ELECTRIC POWER RESEARCH INSTITUTE

Quick Insights

Customer Resilience in the Shared Integrated Grid

RESEARCH QUESTION

What opportunities exist for empowering and enabling customers to be more self-resilient and in doing so increase community and overall grid resilience?

KEY POINTS

- A primary challenge in discussing energy system resilience from the point of generation to the point of consumption is the complex and multifaceted nature of resiliency, which is typically assessed through two dimensions, threats and vulnerabilities—and which may include additional dimensions such as time and scale.
- As proliferation of customer-sited distributed energy resources (DER) continues, there is an opportunity to increase customer benefit and value from their investment in DER, either by enabling point-of-use resilience during outages (for instance, opportunity power from rooftop photovoltaics (PV)), or in some cases "sharing" a resource. This allows customers to maximize their investment in DER while contributing to overall community and energy system resilience.[1]
- There are unique opportunities for residential, commercial, and industrial customers to contribute to resilience, depending on the type of DER that they adopt, the business model(s) available for equipment purchase and use, and the available value streams for those on-site DER.
- Broader community resilience objectives are the starting point for conversations about customer and community energy supply resilience, and those broader objectives inform the choice of technical solutions considered for a particular community.
- The needs of the grid, energy providers, and society must be considered alongside a community's needs, to identify technical solutions that are cost-effective from an infrastructure investment perspective, that support local grid resilience, and that support broader societal goals such as economic development and health and safety improvements.

INTRODUCTION

Resilience has emerged as an important topic over the last two decades as both natural disasters and cyberattacks, among other things, have unearthed possible vulnerabilities within interconnected energy networks. Beyond impacting energy supply and the grid, these events have broad economic and societal impacts that affect customers, energy providers, and society.

1 EPRI Shared Integrated Grid Infographic, https://www.epri.com/#/pages/product/3002014551/.

In 2016, EPRI put forth that the power system needed to be more resilient, flexible, and connected as part of a larger Integrated Energy Network.[2] Resilience is conceptually complex and multifaceted in its dimensions considering threats crossed with vulnerabilities (exposure, scale, scope), and possible third dimensions that may include timeframe or scale of threats. EPRI's 2016 white paper on challenges and opportunities in electric power system resiliency defines resiliency as follows: "In the context of the power system, resiliency includes the ability to harden the system against—and quickly recover from—high-impact, low-frequency (HILF) events."[3] The importance of resiliency of the electricity grid, as a feeder to the nation's infrastructures supporting essential services within communities, was recently highlighted by Bruce Walker, Assistant Secretary, Office of Electricity at the U.S. Department of Energy, with November being named Critical Infrastructure Security and Resilience Month in the United States.[4] Additional definitions of resiliency are presented here[5] to demonstrate the variation, although these definitions have common threads including anticipation, absorption, and recovery from events. More broadly, resiliency may be thought of as a characteristic of a system where adequacy, value, and investment decisions must be evaluated from a particular stakeholder's perspective, and in the context of how they define resiliency.

> *"Infrastructure resiliency is the ability to reduce the magnitude and/or duration of disruptive events. The effectiveness of a resilient infrastructure or enterprise depends upon its ability to anticipate, absorb, adapt to and/or rapidly recover from a potentially disruptive event."*
>
> – National Infrastructure Advisory Council (NIAC), 2010[6]

> *"Resiliency is the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents."*
>
> – Presidential Policy Directive 21 (PPD-21), 2013[7]
> – Sandia National Laboratory, 2015

> *"Resilience [...] emphasizes an assessment of the system's ability to anticipate and absorb potential disruptions, develop adaptive means to accommodate changes within or around the system and establish response behaviors aimed at building capacity."*
>
> – Francis and Bekera, 2014[8]

> *"Resiliency is defined as the ability of the system and its components (i.e. both the equipment and human components) to minimize damage and improve recovery from non-routine disruptions, including high impact, low frequency (HILF) events, in a reasonable amount of time."*
>
> – NATF, 2017[9]

Research shows that the number of weather-based catastrophic events has increased over the past decade, with an estimated annual cost of $20–55 billion.[10] Looking at the largest U.S. power outages from storms through 2017 (see Figure 1),

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2 *Power System Transformation: Flexibility, Connectivity, Resiliency*. EPRI, Palo Alto, CA: 2016. 3002007377. Available: https://www.epri.com/#/pages/product/3002007377/.

3 *Electric Power System Resiliency: Challenges and Opportunities*. EPRI, Palo Alto, CA: 2016. 3002007376. Available: https://www.epri.com/#/pages/product/3002007376/.

4 November: A Time When the Nation Focuses on the Vital Importance of Keeping the Nation's Critical Infrastructure Secure and Resilient." Energy.gov. Accessed November 05, 2018. https://www.energy.gov/oe/articles/november-time-when-nation-focuses-vital-importance-keeping-nation-s-critical.

5 *Technical Assessment of Resiliency Metrics and Analytical Frameworks*. EPRI, Palo Alto, CA: 2018. 3002014571.

6 National Infrastructure Advisory Council (NIAC). 2010. "A Framework for Establishing Critical Infrastructure Resilience Goals."

7 The White House, "Presidential Policy Directive – Critical Infrastructure Security and Resilience," White House Office of the Press Secretary, February 12, 2013.

8 Francis, Royce, and Behailu Bekera. 2014. "A metric and frameworks for resilience analysis of engineered and infrastructure systems." Reliability Engineering and System Safety 90-103.

9 *Transmission system resiliency - An overview*. North American Transmission Forum. 2017.

10 Sullivan, Michael, Myles T. Collins, Josh Schellenberg, and Peter H. Larson. Estimating Power System Interruption Costs: A Guidebook for Electric Utilities. Publication. July 2018.

based on lost electricity service, two of the top five occurred in 2017.[11] Hurricane Maria caused 3.4 billion lost customer-hours with significant economic and societal repercussions.

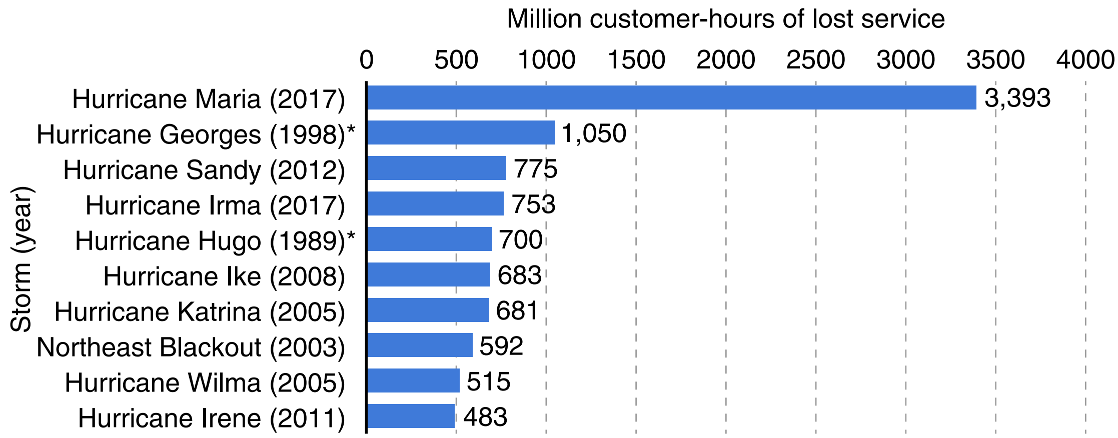
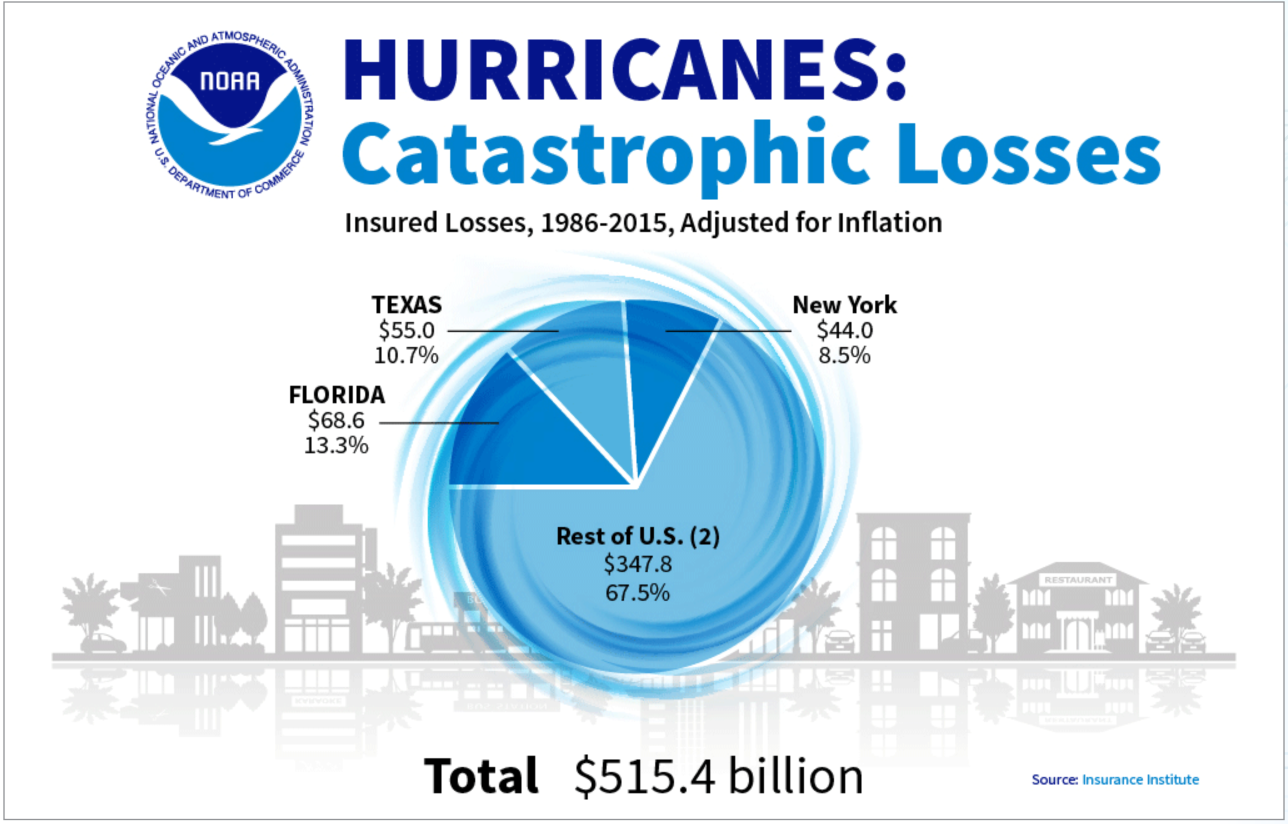


Figure 1

Summary of Service Loss from the Largest Power Outages Associated with Storms, through 2017[12]

Insured losses[13] from hurricanes from 1986 to 2015 total over $500 billion. Nearly one third of these losses came from three states; Florida, Texas, and New York.[14] As these states have higher coastal exposure, this indicates that regional differences in threats may merit different levels of investment. On the other hand, in these three states, customers are more likely to have some level of experience with multi-hour outages, and a different level of preparedness than customers in regions with lower risk of hurricanes or major- and wide-spread weather-related events. In these cases, customers may be more open to



11 Houser, Trevor, Peter Marsters. The World's Second Largest Blackout. April 2018. Accessed November 5th, 2018. https://rhg.com/research/puerto-rico-hurricane-maria-worlds-second-largest-blackout/.

12 Note: This information does not take into account natural events that occurred in 2018.

13 Insured property losses from natural catastrophes, specifically hurricanes.

14 "OFFICE FOR COASTAL MANAGEMENT." Hurricane Costs. Accessed October 29, 2018. https://coast.noaa.gov/states/fast-facts/hurricane-costs.html.

installing and using DER that support point-of-use resilience, and may more readily see the value in self- or community-supply than customers that have not had recent experiences with long-duration outages.

In an effort to combat the effects of these events, energy system resilience planning is necessary from a customer, community, society, and grid perspective. With the need for community resilience planning identified, it is important to outline the existing and potential opportunities for utilities, customers, communities, and other stakeholders.

NEW FRONTIERS IN CUSTOMER SELF-RESILIENCE

Beyond economic damages and quality of life issues arising from extended power outages, are extreme cases involving risk of loss of life. A Harvard study published in the New England Journal of Medicine estimates 4,645 deaths in Puerto Rico from Hurricane Maria.[15] Most of the deaths were not from the hurricane's immediate ferocity, but a lingering aftermath that left large swaths of the island without power for months. This translated into lack of access to hospitals, medical devices, and refrigeration for medications. The study found interruption of medical care to be the primary cause of death. Increasing resilience can better support the public in these extreme events.

From a customer perspective, the objective of resilience is to support primary needs in the event of an extended outage. As proliferation of customer-sited DER continues, there is an opportunity to increase customer benefit and value from DER, either by enabling self-resilience during outages (for instance opportunity power from rooftop PV), or in some cases "sharing" a backup resource allowing customers, from the home to the factory, to maximize their investment in DER while contributing to overall community and energy system resilience. EPRI's shared integrated grid concept imagines a future when customers' energy assets become shared energy solutions that enhance grid reliability, resiliency, and value for all.[16]

There are unique opportunities for residential, commercial, and industrial customers to contribute to resilience, depending on the type of DER they adopt, the business model(s) available for equipment purchase and use, and the available value streams for those on-site DER. Several opportunities may be available to either use DER as backup (self-resilience) or to use backup resources as DER (expanded value streams).

Comparing outage frequency without major events, to frequency considering all events (Figure 2), the majority of outages are due to routine events that impact the distribution system.[17] Point-of-use resilience technologies empower customers to invest in self-resiliency, and allow for "bottoms up" resilience improvements. In some cases these investments may compliment utility investment in DER (non-wires alternatives) to support targeted local resiliency needs.

Three primary customer needs in adapting with HILF events are communications (cell phone and internet), comfort (space heating and cooling), and refrigeration (medication and perishable foods). There are technologies currently available to help meet these needs in a power outage. For instance, customers may purchase solar phone chargers to maintain cellular communications as long as the telecommunications system is available. Refrigerators with battery backup are also available to sustain medical supplies during an outage. Additional point-of-use resiliency technologies are described in the following sections, highlighting technology development opportunities (residential advanced heating system), and opportunities to expand the value of DER investments for backup power.

15 Kishore, Nishant, M.P.H., Domingo Marques, Ph.D., Ayesha Mahmud, Ph.D., et al. "Mortality in Puerto Rico after Hurricane Maria | NEJM." New England Journal of Medicine. July 12, 2018.

16 Electric Power Research Institute. "Shared Integrated Grid." YouTube. August 13, 2018. https://www.youtube.com/watch?v=PknNL0TnCxQ.

17 Silverstein, Alison, Rob Gramlich, and Michael Goggin. *A Customer-Focused Framework for Electric System Resilience*. NRDC and EPA. Report. May 2018.

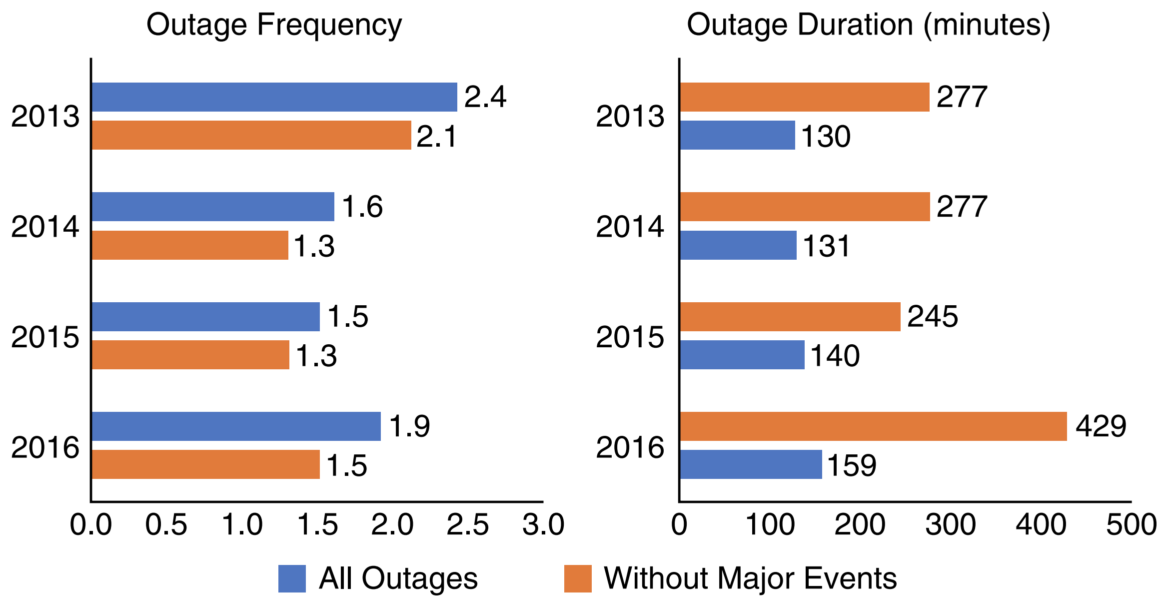


Figure 2

Summary of Customer Outages in Terms of Frequency and Duration, 2013-2016[18, 19]

Residential Advanced Heating System

Fossil-fueled furnaces are the predominant heating source in the United States, accounting for about 48% of main heating equipment as of 2015.[20] When considering customer preferences for electric vs. fossil-fueled end-use options, natural gas furnaces (41% U.S. saturation) are often thought of as a "security blanket" allowing customers to heat their homes with natural gas in the event of a power outage. Unfortunately, the systems that support gas heat require electricity including the blower that forces air across the heat exchanger and throughout the duct system into a home and controls to safely trigger furnace ignition.

There is an opportunity to design a heating, ventilation, and air conditioning (HVAC) system that is able to heat a home in the loss of grid power, maintaining minimum heating levels during longer-duration outages. EPRI is currently exploring research in this space to allow for increased point-of-use resilience in colder climates. If space heating is needed during the relatively small amount of outage time the average customer experiences, a "backup-enabled" heating system could greatly improve the customer value proposition overall.

Rooftop PV + Off-Grid Inverter

Currently customer-sited resources must cease operation with the loss of grid supply. There are commercially-available inverters with off-grid capabilities, that can supply critical loads in the event of the loss of grid supply, when the systems can no longer feed power back to the grid (illustrated in Figure 3). If installed as part of a rooftop PV system, customers can use power from their PV whenever the solar resource is available. If an inverter with off-grid capability is used when installing new PV systems, the incremental cost for opportunity power is the cost of the emergency power switch (EPS) and additional electrical work to install the switch. This system has been tested for supplying household electronics (phone charger or computer), fans, a portable space heater (900 W), and even a refrigerator.

While this basic configuration may not be able to supply an air conditioning load, it can provide basic levels of connectivity, heat, cooling (fans), and refrigeration to sustain a family during a longer-duration outage. The addition of storage with an off-grid inverter allows for increased self-reliance in the event of a grid outage. Again, while the "backup" capabilities

18 Larsen, John, Trevor Houser, and Peter Marsters. "Electric System Reliability: No Clear Link to Coal and Nuclear." Rhodium Group. October 23, 2018.

19 Note: According to the source, major events include severe weather or other unusual phenomena.

20 "U.S. Energy Information Administration – EIA – Independent Statistics and Analysis." Residential Energy Consumption Survey (RECS) – Data – U.S. Energy Information Administration (EIA).

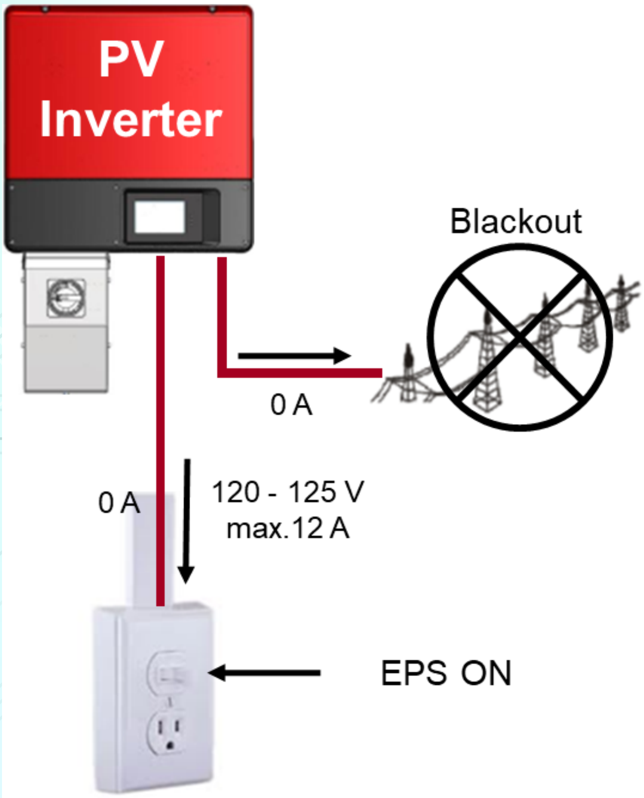


Figure 3
PV Inverter with Emergency Power Switch for use in Power Outage

of the PV system may not be needed the majority of the year, the untapped potential value added with an off-grid inverter allowing customers access to the opportunity power from this resource may outweigh the incremental costs.

Backup Generation

The opportunity for increased value in this case comes from the use of a backup resource—installed to support customer resilience during power outages—as part of a virtual power plant (VPP), or participating in markets during the majority of the year when there is no outage. Here the resource is designed and installed for point-of-use resilience, and there is an opportunity for increasing value for the asset owner in providing grid services (including energy and capacity) outside of outages.

Several commercial backup solutions providers provide turnkey backup generation for commercial and industrial customers, taking advantage of market opportunities or exploring opportunities to participate in VPPs during the rest of the year. As one example, Enchanted Rock[21] is a turnkey backup generation solution working with customers in market settings where the resource may participate in capacity and energy markets outside of its use for end-use customer backup. A second example, PowerSecure[22] also offers turnkey backup generation, currently primarily in vertically integrated utility territories, where there are opportunities to participate in a VPP supplying to a utility when there is no outage. In both cases, in market environments and vertically integrated settings, backup generation providers can a primary customer need for point-of-use resilience, while also exploring opportunities to maximize the investment by tapping into additional value streams during the majority of the year.

Community Resources: Microgrids

Microgrids connect multiple customers and customer-owned DER into a network. Microgrids support adaptability for multiple customers or a community, as opposed to the previous technology examples that support a single customer or premise. If a microgrid is sited and designed with resiliency in mind, there is an opportunity to support critical local services including hospitals, fire stations, and shelters. Again, understanding where there are year-round opportunities for value from a microgrid, for instance as a non-wires alternative to support local reliability, increases the value of the investment while supporting broader community resilience.

Empowering customers with point-of-use resilience options to support primary adaptability needs allows energy providers to focus on complimentary central infrastructure needs. For instance, to support customer communications in an outage, if customers purchase a solar phone charger (customer investment with the possibility for incentives), utility restoration of cell towers may be prioritized (benefitting all customers) over restoring a few homes (with no cell service for anyone). Understanding customer needs and preferences allows utilities to translate favorable shared resiliency opportunities into new products and services. Research needs in this space include:

1. Baseline research on how people currently value the grid
2. Baseline research of how customers currently cope in a prolonged outage

21 "Onsite Backup Power Generation – Reliable & Affordable." Enchanted Rock. Accessed November 02, 2018. http://enchantedrock.com/.
22 "PowerSecure, Inc." PowerSecure Inc. Accessed November 02, 2018. https://powersecure.com/.

3. Customer research into potential interest in new "resilience" products and services
4. Customer research on perceptions of self-resilience with PV, battery storage, gas furnace, or other relevant technologies

FRAMEWORKS FOR RESILIENCE PLANNING

The needs of the grid, energy providers, and society must be considered holistically alongside a community's needs, in order to identify technical solutions that are cost-effective from an infrastructure investment perspective. The solutions could support local grid resilience and support broader societal goals such as economic development and health and safety improvements. The opportunities identified here specifically consider expanding the value proposition of DER while simultaneously increasing resiliency.

Resilience planning is supported by frameworks that consider a mix of threats (physical and cyber) and a mix of improvement options that contribute to mitigation, prediction, adaptation. There are various frameworks and metrics already in existence which may be adapted for customer and community work. Having a consistent approach to valuing resources, whether customer-sited or centralized resources, is particularly important when considering customer-sited DER as an option in a portfolio of bulk system resiliency investment options.

Unfortunately, there is currently no standardized framework for resiliency assessment or evaluation of resiliency investment options. Unique attributes of resilience include, but are not limited to, the diversity of threats faced, and varying vulnerability and exposure to these threats, which complicates the ability to develop a standard set of resilience metrics. In the absence of more appropriate metrics, the benefits of resilience measures are being estimated with metrics that have been traditionally used for reliability planning. Critical differences between reliability and resilience point to the need for more focused research on identifying metrics specific to resilience.

While the selection of resilience metrics is situationally dependent, it may be possible to organize the metric development, identification, and evaluation process around a consistent framework. It is worth keeping in mind, however, that there is no "one-size-fits-all" metric and that resilience is not reducible to a single measurable element. Resilience can be examined across multiple dimensions, and what may be appropriate for assessing one dimension may not be appropriate for another.[23]

It is not feasible to assess, plan, and take action for all possible combinations of HILFs and their mitigation opportunities. This indicates that a risk-based approach to threats assessment is desirable to focus on higher-risk events to get the biggest combined system "bang for your buck"[24] when considering resilience investments. The Resilience Analysis Process (RAP) framework developed by Sandia National Laboratory emphasizes the importance of incorporating a risk-based approach for assessing resilience and identifying resilience metrics. Steps 3 and 4 of the RAP process state that users should identify threats and determine the level of disruption to the system caused by that threat.

EPRI developed a research framework for organizing resiliency assessments as part of its transmission resiliency initiative (see Figure 4). The framework involves five steps: threat characterization, component vulnerability assessment, impact identification and assessment, mitigation options assessment, and trial implementation. Implicit to this framework is the notion that resiliency assessment is a recurrent process that should be revisited regularly to ensure that system resiliency levels are at least maintained, if not continuously improved over time.[25]

EPRI is currently working on a project with the North American Transmission Forum (NATF) with the intent to create a transmission resiliency maturity model. This maturity model may be used by utilities to assess their resiliency posture, look for trends and areas of improvement, and help drive continuous improvement across various facets of their organization.

A framework similar to this could support customer and community planning in understanding vulnerability to a ranges of threats (focusing on customer and community impacts), and considering mitigation options to support customer and commu-

23 *Technical Assessment of Resiliency Metrics and Analytical Frameworks*. EPRI, Palo Alto, CA: 2018. 3002014571.
24 *Distribution Grid Resiliency: Prioritization of Options*. EPRI, Palo Alto, CA: 2015. 3002006668.
25 *How EPRI Transmission Resiliency Research Fits Together*. EPRI, Palo Alto, CA: 2015. 3002006429.

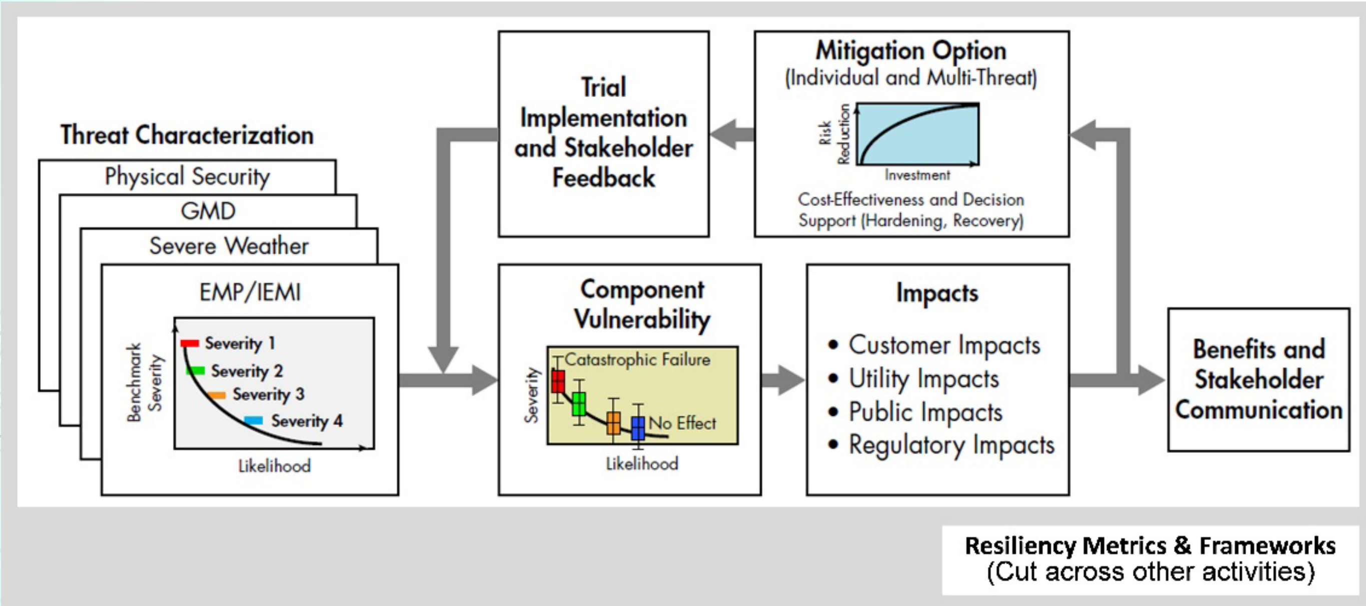


Figure 4

EPRI Resiliency Assessment Framework

nity resiliency goals. The contribution of DER to mitigation, adaptation, and recovery from the customer's perspective would be considered instead of the contributions to bulk resiliency. Depending on what level of resource sharing is considered, individual customer DER may be aggregated to take advantage of resource diversity to supply critical services, or participate in system restoration.

From the system perspective, if the resilience capabilities of customer-sited technologies are well understood, and there is value in customers "sharing" those capabilities, the aggregate DER capability may be weighed against more traditional utility resilience options to find the most cost-effective means of meeting resiliency goals. Focusing back on the customer value proposition, the components needed in a customer or community resilience "toolbox" may include frameworks, maturity models, and metrics that are based in the customer's experience.

RESILIENT COMMUNITIES—LISTEN, THEN LEAD

In terms of community resilience, energy supply resilience is just a piece of the overall picture. Aside from maintaining energy supply for individual needs, supporting critical services and infrastructure within communities is a key opportunity to maintain a minimum level of quality-of-life, and to support surrounding communities. There are opportunities for local technologies, like those discussed previously, to contribute to system hardening, adaptation, and restoration.

Broader community resilience objectives, like sustainability, economic development, and well-maintained infrastructure[26], are the starting point for conversations about community energy supply resilience, and help with decision support for the choices of technical solutions that may make sense in a particular community.

Traditionally, utilities or infrastructure owners/operators make investments in resilience, by hardening the system, increasing monitoring capabilities, improving adaptability, or improving restoration capabilities. Along with these actions comes the responsibility for the resulting levels of reliability, resiliency, and cost to customers. The needs of the grid, energy providers, and society as a whole must be considered alongside a community's needs, in order to identify technology opportunities that are cost-effective from an infrastructure investment perspective. These solutions must support local grid resilience and broader societal goals such as economic development and health and safety improvements.

The opportunity for leveraging customer or community-sited DER in adaptation and restoration following outages requires more work to effectively map the associated benefits and costs. In addition to understanding the benefits and costs, who

26 Resilience Library: International Federation of Red Cross and Red Crescent Societies, Southeast Asia Resources. Accessed October 29, 2018. http://www.rcrc-resilience-southeastasia.org/community-resilience/#1475059434629-7e43a171-e72c1475119036470.

incurs those benefits and costs also must be considered, and this will inform how investments may be made. EPRI's research could provide unbiased information for the various stakeholder groups that benefit from and invest in self-resilience technologies, providing support for those judging these investments.

NEXT STEPS/ONGOING EPRI RESEARCH

The continuing transition to a customer-focused energy future opens the door to new energy products and services, with the opportunity to include offerings that target resiliency. An understanding of DER and microgrid resilience capacities supports feasibility studies which can identify community resilience technology options, while also considering regional risk profiles and community-defined resilience goals.

Capability gaps in this space include:

1. Understanding customers' perceptions of and expectations for resilience through customer preferences research,
2. Metrics and valuation framework to capture benefits and costs of self-reliance and resource sharing from a customer perspective, which could show, for example, the increased value when investing in DER and the maximum leverage of shared resources,
3. Research into potential customer interest in new resilience-related products and services, and
4. Support in development of educational materials for stakeholders, including customers, utilities, regulators, and policy makers.

These research needs are illustrated in the following (Figure 6), underpinned by EPRI's ongoing threats assessments, infrastructure resilience research and tools, DER, and customer behavior research.

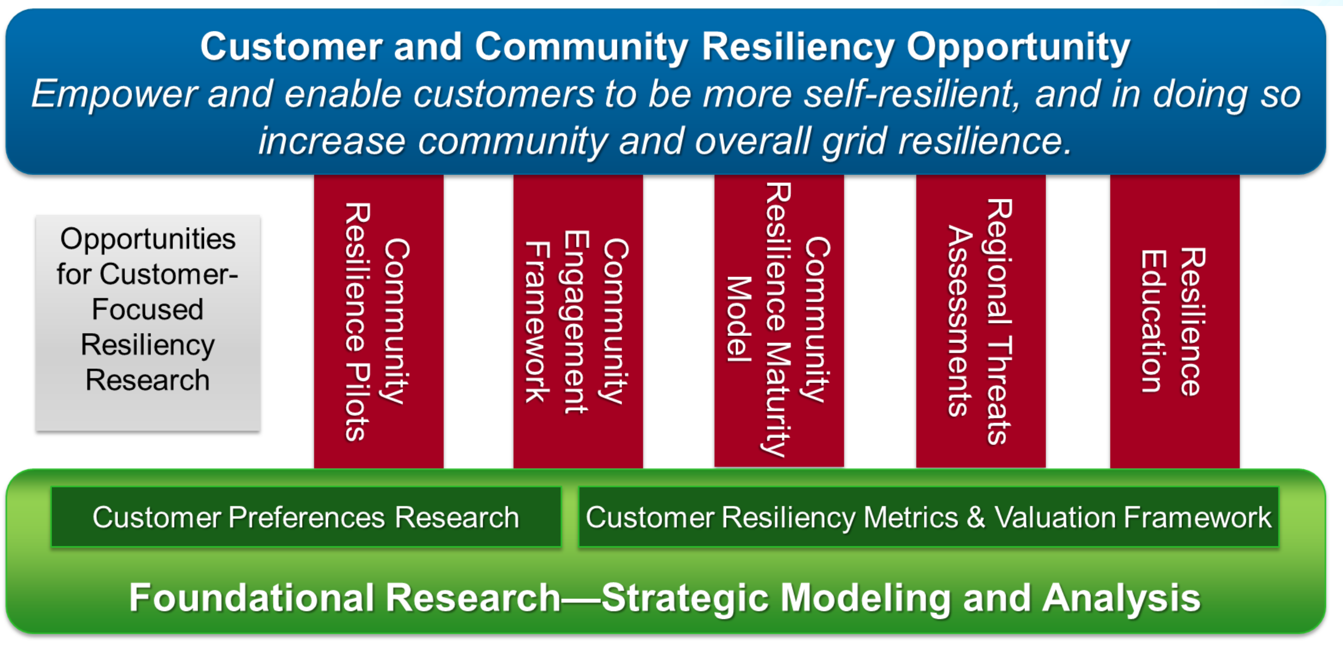


Figure 6
Customer and Community Resilience Research Opportunities

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