and G. Sansbury, senior client manager, Hartford Steam Boiler, pers. comm., June 2016). This does not pair well with insurance products designed to insure performance given a certain set of design parameters. Real-world performance data are necessary to provide a full picture of CHP system performance beyond the vendor's specifications.

Real-world data points that could be collected on CHP and microgrids include the following:

- The number, duration, and cause of unexpected outages
- Operational efficiencies and temperature of heat output
- Maintenance needs and performance of components as assessed during regular maintenance
- Number, duration, and success of attempts to fully disconnect and island load from the grid

In this data collection effort, it is critical to identify the role of an in-place operation and maintenance (O&M) program. Insurers expressed comfort in dealing with energy service companies on distributed generation projects because they believed that project investors would not abide a lack of precision or attention to O&M activities, and they would require appropriate measurement and verification as well as continuous commissioning. Absent documented regular maintenance and performance measurement, they would assume that the project would continually degrade.

A long history of CHP programming at the state and utility level has generated an array of data on CHP system performance that could be mined for applications in resiliency valuation. Recent programs that explicitly encourage microgrid deployment are also tracking system performance. Sources of performance data include the following:

- Annual evaluation reports for CHP programs run as energy efficiency programs in states like Maryland, New York, Massachusetts, and California
- Case study data maintained by individual CHP and microgrid project developers
- Data collected by NYSERDA and DOE in their package deployment efforts that document performance data of CHP and related equipment in different configurations and catalog systems as a single product in a one-stop shop approach to customers[16]
- The database of existing CHP systems maintained by ICF International on behalf of DOE[17]
- Performance data for microgrids supported by funding from states such as in New York and Connecticut, where islanding capabilities are explicitly called out in performance data requirements
- Performance data for microgrids deployed as demonstration projects by the National Laboratories and other academic research centers

Appendix B also contains a list of programs and resources that may offer publicly available data on CHP and CHP-anchored microgrids.

### *GRID PERFORMANCE METRICS AND DATA*

Standard protocols exist to describe energy reliability, and several metrics commonly used across the electricity sector are collected and published for most US utilities. Metrics that describe the performance of the distribution system include the following:

- *System Average Interruption Frequency Index* (SAIFI). The number of times that an average customer experienced an outage over the course of a year.
- *System Average Interruption Duration Index* (SAIDI). The length of total outages (in minutes) that the average customer experienced over the course of a year.
- *Customer Average Interruption Duration Index* (CAIDI). The average length of a single outage that the average customer experienced over the course of a year.

These metrics often exclude major catastrophes—such as hurricanes or earthquakes—and instead describe high-probability, lower-consequence events such as brief outages due to a minor windstorm or minor equipment failure. Further, utilities define for themselves what constitutes a major event for their data collection efforts. The SAIFI, SAIDI, and CAIDI numbers are thus more representative of the typical, rather than exceptional, customer experience.

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[16] DOE's program requires participating developers to offer a multiyear warranty on their package system's performance, further building and strengthening confidence in the market. In this way, the expected performance could be integrated into risk assessment and underwriting with greater confidence.

[17] See DOE 2016b for the ICF CHP database.

SAIDI, SAIFI, and CAIDI are useful for determining a utility system's reliability, but they make it somewhat hard to compare utility to utility and region to region because of the differences in reporting requirements. In 35 states, utilities have a requirement to report reliability metrics, and about half of US states have set reliability goals for their utilities (Rouse and Kelly 2011). A major drawback of using these metrics, however, is that they do not adequately describe how a system handles a catastrophic disruption. Further, because they describe the average customer experience, they also fail to pinpoint specific areas of the system that might be uniquely susceptible to outages.

We know that US SAIDI, SAIFI, and CAIDI metrics compare unfavorably to those of other developed countries (Rouse and Kelly 2011). However they also vary dramatically from one US utility to another. Therefore, to be valuable, a true assessment of the risks and avoided costs related to outages must include utility-specific data.

Figure 2 shows the 2005–2015 SAIDI minutes for utilities that annually report their reliability statistics to the IEEE Working Group on Distribution Reliability. The 96 utilities included are of all sizes and represent about 90 million customers across the United States and Canada. This group is considered broadly representative of the North American utility sector. The figure shows the utilities in quartiles based on their reliability performance; those with the shortest total disruption of the system had well under 100 minutes of outages during the year, while those with the longest disruptions had total outages of 1,000 minutes. The figure also shows that the worst performing utilities (those in the fourth quartile) had larger deviations, while the best performing utilities (those in the first quartile) had smaller deviations. This suggests that reliability data for customers in the fourth quartile utility service territories especially should be utility-specific rather than a deemed metric derived from national or regional averages.

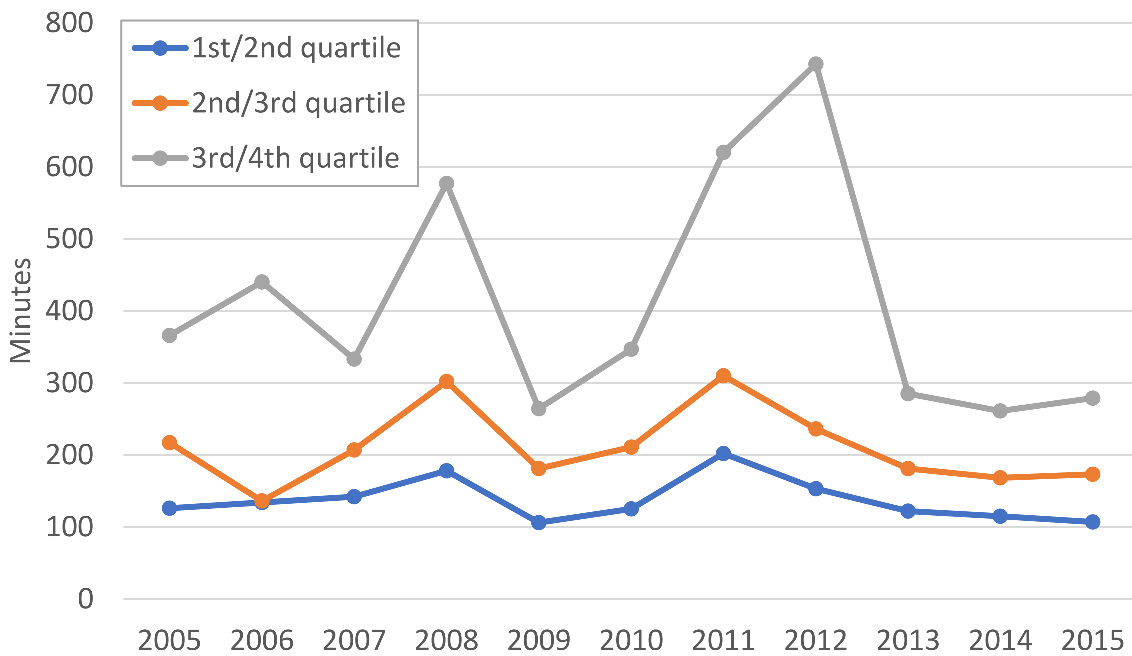


Figure 2. Total reported SAIDI minutes 2005–2015 by utility performance quartile. *Source:* IEEE 2016.

Other metrics describe the broader resiliency of an individual utility given potential threats. One common metric is *loss of load probability* (LOLP), which describes, in each hour, the probability that a utility's generation capacity will fall below its demand. Utilities engaged in long-term planning assess LOLP and other metrics of various scenarios to determine how different investment plans might impact their ability to serve customers.

While utilities typically report reliability data in aggregate across their service areas, specific areas of a given distribution system, such as an area served by a certain substation, might be more constrained than other parts of the system. For this reason, data on the specific geographic areas that experience the most strain would be useful. To the extent that utilities collect this information, most do not disclose it publicly, primarily for security reasons.

Most utilities also do not model how different types of weather events and other disasters will impact specific parts of their systems. For instance, ice storms can take longer to recover from than wind storms, so combining weather impact models with historical utility performance information could help companies better understand how facilities located in different areas of the country might be impacted by different weather events (D. Tine, product development manager, R. Jones, senior vice president of research and engineering, and G. Sansbury, senior client manager, Hartford Steam Boiler, pers. comm., June 2016).

### *OTHER BACKUP SYSTEM PERFORMANCE*

Traditional backup diesel or natural gas generators can give facilities peace of mind that they will have service during outages. However, according to the Electric Power Research Institute, backup generators fail about 15% of the time (Kopytoff 2012). There is little additional evidence to either support or dispute this claim, although it is clear that we need additional data on typical generator performance. Companies such as generator manufacturer Generac collect data on their backup generator performance and analyze them in comparison with batteries. Additionally, using uninterruptible power supply (UPS) equipment, which provides shorter backup supply for critical electronic loads, can be assessed to determine the typical cost of systems for certain industries. These costs can inform whether using CHP might reduce the need to invest in substantial UPS equipment. At a system level, this analysis should include consideration of substation-sited storage, which utilities can deploy to meet short-term backup needs.

Many critical facilities, such as hospitals, are required to maintain a certain amount of onsite backup generation. For hospitals, building code requirements for backup power, emergency lighting for stairs and hallways, and so on, are already embedded in facility design.[18] However emergency and standby power is typically diesel-powered in the health care sector. Recent analysis indicates that certain types of health care facilities prefer CHP to backup generators. The City of Portland, Oregon, recently approved a change to its building codes and now allows buildings that had previously been required to have backup generators to have CHP instead. This decision was based on a Portland-specific

[18] Examples of codes applicable to the health care industry include the National Fire Protection Association's 110 standard for emergency and backup power and its 99 standard for health care facilities (NFPA 2018).

determination that CHP can provide premium reliability and offers additional benefits on a daily basis (Portland Bureau of Development Services 2016).

### *THE COSTS AND VALUE TO USERS*

When the grid goes down, whether for five minutes or five days, the economic impact to different facilities can vary substantially. Thus, the willingness of consumers to pay to mitigate that risk will vary as well. There appear to be significant data on how different sectors of the economy are economically impacted by poor energy performance, and there are many ways to value improvements in energy performance.

One approach is to examine the different assessments that utilities use to understand what "reliable service" means to their individual customers. Table 3 summarizes a 2015 meta-analysis by the Lawrence Berkeley National Laboratory examining the variation in costs of downtime for different types of businesses.

**Table 3. Estimated interruption costs per event (2013$)**

| Customer class | Momentary | 30 min. | 1 hour | 4 hours | 8 hours | 16 hours |
|---|---|---|---|---|---|---|
| Medium and large commercial and industrial (C&I) facilities | | | | | | |
| Cost per event | $12,952 | $15,241 | $17,804 | $39,458 | $84,083 | $165,482 |
| Cost per average kW | $16 | $19 | $22 | $48 | $103 | $203 |
| Cost per unserved kWh | $190 | $37 | $22 | $12 | $13 | $13 |
| Small C&I | | | | | | |
| Cost per event | $412 | $520 | $647 | $1,880 | $4,690 | $9,055 |
| Cost per average kW | $187 | $237 | $295 | $857 | $2,138 | $4,128 |
| Cost per unserved kWh | $2,254 | $474 | $295 | $214 | $267 | $258 |
| Residential | | | | | | |
| Cost per event | $4 | $5 | $5 | $10 | $17 | $32 |
| Cost per average kW | $3 | $3 | $3 | $6 | $11 | $21 |
| Cost per unserved kWh | $31 | $6 | $3 | $2 | $1 | $1 |

*Source:* Sullivan, Schellenberg, and Blundell 2015

As table 3 shows, sectors experience different impacts; a very short outage is likely to cost a residential customer much less than it will cost a large commercial facility. As noted earlier, manufacturing companies that have product and equipment damaged or ruined during unexpected outages are often very negatively affected by these outages. The 2015 meta-analysis looked at the difference in costs to medium and large commercial and industrial customers for manufacturing and nonmanufacturing facilities. Figure 3 shows that manufacturing facilities suffer far more damage on average than nonmanufacturing ones.

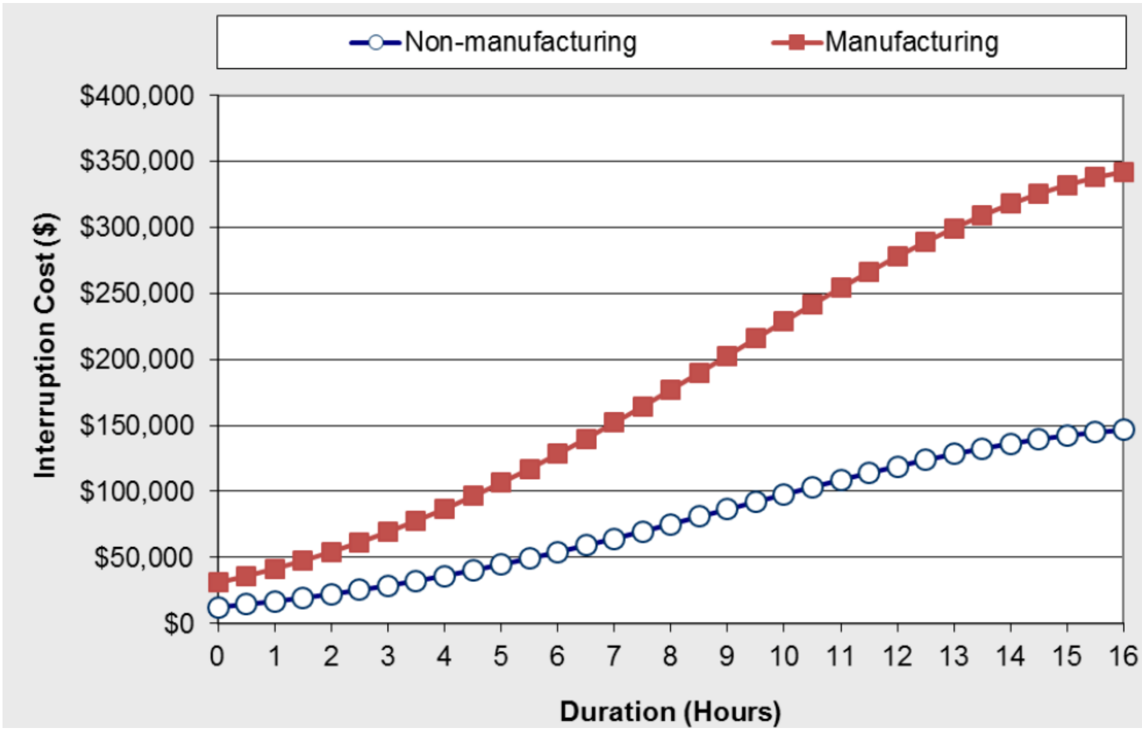


Figure 3. Estimated summer customer interruption costs (US 2013$) by duration and industry for medium and large commercial and industrial facilities. *Source:* Sullivan, Schellenberg, and Blundell 2015.

If the difference in downtime costs for different kinds of residential customers were small, it would make sense to derive one average factor to use in cost-benefit analyses. However these data suggest that sector-specific analyses of the costs of poor energy resiliency must be conducted, especially for sectors with high variations. In situations where the difference between different types of facilities is significant, as is apparently the case in commercial and industrial facilities, it makes sense to derive subsector-specific factors. Table 4 shows a 2009 analysis of how different subsectors experience outages.

Table 4. Estimated average electric customer interruption costs per event by duration (2008$)

| Sector | Momentary | 30 min. | 1 hour | 4 hours | 8 hours |
|---|---|---|---|---|---|
| Medium and large C&I | | | | | |
| Agriculture | $4,382 | $6,044 | $8,049 | $25,628 | $41,250 |
| Mining | $9,874 | $12,883 | $16,366 | $44,708 | $70,281 |
| Construction | $27,048 | $36,097 | $46,733 | $135,383 | $214,644 |
| Manufacturing | $22,106 | $29,098 | $37,238 | $104,019 | $164,033 |
| Telecommunications & utilities | $11,243 | $15,249 | $20,015 | $60,663 | $96,857 |
| Trade & retail | $7,625 | $10,113 | $13,025 | $37,112 | $58,694 |
| Finance, insurance, real estate | $17,451 | $23,573 | $30,834 | $92,375 | $147,219 |
| Services | $8,283 | $11,254 | $14,793 | $45,057 | $71,997 |
| Public administration | $9,360 | $12,670 | $16,601 | $50,022 | $79,793 |

| Sector | Momentary | 30 min. | 1 hour | 4 hours | 8 hours |
|---|---|---|---|---|---|
| Small C&I | | | | | |
| Agriculture | $293 | $434 | $615 | $2,521 | $4,868 |
| Mining | $935 | $1,285 | $1,707 | $5,424 | $9,465 |
| Construction | $1,052 | $1,436 | $1,895 | $5,881 | $10,177 |
| Manufacturing | $609 | $836 | $1,110 | $3,515 | $6,127 |
| Telecommunications & utilities | $583 | $810 | $1,085 | $3,560 | $6,286 |
| Trade & retail | $420 | $575 | $760 | $2,383 | $4,138 |
| Finance, insurance, real estate | $597 | $831 | $1,115 | $3,685 | $6,525 |
| Services | $333 | $465 | $625 | $2,080 | $3,691 |
| Public administration | $230 | $332 | $461 | $1,724 | $3,205 |

*Source:* Sullivan et al. 2009

As table 4 shows, a very short outage is likely to cost an agricultural company much less than it will cost a manufacturing company, which reinforces the notion that specific subsector analyses of the cost of poor energy resiliency are required in certain sectors.

One tool, the Interruption Cost Estimate Calculator (ICE), developed and maintained by the Lawrence Berkeley National Laboratory and Nexant, incorporates significant data about the various costs of downtime to various sectors. It can model the costs of poor energy reliability for up to 16 hours and can make estimates about costs based on reported system reliability data (e.g., SAIFI and SAIDI) and the facility's state of operation. ICE automatically populates key factors, such as the expected times of day during which outages occur, the area's economic makeup, and the prevalence of backup generators in the area (Nexant 2018).

### *MOVING FROM DATA TO DECISION MAKING*

To effectively utilize existing data on energy performance and any new data identified going forward, individual facilities and energy system planners must be able to compare apples to apples. At present, the value one company finds in a proposed investment in onsite CHP may not translate to a company across the street. Beyond better normalization of data, more data points must be collected to help move the discussion of CHP benefits beyond the anecdotal. Although enough data exist to begin these discussions, substantial gaps remain.

## Leaders in Valuing Energy Resiliency

Although the data are not as robust as some would hope, there are examples of programs and organizations that have done a better job of integrating energy resiliency and reliability data into actionable information for decision making. The worldwide interest in improving resiliency requires that we assess how to define the term and how to develop our infrastructure in a way that meets resiliency needs. This section explores some of the existing approaches to valuing the energy resiliency of different investments and offers evidence that it is not only possible to integrate energy resiliency into investment decision making, but that it is indeed already occurring.

### NY PRIZE

New York, more than other states in the country, has identified energy resiliency as a key driver within the total overhaul of the state's energy regulatory framework. One of the main efforts to encourage investment in highly resilient energy infrastructure is NY Prize, a competitive program that aims to fund the development and deployment of resilient microgrids, many of which are anchored by CHP (NYSERDA 2017a). Microgrids in the program must be able to fully island from the grid and to *black start*—that is, to turn on without any outside power supply so that they can begin operating when the grid is down.

NY Prize established a clear cost–benefit analysis framework for microgrids entered into the competition. The costs and benefits are designed to reflect the sector-specific impacts of outages both short and sustained. The NY Prize approach to valuation of improved resiliency and reliability includes the quantification of many different metrics that help better characterize how much an outage would impact a certain facility. Table 5 shows some of the metrics incorporated into the cost–benefit tests delineated by the NY Prize program. The values have been populated for a fictional hospital-based microgrid. In this scenario, the metrics describe the value to the community of a hospital staying online rather than failing and requiring that critically ill patients seek care elsewhere.

**Table 5. Selected resiliency metrics considered in NY Prize program and exemplary values for a hospital project**

| Metric | Metric type | Exemplary value |
|---|---|---|
| Likelihood of backup generation failure | Percentage | 15% |
| Annual emergency department (ED) visits per capita | ED visits/person | 0.40 |
| Increase in ED visits during a natural disaster | Percentage | 25% |
| Cost of time | 2007 dollars per hour | $28.11 |
| Cost of mileage | 2008 dollars per mile | $0.51 |
| Number of people per trip | People/trip | 2 |
| Death rates per capita from acute myocardial infarction (AMI) | Deaths/person/year | 0.000509 |
| Death rates per capita from unintentional injuries | Deaths/person/year | 0.000397 |
| Increase in number of deaths due to a one-mile increase in distance (due to AMI) | Percentage | 6.04% |
| Value of a statistical life | 2008 dollars | $5,800,000 |

*Source:* NYSERDA 2015

The above metrics are only a small portion of the ones NY Prize incorporates into its cost–benefit framework. Applicants can add and adjust the metrics based on information specific to their project and location. The framework incorporates the area grid's known performance and also considers existing backup generator performance.

In addition to a cost–benefit test that incorporates resiliency valuation, the NY Prize framework also includes consideration of whether certain geographic areas would be particularly well served by microgrid deployment. Called *opportunity zones*, these areas have constrained distribution system infrastructure and would benefit from a strategically sited microgrid system. Figure 4 shows how opportunity zones are presented to potential project developers.

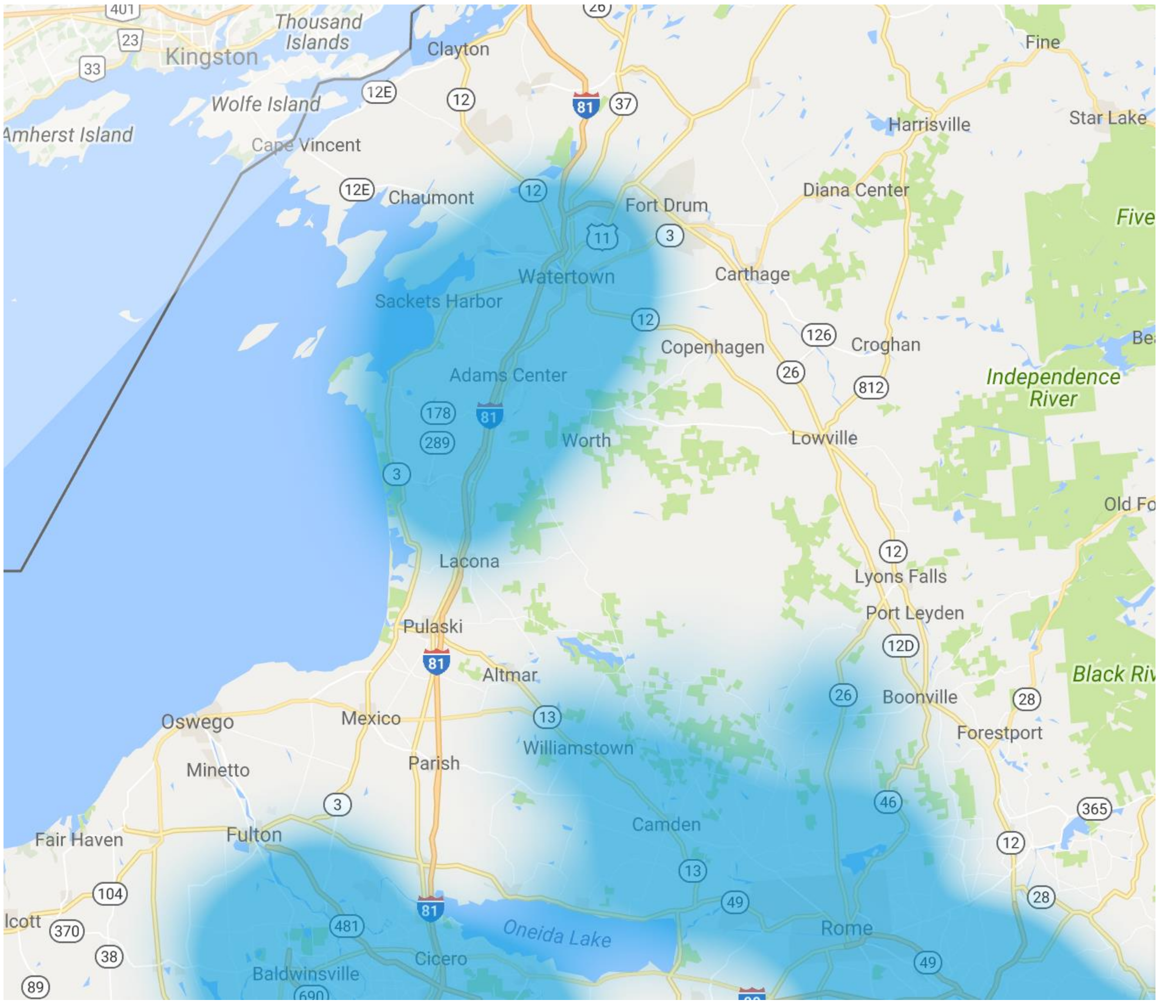


Figure 4. Opportunity zone for NY Prize program around Watertown, New York. *Source:* NYSERDA 2017b.

The opportunity zone information is purposefully vague, as utilities are typically hesitant to share detailed data on their distribution system components, and there are very real national security concerns associated with sharing such information. To address this, the NY Prize identifies specific facilities—fire stations and potential shelters, such as school buildings, for example—within an opportunity zone to help communities identify possible microgrid hosts.

### *CALIFORNIA DISTRIBUTION RESOURCE PLANNING AND CHP PROGRAMS*

California has identified CHP for its emissions and efficiency benefits, and increasingly for its resiliency and reliability benefits in grid areas that are particularly constrained. California now requires distribution resource plans from its regulated utilities. In these plans, utilities consider optimal locations to deploy distributed resources, including "distributed generation, energy efficiency, energy storage, electric vehicles, and demand response technology" (CPUC 2018a).

This rulemaking is explicitly focused on encouraging utilities to identify the locational benefits of various distributed resources, and to identify where those resources would bring the most benefit to their distribution system. To calculate these benefits, utilities considered avoided costs that distributed resources would yield, including

- Avoided substation and feeder infrastructure investments
- Avoided transmission capital expenditures
- "Any societal avoided costs which can be clearly linked to the deployment of [distributed energy resources]"
- "Any avoided public safety costs" that can also be linked to the deployed resources (PG&E 2015)

These benefit categories include improvements to a utility system's reliability and overall resiliency. Importantly, this planning framework encourages a feeder-by-feeder opportunity assessment to get a more detailed look at how such resources could support a grid. While the plans developed as a result of this rulemaking do not take a focused look at CHP islanding capabilities, they do establish an important precedent for California's largest utilities to begin embedding some of these harder-to-quantify benefits in their cost–benefit analyses.

SoCal Gas offers its customers an optional tariff called GO-DERS that is designed to encourage greater deployment of CHP and CHP-based microgrids. The utility makes the initial investment in infrastructure at customer sites, and the customers then own all the energy products. Projects considered under the tariff will use the same avoided-cost assessments as the California Self-Generation Incentive Program and the above-mentioned distribution resource plans.[19] The direct, grid-supporting benefits of projects developed within this framework and the locational benefits can be included in financial decision making.

### *HARTFORD STEAM BOILER*

The Hartford Steam Boiler (HSB) insurance company, a subsidiary of Munich Re, has developed two distinct products that help customers better identify and enjoy the resiliency benefits of distributed generation.

In conjunction with Atmospheric and Environmental Research, HSB developed and markets a blackout risk model that allows users to "predict the severity of business impacts" from outages, as well as the associated economic loss (Munich Re 2017). The model can assess vulnerability down to the zip code level and analyze a variety of different grid disruptions,

[19] California's Self-Generation Incentive Program provides rebates for qualifying distributed energy systems. For more information see CPUC 2018b and Appendix A here.

each with its own thumbprint on the electrical grid (D. Tine, product development manager, R. Jones, senior vice president of research and engineering, and G. Sansbury, senior client manager, Hartford Steam Boiler, pers. comm., June 2016). Interestingly, the primary customers of the service thus far have been other insurance companies interested in determining their own exposure related to blackouts.

HSB also developed Energy Shortfall, which underwrites the specific risk that a given distributed energy generation system will not perform as designed or intended. The company relies on significant in-house experience to assess the performance of CHP and other types of distributed generation projects to determine the risk associated with a certain project configuration. This includes the technology involved, the fuels, the location, and the planned operations and maintenance of the system.

Policymakers perceive each CHP system and microgrid as unique, and view generalizations about their performance as insufficient to inspire confidence in their resiliency (GBCI 2018). Energy Shortfall and products that other insurers might offer would address the uncertainty parties feel when determining whether CHP and CHP-based microgrids can truly offer resiliency benefits. A system with an Energy Shortfall-type of policy would seem safer to rely on for resilient power when the grid goes down.

### *PERFORMANCE EXCELLENCE IN ELECTRICITY RENEWAL (PEER)*

The PEER rating process is the only national attempt to evaluate power system performance and sustainability using a wide swath of performance indicators, including resiliency and reliability. PEER is administered by the US Green Business Certification, Inc., the same entity behind the LEED rating system (GBCI 2018).

PEER rates power systems on reliability and resiliency, which includes SAIFI and SAIDI data, as well as capabilities not previously addressed in any widespread utility analysis. These include the following:

- The ability of all or part of the system to island during a broader disruption
- The ability of a system to load-shed nonpriority loads and serve priority ones
- The presence of black start capabilities
- The presence of an alternative electric generation resource connected on the customer side of the meter
- The presence of a protocol to regularly assess the potential impact of catastrophic weather events on the system (GBCI 2018)

PEER is targeted at large utility systems and at microgrid and district energy systems at the local and campus scale. A critical aspect of PEER's approach to rating electric systems is that it compares them against other systems within the specific region to account for regional variations. For facilities considering a CHP investment, PEER ratings could be used to assess the resiliency of their area grid, as well as act as a mechanism for recognizing the increased benefits that grid-connected CHP brings for all grid users.

### *THE SUSTAINABILITY ACCOUNTING STANDARDS BOARD (SASB)*

The SASB is an independent standards-setting organization for sustainability accounting standards. It encourages both publicly traded and privately held organizations to more effectively disclose their use of raw materials, natural resources, and other inputs to improve transparency and better represent risk to investors (H. Phadke, research director, Sustainability Accounting Standards Board, pers. comm., November 2015). SASB is developing voluntary standards to encourage companies to disclose more information about energy use, energy management, and dependence on the local grid. It targets companies and organizations on a sector-by-sector basis and develops guidance and standards to help them identify and populate the metrics most applicable to their industry.

SASB's goal is to better inform investors about the material risks of their targeted companies, especially those risks that pertain to overall environmental sustainability. These standards improve transparency and give investors information about the energy reality facing each company. SASB identifies the economic sectors in which energy management is a material issue that could affect a company's finances.

SASB standards include disclosing the degree to which a company generates its own power and how exposed a facility is to catastrophic weather events such as hurricanes. By establishing a standard through which companies report this information to investors, SASB is building the market for better and more representative metrics. SASB is also driving investor demand for resiliency-related metrics to better value these characteristics of individual companies. A guiding principle behind all sustainability accounting is the notion that, if you measure it, you manage it; collecting data may highlight opportunities and risks a company might not otherwise notice.

## Distributed Energy Resource Resiliency Value (DERRV)

Stakeholders need a commonly accepted metric (or set of metrics) to describe the resiliency value of onsite distributed resources for both individual facilities and the grid. The development of such a metric with broad relevance, acceptance by most stakeholders, and clear protocols for data collection and analysis could underpin the development of a consensus-based standard that would help facilities and communities maximize energy resiliency.

Such a standard would help organizations implement best practices in energy resiliency risk assessments, mitigation strategies, and investment decision making. It would provide stakeholders with the necessary information to make informed decisions about risk calculation and company- or facility-specific determinations about impacts and costs. Absent this standard, a full accounting and assessment of the risks inherent in less resilient energy infrastructure will not likely occur.

A viable standard should include the aggregated resiliency benefits provided by all distributed energy resources deployed at a customer site. CHP is increasingly deployed not in isolation, but rather as part of a larger microgrid, and microgrids themselves are increasingly incorporating storage and various types of renewable generation.

As a foundation for this standard, the sections that follow propose a simple metric that we call a *distributed energy resource resiliency value* (DERRV).[20]

### *CALCULATION*

Using a DERRV, an organization of any scale could determine whether investing in CHP and CHP-anchored microgrids represents a net benefit over business-as-usual behavior (typically, full reliance on the grid). Broadly, the DERRV calculation for an individual facility would produce a value that captures the cost of the risk avoided by installing CHP.

An organization could produce a DERRV value in many ways, with a goal of determining the most likely number of downtime minutes a CHP system would avoid annually in comparison to business as usual. This could then be translated to cost savings derived from prior experience, new estimates, or industry-specific estimator tools.

Here we present one possible conceptual framework for calculating such a figure. In its simplest form, an organization could start by calculating two scenarios:

> **A. Probable downtime associated with relying on the grid** = (Probability that *X type of event* will happen in *location Y*) × (Probability that *X type of event* will cause downtime) × (Estimated length of downtime)
>
> **B. Probable downtime associated with relying on CHP** = (Probability that *X type of event* will happen in *location Y*) × (Probability that *X type of event* will cause downtime with CHP in place) × (Estimated length of downtime with CHP)

The organization could then compare the two scenarios. For example, a factory located inside a 25-year floodplain might have an estimate of the probability of being flooded for one day each year. Company executives might estimate, based on past experience, that such a flood would knock out power, and therefore production, for 36 hours. In comparison, with CHP, it will lose only 8 hours of production since it is expected to take 8 hours to get back to full power with the CHP system. The company could use these estimates and any known figures for lost revenue due to lost production to determine their relative risks of each scenario.

The DERRV can be tailored to the facility or, if desired, to a broader area. Greater accuracy might be possible with weighted average DERRV values calculated for peak and nonpeak hours, certain seasons, or certain production times. If the cost per minute of downtime is known (derived from prior experience, new estimates, or industry-specific estimator tools such as those discussed previously) the DERRV could be represented in dollars instead of minutes.

Some variables in a DERRV calculation will be less certain than others. For example, the likelihood of certain weather events occurring in given geography will rely on meteorology and climate predictions, which often have low probability and high uncertainty. The specific

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[20] For brevity, *DERRV* will be used to describe this set of metrics, though it should be considered a placeholder for use in the broader conversations this issue requires. This is the first instance of using the *DERRV* term.

physical impacts of specific weather events may be something that various industries can easily agree on, although there may be less agreement on costs.

The DERRV metric could be integrated into financial decision-making cost–benefit analyses. It could also become the numerator over a denominator representing a company's threatened economic activity such as annual revenue. That would produce a risk valuation that informs investors and others about the degree to which a company is at risk for outage-related losses, and how that risk compares to other risks or financial sensitivities.

Finally, to the extent that a facility already has other types of backup generation or is considering them, it would need to include a third scenario assessing the likely costs associated with relying on such backup generation during poor grid performance. In such cases, the DERRV could be used as a scoring mechanism to compare multiple options.

### *Development of the DERRV*

Stakeholders could work together to develop a proposed DERRV metric framework and begin collecting and organizing the necessary data. Sandia National Laboratories created a framework for developing resiliency metrics for a wide swath of the energy industry. The conceptual framework identifies appropriate processes and stakeholder considerations that can be applied directly to valuing the resiliency benefits of CHP and CHP-anchored microgrids. This Sandia framework informs the proposed activities listed in the box below (Watson et al. 2015). These activities need not be conducted in order, and many will be continually conducted throughout the effort. They represent the major activities required to establish the DERRV and begin the move toward a true energy resiliency standard.

**Framework for Developing Resilience Metrics**

- Determine who wants to participate and who will lead this effort. Identify which industry trade associations and individual companies seem most interested in addressing these threats.
- Determine each industry's relevant units of consequence in terms of the costs of poor energy resiliency.
- Assess existing available data on utility performance and the degree to which weather-impact models and other reliability data could be made more accessible.
- Collectively identify data gaps for measuring units of consequence.
- Determine how easy or difficult it will be to fill the data gaps.
- Determine whether standardized/normalized units of consequence already exist for decision making across the decision-making spectrum.
- Identify ways to use and leverage existing data now, while identifying ideal data to collect in the future. This can allow for more informed decision making today, while providing space and time for clearly articulating a more accurate and actionable data collection effort.
- Broadly share best practices in data collection and management (e.g., the suggested protocols for measuring impact within food processing facilities).
- Assign responsibility to industries to help fill data gaps.
- Create a national index of CHP and microgrid project performance that adequately incorporates not only individual system components but also the degree to which a reliable O&M program is in place. Make the index publicly available and editable. Focus specifically on known resiliency and reliability performance.
- Develop guidance for states around utility planning, specifically addressing traditional IRP planning (i.e., not cutting-edge New York or California frameworks) so that states can act now regardless of long-term regulatory changes. Piggyback on situations where avoided-cost calculations include emissions, and advocate that resiliency be included as well.
- Develop a library of suggested performance indicators for dissemination across all industries and stakeholder groups.
- Develop a model DERRV template that can be augmented for different industries or stakeholders.
- Develop a platform for sharing and exchanging best practices for using the DERRV metric.
- Identify which stakeholders would be interested in moving forward with DERRV-based standard development activities.

There is no need to reinvent the wheel in standards development. Existing consensus-based standards and valuation approaches on a variety of environmental and corporate social responsibility issues offer precedents for a standard that might use a DERRV-style metric. For example, the Global Reporting Initiative's global standards for reporting sustainability impacts include energy use and conservation efforts on a facility basis. The CDP (formerly Carbon Disclosure Project) takes a global approach to collecting and standardizing environmental performance data, geared toward providing investors and policymakers with actionable but largely nonfinancial data. The SASB discussed above also has global optional standards and guidelines for measuring sustainability impacts. These are tailored to a variety of specific industries. The Global Real Estate Sustainability Benchmark is a global organization that benchmarks the sustainability of real estate companies and real estate investment funds to ascertain the sustainability of real property relative to other similar portfolios.

There are also precedents in the energy efficiency community for developing these kinds of metrics. Deemed savings metrics establish broadly approved energy savings estimates or engineering calculations for given energy efficiency upgrades. These are used to make informed estimates about energy savings without requiring individual submetering for each building in question. On the other hand, just as some energy efficiency programs recognize that certain facilities are complex enough to require onsite metering, some facilities that wish to assess their energy resiliency will require onsite assessments of their energy risk exposure.

Building on these precedents, the development of the DERRV metric framework will be iterative, and only the most forward-thinking firms and organizations will use it initially. However a major outcome of DERRV development will be a more cohesive family of datasets that can be analyzed and augmented with new data by all stakeholders. This outcome alone would do much to move energy resiliency into a more prominent place in investment decision making.

### *DATA NEEDS*

DERRV calculation will require multiple sets of accurate data. Table 6 delineates the types of actionable information a metric should provide, and how existing data and organizations might help provide it. It also indicates the degree to which major data needs are still unmet.

Table 6. Data needs and potential sources for DERRV development

| Targeted data and metrics | Data sources | Required precision | Outstanding data needs |
|---|---|---|---|
| Reliability of the electric grid | | | |
| • Weather models<br>• SAIFI/SAIDI/CAIDI and major event data<br>• Models of weather impact on specific systems<br>• Models of other threats and impacts to grid | Private sector weather modeling companies; utilities; utility trade associations; US Energy Information Administration | At least utility-level; substation level for reliability data | Better data on localized disaster impacts, including earthquake risks |
| Reliability of the electric grid and backup generators | | | |
| • Information on typical backup generator performance during major events<br>• Data on fuel delivery constraints<br>• Uninterruptible power supply (UPS) performance data | Generator and UPS manufacturers; Electric Power Research Institute; Federal Energy Regulatory Commission; industry associations that share best practices on emergency management | Broken down by size, age, fuel, and application; fuel delivery may be geography-dependent | Better data on which on-site characteristics (including O&M history) influence generator performance |
| Costs of downtime | | | |
| • Industry and facility-led estimates<br>• Insurance company models<br>• National estimates like ICE<br>• Individual utility cost of service studies | Insurance companies; trade associations could also assess the amount individual facilities have justified paying for UPS resources/assets | Facility-specific (for individual facilities); subsector archetypes (for broader utility/city-wide decision making); might resemble $/kWh, broken down by time of day, season, etc. | |
| CHP and microgrid performance and costs | | | |
| • CHP and microgrid program performance and evaluation reports<br>• CHP and microgrid developer case studies | Utilities and third-party entities that run programs; CHP and microgrid developers; regulatory bodies that require evaluation reports | To be determined by CHP and microgrid industry and might include number of unexpected outages, number and length of attempted, successful, and failed islanding events; kW load-shedding capabilities and proven performance | Major gaps remain; are there specific archetypes that can be developed with given technologies and system designs? |

While the existing unmet data needs are considerable, DERRV developers will not have to meet all of them before improved valuation can occur. Rather, incremental improvement in data collection and gathering will continually offer better assessments of resilience. Archetypes will emerge in many categories with sufficient data collection, dramatically reducing the transaction costs associated with developing the DERRV. Coalescing around some broadly representative metrics will ensure that not every facility or utility will have to undertake a full avoided-cost assessment every time it needs a resiliency value. Instead, the facility could use data for facility archetypes and develop average avoided downtime numbers in lieu of specific data.

DERRV calculations could also be customized based on unique site characteristics. The specific data needs around local valuation will be customer and stakeholder-led, since these constituencies will be best versed in their particular reliability issues and associated costs (Dawson 2012). For instance, in New York City, a 7.5 MW CHP system at the New York Presbyterian Hospital required new investment in the distribution system's fault protection to handle the new CHP system. The local utility decided to undertake the fault protection investment after determining that the costs of a new substation, which would have been required if the CHP system had not been installed, was 14–34 times the cost of the fault protection.

On the other hand, broadly assessing the risks associated with certain weather or other disruptive events and the likely impact on the grid infrastructure would be region- or utility-specific. The public sector may need to pay for these kinds of data; currently, they are developed and maintained primarily by the private sector and are not widely available to the public.

## *PARTNERS IN DERRV DEVELOPMENT*

The development of a DERRV metric would need full buy-in from the key constituencies that stand to gain from better assessing energy resilience. Indeed, it must be led by these constituencies to ensure that it is taken seriously by all parties and produces tools that are useful and relevant to their specific needs and concerns.

A variety of stakeholders should be involved including

- CHP and microgrid developers and equipment manufacturers
- Individual industries, such as hospitals, that have major concerns about the cost of poor energy performance
- Utilities that are beginning to consider the long-term impact of deploying more distributed resources within their territories
- Cities and states interested in improving their energy resiliency
- Insurance companies that want to better understand their exposure to poor energy performance
- Investors and investor groups that wish to better assess their investment targets' vulnerabilities to energy disruptions

The following sections explore the different roles these stakeholders might play.

### CHP and Microgrid Developers and Equipment Manufacturers

The CHP and microgrid industries, including manufacturers, developers, and trade associations, should be leaders in this effort. To date, data on the resiliency benefits of CHP and microgrid systems have been project-based and largely anecdotal. The sources of this information are CHP and microgrid developers, who use widely varied approaches for collecting real-world data on their systems to help potential customers consider resiliency benefits. Proprietary issues must be considered in efforts to stimulate interaction among industry players. CHP and microgrid developers will need to work together to address these proprietary concerns while also recognizing that more uniform valuation approaches will benefit the individual industries.

Microgrid developers are deeply immersed in the question of valuing resiliency and have much of the first-hand experience around valuing improved power quality. Some of the most demanding customers of perfect power are identifying microgrids as a good solution. Developers help them quantify the costs of their existing poor power, and these values are a critical component of the financial decision-making process.

### Companies Concerned about Energy Risk

Companies and institutions that rely on resilient energy and view it as a fundamental part of their business strategy are already measuring its value, though sometimes in a less than methodical way. Facilities such as data centers, hospitals, first-responder stations, and wastewater treatment centers cannot be without power. Many of these stakeholders have trade associations dedicated to their specific needs, and some have special trade associations specifically for facility engineers. These groups could help their industries coalesce around metric collection and downtime valuation, and share best practices in tracking costs.

### Utilities

Utilities are beginning to make investments in CHP and microgrids in part because of the calculated benefits to their own systems. This is a clear sign that utilities see a business opportunity in investing in these resources and that utility resistance to CHP and microgrids is ebbing.

Utilities are facing a paradigm shift in their industry, and some are looking to CHP and microgrid deployment as a way to offer services that differentiate them from competitors. SoCal Gas, Duke Energy, Commonwealth Edison, and other utilities are taking new business directions in CHP and microgrid deployment. Utilities as yet have a brief history with controlling small distributed generation loads and considering facility-specific resiliency. New efforts to better identify where distributed resources can add value to the grid will yield valuable data about the benefits of siting CHP and microgrids in the distribution system.

Utilities are also key to accessing data on where the most stressed distribution assets are located and thus where distributed resources would be most beneficial. They will need to become active partners in the valuation effort and, like utilities in New York State, begin to share information about where their systems might benefit from CHP and microgrids.

### City and State Policymakers and Regulators

Cities have begun developing resiliency plans and making more concerted efforts to identify the facilities that must be protected from grid failure. In some instances, cities will be able to provide the best data on the cost to society when a wastewater treatment plant loses power, or the social impact when a community center designated as a disaster refuge area suffers from poor reliability. One way to encourage more holistic resiliency considerations is to distribute disaster-relief funds in a way that incentivizes investment in infrastructure that is more resilient than the infrastructure it is replacing. Resiliency valuation could help determine the best way to target such disaster-relief funds.

At the state level, utility regulators have slowly begun integrating greenhouse gas emission valuation and other societal costs into utility cost tests. State regulators design the frameworks that shape the design of IRPs, and they can encourage utilities to pay more attention to resources deployed in the distribution system. Because valuation approaches must be approved and endorsed by state regulators, they also must play an active role in designing the DERRV.

Stakeholders who are broadly concerned with promoting resiliency might consider the importance of cross-industry resiliency modeling at the regional level. A heavier reliance on natural gas by CHP and CHP-anchored microgrids is likely to mirror a heavier reliance on natural gas by centralized power plants. This issue came to a head during the Polar Vortex of 2013–2014, when both electric generators and direct-use gas customers leaned heavily on the natural gas system to stay warm in the bitter cold. No one entity is responsible for modeling these types of cross-industry and cross-geography challenges. Local, state, and regional policymakers engaged in resiliency planning could find a way to use resiliency valuation to encourage resource decisions that will withstand various worst-case-scenario modelings. It could be argued that the Federal Energy Regulatory Commission should conduct this kind of modeling, or at least help guide regulated regional transmission organizations in developing DERRV-type metrics.

Resiliency is a community issue, and insurance companies that protect physical assets are often locked in a building-by-building approach. A community needs partners to underwrite risk in a broader, more comprehensive way, and it is up to local policymakers to help support that activity. For example, as we described earlier, resiliency valuation could help determine the best way to target disaster-relief funds.

### Insurance Companies

Insurance companies exposed to grid failure include those that

- Offer business continuity insurance that is triggered by a loss of power
- Insure the performance or services associated with government facilities
- Insure utilities for liability and damages
- Insure businesses and homes against other damages that might result from blackouts

The risk is high that we will face another Katrina or Sandy or a cyberattack on the US electric grid; insurance companies plan for it and the potential damage is huge. Investing in CHP and CHP-based microgrids could improve day-to-day system reliability, while also improving the entire economy’s resilience in the face of devastating black swan events.

One researcher suggests that the effects of climate change are a stress test for the insurance industry (Mills 2012). Insurance companies typically try to protect against risks that they estimate will happen at least once every 200 years. Major weather catastrophes, and the blackouts they cause, are clearly happening more frequently than once every 200 years. Insurance companies understand that these events are well within their benchmark return periods, and the impacts of them must be adequately reflected in their risk models. This is why the most innovative insurance companies, such as Allianz, Lloyd's of London, and the Zurich Insurance Group are addressing climate change challenges head-on (Maynard and Beecroft 2015; Mills 2012, 2013). Understanding and preparing for this threat gives them a competitive advantage.

Reinsurance companies offer products that are purchased by insurance companies to help transfer risk and cover major unexpected losses. These companies are concerned broadly about the impacts of climate change on the entire insurance industry and are keen to encourage both climate mitigation and adaptation strategies. CHP and microgrid energy services typically have fewer greenhouse gas emissions than other sources. Because of this, they offer one of the few energy resiliency strategies that both mitigate climate change and protect against its effects.

New specialized offerings from companies such as Hartford Steam Boiler and Energi suggest that the market for products that insure energy project performance is growing (Energi 2018; C. Lohmann, vice president, alternative energy solutions, Energi, pers. comm., October 2015; D. Tine, product development manager, R. Jones, senior vice president of research and engineering, and G. Sansbury, senior client manager, Hartford Steam Boiler, pers. comm., June 2016). These companies will be critical partners in developing a DERRV, as they have significant data that can help us understand which data sets are most relevant for assessing project-level risk.

### Investor Representatives and Advocates

To date, only particular types of investors pay attention to reporting on corporate social responsibility (CSR) and environmental, sustainability, and governance (ESG) goals. Moving concerns about the resiliency of investments to a more mainstream investor population is an outstanding challenge. For example, organizations that may not necessarily represent mainstream investors have advocated for the disclosure of sustainability issues in publicly traded companies' financial statements (Huber 2014). However, for companies to take these kinds of disclosures seriously, mainstream investors must view them as truly material, regardless of their degree of environmental concern. Resiliency in the face of catastrophic events is an aspect of publicly traded companies that transcends environmentalism. The ability of a company to stay online and operational if the grid around it fails absolutely affects its bottom line and value to investors.

Champions of improved disclosures and shareholder transparency, such as the SASB and the SEC's Office of the Investor Advocate, can help identify how disclosure guidelines and standards would be most useful to investor groups. Investors need tools to make apples-to-apples comparisons on the energy resiliency or vulnerability of different systems in order to allocate capital in a rational manner that fully assesses and values risk reduction efforts.

## Conclusion

Only by identifying and valuing the characteristics of a robust and resilient energy system can we encourage the types of investments needed to build a system that will maximize resiliency and serve us best. To do this, we must ascribe value to the benefits that comprise resiliency in our electric grid.

Our energy infrastructure could be more resilient, as evidenced in its performance both during catastrophic events and on day-to-day reliability compared to systems in other countries. There are plenty of examples of strengthened grids and CHP-based microgrids around the country, showing that the technology is proven and available. The challenge is not a technological one, but rather one of creating policy and a common valuation practice.

The investment choices we make in our energy infrastructure lack a robust risk assessment and are thus not fully informed. Organizations that invest in our energy infrastructure lack sufficient information to make investment decisions that adequately reflect the risk of poor energy resiliency. This includes companies that invest directly in energy infrastructure, such as utilities, and indirectly, such as companies that insure facilities reliant on energy infrastructure. There are clear ways to better value energy resiliency, and they can be found across the country. We have specific examples of how to ascribe value to resiliency and how to judge the resiliency of a given suite of energy infrastructure components. So, although scattered and varied in format, extensive data exists on the performance of different kinds of energy systems. There are data gaps, but they are fillable.

We must work together to adequately develop the appropriate lens through which to view energy resiliency and to ensure that investments in energy infrastructure are well considered. The disparate industry stakeholders who stand to gain from such an effort would benefit most from a collective approach that serves their near-term needs while also giving them a tool to transform the market.

The end goal of developing a DERRV metric is to better value risk where it matters, and for whom it matters. Securing commitments and engagement by a wide-ranging group of stakeholders will be no small task. However it is a task with precedent as parties across the world increasingly tackle risk assessment and transparency issues. Further, substantial precedents exist in establishing consensus standards on a wide variety of energy and environmental issues. The processes for developing these standards are mature and can be directly applied to the issue of energy resiliency valuation.

Capital available to invest in infrastructure is limited. Full valuation of energy resiliency and vulnerability will ensure that this limited capital is optimally allocated. Our disaster relief funds could be better spent on infrastructure that is provably less vulnerable than the infrastructure it is replacing. Resiliency valuation will lead to less reliance on incentives, a more resilient electric grid, and fuller disclosure of risk to investors and insurers. It will also help inform how much individual facilities should invest to avoid the costs associated with grid downtime. It will also give us a more objective lens for utility resource planning and a better sense of which geographic areas and industries are best prepared for the ravages of climate change or cyberattacks. The ultimate result will be a smarter, more resilient US energy system to carry us through the 21st century.

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## Appendix A. Additional Data Sources

**Table A1. Additional data sources and descriptions**

| Category | Description | Link |
|---|---|---|
| Program report data on system performance | Latest California Self-Generation Incentive Program (SGIP) evaluation report | cpuc.ca.gov/General.aspx?id=7890 |
| | Latest Massachusetts CHP Program impact evaluation report | ma-eeac.org/wordpress/wp-content/uploads/Combined-Heat-and-Power-2011-12-Program-Evaluation-November-2013.pdf# |
| | Latest New York State Energy Research and Development Authority CHP program impact evaluation | nyserda.ny.gov/-/media/Files/Publications/PPSER/Program-Evaluation/2015ContractorReports/2015-Distributed-Genertation-CHP-Impact-Evaluation-Final.pdf# |
| | NY Prize feasibility studies | nyserda.ny.gov/All-Programs/Programs/NY-Prize/Feasibility-Studies |
| Resources for utility data | US Energy Information Administration data on utilities, including reported SAIFI, SAIDI, and CAIDI | eia.gov/electricity/data/eia860/ |
| | IEEE Distribution Reliability Working Group 2015 Benchmark Data | grouper.ieee.org/groups/td/dist/sd/doc/Benchmarking-Results-2015.pdf# |
| Calculating and measuring resilience and reliability | Sandia National Laboratories presentation on resilience metrics | energy.gov/sites/prod/files/2015/01/f19/QER%20Workshop%20June%2010%202014%20Posted.pdf# |
| | US Department of Energy (DOE) conceptual framework for developing resiliency metrics | energy.gov/oe/downloads/conceptual-framework-developing-resilience-metrics-electricity-oil-and-gas-sectors# |
| | US Environmental Protection Agency report on valuing CHP reliability | epa.gov/chp/valuing-reliability-combined-heat-and-power |
| | Disaster resiliency and NFPA codes and standards | nfpa.org/~/media/files/news-and-research/resources/research-foundation/research-foundation-reports/building-and-life-safety/rfdisasterresiliencyandnfpacodesandstandards.pdf?la=en |
| Estimating the costs of downtime | Estimated value of electric service reliability report | emp.lbl.gov/publications/updated-value-service-reliability |
| | DOE Interruption Cost Estimate Calculator | icecalculator.com/ |
| | Hartford Steam Boiler's blackout risk model | munichre.com/HSB/blackout-risk/index.html |

| Category | Description | Link |
|---|---|---|
| Ratings, certifications, and prizes | Performance Excellence in Electricity Renewal (PEER) | peer.gbci.org/home |
| | NY Prize competition for microgrids | nyserda.ny.gov/All-Programs/Programs/NY-Prize |
| | Sustainability Accounting Standards Board (SASB) | sasb.org/ |
| | Hartford Steam Boiler insurance products | munichre.com/HSB/products/index.html |
| Miscellaneous | California Distribution Resources Plans | cpuc.ca.gov/General.aspx?id=5071 |
| | LBNL Distributed Energy Resources—Customer Adoption Model (DER-CAM) | building-microgrid.lbl.gov/projects/der-cam |
| | Sandia NL research on grid resilience | energy.sandia.gov/energy/ssrei/gridmod/resilient-electric-infrastructures/ |
| | DOE Combined Heat and Power for Resiliency Accelerator | betterbuildingsinitiative.energy.gov/accelerators/combined-heat-and-power-resiliency |

## Appendix B. Stakeholder Groups

**Table B1. Stakeholder groups and descriptions**

| Group name | Description | Website |
|---|---|---|
| AFCOM | Professional network of IT infrastructure professionals that provides education and networking opportunities | afcom.com/ |
| American Risk and Insurance Association (ARIA) | Professional association of insurance and risk management scholars | aria.org/ |
| American Society for Healthcare Engineering (ASHE) | ASHE is a member organization of professionals dealing with health care facility design, maintenance, and operations. Its Energy to Care program encourages hospitals to benchmark energy and improve energy efficiency and resiliency. | ashe.org/ |
| Association for Facilities Engineering | Professional facilities engineering membership and certification organization that works to promote optimal operations and maintenance practices for commercial, industrial, and public facilities | afe.org/ |
| C40 Cities | Network of the world's largest cities that provides resources including knowledge sharing, resources, and networking opportunities for addressing climate change at the city level | c40.org/ |
| Combined Heat and Power Association (CHPA) | CHP trade association that brings together stakeholders to promote US CHP growth | chpassociation.org/ |
| Data Center Knowledge | News source on data centers | datacenterknowledge.com/ |
| International Risk Management Institute | Institute that provides certifications, education, and networking opportunities to insurance and risk management professionals | irmi.com/ |
| Microgrid Knowledge | News source on microgrid and distributed energy resources | microgridknowledge.com/ |
| Microgrid Resources Coalition (MRC) | Subsidiary of the International District Energy Association; its stakeholders advocate for widespread microgrid implementation | districtenergy.org/about/microgrid-resources-coalition |
| National Association of Regulatory Utility Commissioners (NARUC) | Association that works to improve the effectiveness of US regulatory commissions by providing education and advocacy resources on regulatory issues such as distributed energy integration | naruc.org/ |
| National Association of State Energy Officials (NASEO) | Organization of governor-designated energy officials that facilitates learning among state energy offices and advocates for the interests of state energy offices | naseo.org/ |
| State public utility commissions (PUCs) | Key stakeholders for approving utility actions and cost-effectiveness protocols | Varies by state |