Resilience in Regulated Utilities

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Summary

The word "resilience" seems to be everywhere lately. As a regulatory concept, it is important to define resilience and to understand how to appropriately incentivize it. We argue that for regulators' use, it is *robustness and recovery characteristics of utility infrastructure and operations, which avoid or minimize interruptions of service during an extraordinary and hazardous event*. Resilience fits within the existing structure of reliability that public utility commissions already oversee, but is particularly valuable for dealing with severe and non-traditional hazards. The frameworks used to evaluate reliability investments are not perfectly equipped to address investments dealing with these large-scale and historically unprecedented hazards, and some improvements to the frameworks may be needed. Because making every corner of our utility systems resistant to failure may prove cost-prohibitive, resilience should be selectively applied to the areas that need it most. Existing risk management frameworks can be better deployed to help prioritize where the best investments can be made. A resilience investment may be particularly valuable in the face of high-impact disasters and threats that utility systems have not faced before, like national-scale natural disasters or man-made cyber and physical attacks.

This paper is meant to serve as a conversation-starter for policy-makers working with the electric sector and other utility sectors – particularly State public utility commissions. Its intent is to lay the foundation for establishing common definitions and developing a methodology for utility commissioners and others to consider when exploring the regulatory issues surrounding investments in utility resilience. Further work is needed to develop the evaluative frameworks that allow for strong regulatory review of resilience investments that, in the long run, may deliver more reliable and affordable service for ratepayers.

1. Introduction

Resilience is a word that's easy to love: it's been trumpeted by everyone from Charles Darwin to Dr. Seuss. Governors and CEOs alike invoke it on TV,[1] the President has put resilience as the core concept in the architecture of our nation's preparedness [2] and Public Television says it's a key to a person's lifetime happiness.[3] Lately, it has even made appearances before State public utility commissions, who have started to see requests by electric, gas, water and other companies to authorize investments in resilience as it relates to infrastructure. Given the interest in making resilience part of utility operations, systems and networks, policy-makers may want to verify that resilience means to them what it means to everyone else in the room. Even if utilities and their regulators can agree on what it is, the way we approve utility investments today may be biased against investments in resilience. It's fine to have a vernacular, everyday understanding of it, but we argue State regulators may need a better technical definition of **resilience** as a term of art in the context of their role assuring reliable and affordable service. Perhaps most importantly, being able to survive and bounce back from huge disasters and new hazards may prove enormously valuable, so regulators and utilities won't want to systemically overlook the investments that make our systems more resilient.

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[1] Govs Ritter (CO) and Whitman (NJ), http://www.resilience.org/stories/2013-07-15/risk-and-resilience-governors-ritter-and-whitman; the CEOs of TIAA-CREF, Enel, and Zurich Financial Group, http://www.pwc.com/gx/en/ceo-survey/2012/key-findings/business-risk.jhtml, and lots of others.

[2] http://www.dhs.gov/strengthening-security-and-resilience-nation%E2%80%99s-critical-infrastructure

[3] http://www.pbs.org/thisemotionallife/topic/resilience/what-resilience

So what's a commissioner to do? In this paper we propose a place for resilience within the well-understood terminology of **reliability**. We identify the characteristics that make these investments distinct from other reliability investments and highlight the scenarios when resilience investments present the highest value proposition (such as regional or national-scale emergencies like geomagnetic disturbances or non-traditional hazards like cyber attacks). Finally, we take a look at the methods used to evaluate reliability, explore why under current evaluative frameworks resilience investments might fall off the table, and propose some ideas about how they can be improved to ensure prudent investments can get a fair look.

2. Everybody Loves Resilience

Most people have a pretty good everyday definition or resilience, usually having something to do with the ability to take life's punches without getting knocked down. Psychologists define resilience as "the personal and community qualities that enable us to rebound from adversity, trauma, tragedy, threats, or other stresses—and to go on with life with a sense of mastery."[4] The word holds a special place in our lexicon, and not just for individuals. In the past decade, Presidents Bush and Obama have each praised the resilience of communities – New York, New Orleans, Boston, Joplin, Atlantic City and New York all over again – that have suffered catastrophic and tragic events. Those catastrophic events often constitute utility-constraining events like Hurricane Katrina, September 11 and Superstorm Sandy, to name a few.

Before, during and after these events, utilities serving these communities worked hard to maintain and restore service in conditions that range from everyday to what must feel like *Independence Day*.[5] When the utility companies think about how to deal with keeping service running no matter how bad the day is, they likely think of three sets of circumstances:

- A regular-day state, **before** an event happens (a "blue sky" day)
- **During** an event (like a storm or earthquake or terrorist attack)
- **After** an event (cleaning up and restoring interrupted service)

Utilities certainly invest in making their system run as efficiently as possible on blue sky days. With good maintenance and system management (like tree trimming and effective training), their everyday reliability should be pretty good. In practical terms, in this paper we refer to blue sky day reliability as **availability**.[6]

There are also choices that utilities can make that help assure that service doesn't get interrupted even in the face of a bad day: days of storms, floods, fires and other hazards. Some examples are:

- Poles made of reinforced concrete which cost more, but are harder for high speed winds to knock over than wooden poles (but they also take longer to replace than wooden poles!)
- Equipment that survives likely hazards better, like hydrophobic coatings on equipment that help repel water and reduce ice build-up

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[4] *The Handbook of Clinical Psychology*, Michel Hersen, Alan M. Gross ed., John Wiley & Sons, 2008, Pg. 836

[5] Great movie. Will Smith and Jeff Goldblum battling civilization-destroying aliens? Utility restoration crews must have had their work cut out for them after *that* July 4.

[6] Our use of "availability" to describe the system's ability to serve load in ordinary circumstances in this paper shouldn't be confused with how whose who evaluate power plant characteristics use "availability", as a well-recognized measure of electric generator performance that refers to a generating asset being available when called upon…blue skies or not.

- Adding redundant power lines and selectively undergrounding the most vulnerable and valuable ones
- Training and exercises help asset operators to be more skilled and resourceful in minimizing impacts to systems during emergencies
- Siting infrastructure in more expensive but less vulnerable locations which may help them to stay online in floods, storms, or other events

Unfortunately, despite the best efforts of the companies, sometimes the system gets overwhelmed and service is interrupted. The ways utilities gear up for rapid restoration seem obvious,[7] and utility companies will select from the menu of well-tested and proven choices available to them based on a number of factors, including the topology of their assets, the types of hazards they confront and cost-effective preparedness options. Infrastructure choices that may favor rapid restoration include:

- what types of poles to use (Wooden? Reinforced concrete? Metal?[8]);
- how to position equipment (Outside a flood area? Behind earthen dams?);
- what kinds of workers to employ (to augment their existing restoration crew battalions);
- what kinds of mutual assistance agreements to enter into;
- what local stockpiles of key replacement equipment to keep on hand; and
- whether to use funding pools, like storm reserve funds, to help clean up and replace destroyed essentials.

These options (and many more) help companies and communities get back to normal quickly if service is interrupted.

All of this costs money – paging the folks who oversee **cost recovery**! State public utility commissions care above all about reliable and affordable service by utilities, and oversee and approve prudent investments of all kinds, but the marriage of those two factors makes regulators particularly keen on those investments that cut cost and enhance reliability. These regulators ensure that utilities understand risks, articulate them and enable a comprehensive cost-benefit analysis to determine which risks to address and to what extent.

The actual enforcement of system reliability in the bulk power grid is performed by regional reliability coordinators and the North American Electric Reliability Corporation (NERC). Regulators still have to approve investments that keep the lights on as much as possible and, as part of setting the rates, terms and conditions of utility services, set service benchmarks that utilities need to achieve. To determine if a reliability investment is prudent, Commissions use formulas that weigh the costs of outages to utilities against the costs of investments that avoid or minimize outages. This responsibility is additional to the way reliability is enforced by regional reliability coordinators and NERC.[9]

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[7] For example, Pennsylvania's after action report comparing Hurricanes Sandy and Irene provide a wealth of best practices for positioning ahead of a large natural disaster. Available online at: http://www.puc.pa.gov/utility_industry/electricity.aspx.

[8] Material selection is usually defined by the type of circuit damaged. If it is a transmission circuit, certain design parameters must be maintained and will guide the selection of material.

[9] There are good resources explaining the role of NERC and the regional reliability coordinators in a 2004 primer published by the National Council on Electricity Policy called *Electric Transmission: A Primer*, online at http://www.ncouncil.org/Documents/primer.pdf. And while we're usually loathe to point people to Wikipedia as an authoritative resource, the page on NERC is also a pretty comprehensive introduction to the topic. http://en.wikipedia.org/wiki/North_American_Electric_Reliability_Corporation

This sounds straightforward. Commissions simply need to see that the utility will provide uninterrupted service as much as possible, and when it cannot, that interruptions will be as short as possible. So what's driving this new emphasis on resilience? Resilience comes in when we consider **consequence** – how bad it is for an outage to occur. Some warn that the big events that cause large-scale interruptions – storms, hurricanes, fires, floods and other calamities – are becoming more frequent or more damaging as more economic activity depends on uninterrupted electricity, gas, water and telecommunications. Others point towards new and emerging man-made hazards: sharpshooter fire on a substation, ubiquitous reports of malware probing control systems and the like. Reliability frameworks do well when faced with wind and trees, but simply weren't designed to deal with terrorist attacks or cyber warfare. No matter the avenue, the value of lost service is growing bigger each year. An event that once cost millions now costs billions because we depend more on essential services for more spheres of activity than we once did. Consider, for example, the impact of electric reliability on the internet economy, and in turn the broader economy as a whole.

A catastrophe doesn't have to happen with great frequency to be really bad news. A short outage that affects millions may be more or less impactful than a long outage that affects thousands. A huge disaster that occurs once may not be easily differentiated in a reliability algorithm from a minor event that also only occurs once. Whether it's natural disaster or man-made misery, our view is that the evaluation of resilience needs to go above what we're doing today.

3. Defining Resilience

So what is resilience, anyway? If we're going to use it to justify significant utility expenditures, shouldn't we be able to define it? Some have tried to do this already, especially in the context of national security. The National Infrastructure Advisory Council (NIAC) submitted *A Framework for Establishing Critical Infrastructure Resilience Goals* to President Obama in November 2010,[10] which builds on the Council's 2009 *Critical Infrastructure Resilience* report. That report provided the following common definition of resilience: *Infrastructure resilience 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*.[11] This definition is intentionally broad to allow for sector-specific applicability. The 2010 *Framework* is intended to narrow resilience for various sectors. Further narrowing would explore outcome-focused abilities of the system that fall under (1) robustness, (2) resourcefulness, (3) rapid recovery and (4) adaptability.[12]

The authors of this paper like that definition and think in a national security context it makes a lot of sense, especially when delving into the specific criteria:

- Robustness – the ability to absorb shocks and continue operating
- Resourcefulness – the ability to skillfully manage a crisis as it unfolds
- Rapid Recovery – the ability to get services back as quickly as possible
- Adaptability – the ability to incorporate lessons learned from past events to improve resilience

Another definition set out by Presidential Policy Directive 21 (PPD-21) argues that "the term 'resilience' means 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,

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[10] (National Infrastructure Advisory Council 2010)

[11] (National Infrastructure Advisory Council 2010), pg. 15.

[12] (National Infrastructure Advisory Council 2010), pg. 5

accidents, or naturally occurring threats or incidents."[13] That's a more useful definition for a regulatory context. But while the robustness, resourcefulness, recovery and adaptability criteria above work well for policy-makers determining what resilience means for national security, it's still too imprecise a definition to be used as a regulatory term of art.

The electricity sector has thought a great deal about resilience. NERC defines resilience of the bulk electric system via two main responsibilities – adequacy and security. NERC defines adequacy in this context as "the ability of the bulk power system to supply the aggregate electrical demand and energy requirements of the customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements;" it defines security as the "ability of the bulk power system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system elements from credible contingencies."[14] This definition is also great for the bulk system, but it doesn't capture the distribution system, not to mention the infrastructures of gas, telecommunications and water.

There are a number of other definitions of resilience, but the State utility commissions faced with the word may need a great deal more specificity for it to hold up to the evaluative rigor and scrutiny that everything gets in the regulatory world. One definition referenced by NERC's Severe Impact Resilience Task Force[15] gets very close: the ASIS SPC.1-2009 standard on Organizational Resilience[16] says, "Resilience is the ability of an organization to resist being affected by an event or the ability to return to an acceptable level of performance in an acceptable period of time after being affected by an event."

For commissioners and state staff reading this paper, we propose that a more precise working definition of resilience may be helpful:

Resilience /riˈzilyəns/ *noun, regulatory term of art*:
Robustness and recovery characteristics of utility infrastructure and operations, which avoid or minimize interruptions of service during an extraordinary and hazardous event.

In other words, it's the gear, the people and the way the people operate the gear immediately before, during and after a bad day that keeps everything going and minimizes the scale and duration of any interruptions. If an investment avoids or minimizes service interruptions in the absence of an extraordinary event, it's just an everyday reliability investment, and the means already exist for utilities and regulators to thoroughly consider it. An important point, and one not explicitly included in that definition, is that resilient infrastructure does more than one thing well, because a resilience investment needs to pay for itself and create value for ratepayers, even when it's not being used.[17]

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[13] http://www.whitehouse.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil

[14] (National Infrastructure Advisory Council 2010), pg. 15.

[15] *Severe Impact Resilience: Considerations and Recommendations*, NERC, March 2012 http://www.nerc.com/docs/oc/sirtf/SIRTF_Final_May_9_2012-Board_Accepted.pdf

[16] ASIS SPC.1-2009, http://www.asisonline.org/guidelines/ASIS_SPC.1-2009_Item_No._1842.pdf

[17] For example, advanced metering infrastructure provides reliability benefits by improving outage management. Much of the attention paid to the business case, however, centers on demand response applications that are used to empower customers or that may have non-emergency benefits.

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Utilities' investments in reliability already cover a lot of the investments they are making under this definition of resilience. So, is resilience just one part of reliability? The authors of this paper argue that it is, but that the frameworks we use to evaluate reliability may need tweaking to recognize a good investment in resilience. I know you're anxious to learn how, but the answer won't make sense unless we first do a quick review of reliability and how we measure it.

4. Reliability Metrics: a Brief Overview

In the world of electric utility regulation, everyone basically agrees what reliability *is,* even if we disagree on how to achieve it and on how much is sufficient. If a regulator from Oz sits down with a regulator from Narnia and they discuss "reliability," they are speaking about the same thing, based on quantifiable metrics calculated using generally agreed-upon formulae and statistics.

For a commission to approve (or incentivize) any utility's investments in reliability they need to feel confident that the investment is going to work. In order to evaluate its effectiveness, it needs to be measured. How do we measure reliability? A reliability investment's effectiveness is measured by how well it reduces (1) how long service is interrupted (**duration**), and (2) how often service is interrupted (**frequency**).

In order to calculate the reliability of a system in terms of outage **duration**, we use the System Average Interruption Duration Index (SAIDI) and the Customer Average Interruption Duration Index (CAIDI).[18]

SAIDI is measured by dividing the sum of all customer outage durations by the number of customers served. Here's the formula: [19]

$$SAIDI = \frac{Total\ Duration\ of\ Customer\ Interruptions}{Total\ Number\ of\ Customers\ Served} = \frac{\sum r_i N_i}{N_T}$$

In order to calculate the reliability of a system in terms of outage **frequency**, we use the System Average Interruption Frequency Index (SAIFI), which is the number of interruptions divided by the number of customers served.

$$SAIFI = \frac{Total\ Number\ of\ Customer\ Interruptions}{Total\ Number\ of\ Customers\ Served} = \frac{\sum N_i}{N_T}$$

If you want to get even more precise, you can measure the impact on an average customer, using the Customer Average Interruption Index (CAIDI) which divides how long each customer experiences an outage by how often they experience one.

$$CAIDI = \frac{Total\ Duration\ of\ Customer\ Interruptions}{Total\ Number\ of\ Customer\ Interruptions} = \frac{\sum r_i N_i}{\sum N_i} = \frac{SAIDI}{SAIFI}$$

There are other formulas to measure reliability: Customer Average Interruption Frequency Index (CAIFI), Momentary Average Interruption Frequency Index (MAIFI) and others. The U.S. Department of Energy

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[18] Note that CAIDI can also be reached by dividing a SAIDI value by a SAIFI (see below) value.

[19] (Yeddanapudi 2011)

(DOE) developed an Interruption Cost Estimate (ICE) Calculator in 2011 to aid electric reliability planners in industry and government to estimate interruption costs and benefits to infrastructure investment. The calculator uses SAIFI, SAIDI and CAIFI as well as the distinction between residential, non-residential and state-specific considerations in calculating estimated costs. ICE is nice, but it doesn't differentiate the value of lost kilowatt-hours over time, so the economic damage of large and long outages may be undervalued.

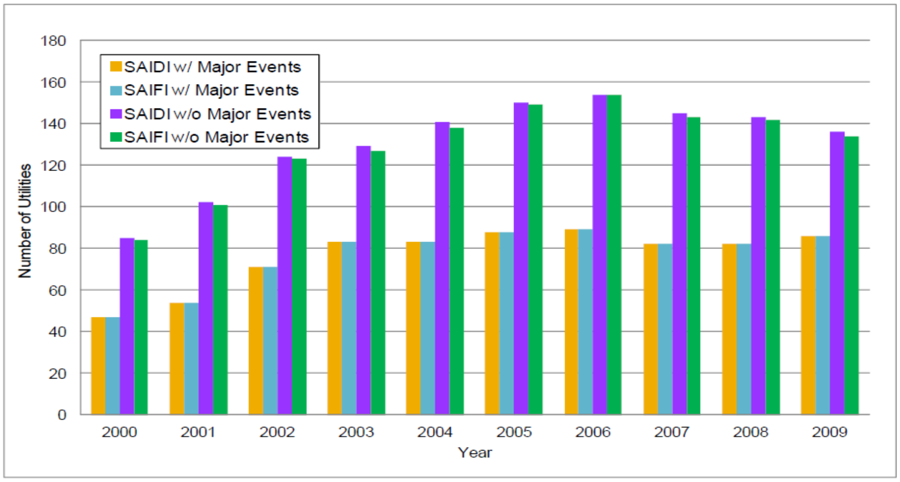
Although we have some pretty good tools, none of these works perfectly to help us focus on the best, most cost-effective investments in utility infrastructure and operations that avoid and minimize interruptions of service during an extraordinary and hazardous event. SAIDI, SAIFI, CAIDI and their sisters may fall short when applied to resilience. Let's explore this a little further below.

5. Where Reliability Metrics Break Down

What's wrong with just applying duration and frequency metrics to resilience? Those metrics miss two components: (1) they often undervalue the impact of large-scale events and focus on normal operating conditions and (2) they price lost load at a flat rate, when in fact the value of lost load compounds the longer it's lost.

The figure below shows how utilities apply SAIDI and SAIFI.[20] About half exclude major events[21] from the calculus. Why? Big events hopelessly swamp the math by costing far more in terms of restoration costs than individual smaller-scale events do. Per-customer outage duration and frequency in big events are not too far out of line with small events, but the costs are far greater. The math in the evaluative frameworks falls apart in big events, so many utilities ignore them. The result? The best investments for large events are left off the table.

Figure 1: Number of Utilities with SAIDI and SAIFI Data



(from *An Examination of Temporal Trends in Electricity Reliability Based on Reports from U.S. Electric Utilities,* Eto et. al., Lawrence Berkeley National Laboratory, 2012. http://certs.lbl.gov/pdf/lbnl-5268e.pdf)

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[20] It may be worth noting that State commissions apply these metrics and evaluate the results in different ways, but more detail on these differences is outside the scope of this paper.

[21] These large-scale events are identifiable based on the extent of damage, geographic area, number of customers out of service, and long outage duration.

That's not to say that utilities and regulators are ignoring resilience, no matter how they define it. Generally extraordinary hazards are evaluated in a narrative (rather than mathematic) way and each Commission that has taken it on has done so by inventing its own wheel. Section 9 of this paper (*Resilience In Action*) highlights the very good work being done in a number of States to tackle this problem. Better tools may help us not only approve good proposals, but map out where good proposals are still needed.

Large scale events warp the math because the restoration costs are so high, and because they are likely to inflict longer-term service interruptions. **In catastrophe situations the value to ratepayers for surviving the event without losing service is especially high.** The best investments for large-scale events will not be evaluated if you ignore large-scale events.

Finally, the duration formulas – SAIDI and CAIDI – value each lost kilowatt hour (kWh) equally across time. But customers value costs differently in the first few hours of an outage, when it's merely inconvenient, than they do after weeks of lost service, when modern life becomes simply impossible. The reason is the value of a kWh is based on willingness to pay, but the price is set by the cost of service. So does the value of lost service compound exponentially? Arithmetically? How much more will customers pay to restore service after a week than they will after an hour? Research evaluating this issue has not come up with a single approach, but it's logical to assume a compounding value rather than a fixed value for lost service over time.[22] The inability to compare the value of a lost kWh with its cost may also be a gap in the evaluative frameworks.

Moreover, as we'll discuss in Section 7, customers vary, and simplifying the explanation of these issues for clarity's sake shouldn't imply a uniformity of expectations for reliability and costs of service interruptions across (or within) residential, industrial and commercial customer classes. Utilities proposing resilience investments may be well served by articulating the different impacts faced by customers, ranging across inconvenience, economic difficulty and systemic breakdowns.

Finally, there's a growing chorus of voices calling for utility systems to contend with a lengthening list of hazards. It's easy to argue that the SAIDI/SAIFI toolbox evaluates all outages equally and doesn't care about how the outage occurs, but those caused by cyber attacks, kinetic attacks, vandalism or other malfeasance may manifest in different ways and need different strategies than natural events. If traditional reliability evaluative frameworks don't cover resilience investments exhaustively, can they be improved to account for big, bad, extended outage events?

6. Resilience as a Component of Reliability

Under existing evaluative frameworks geared towards reliability and affordability under ordinary conditions, we might have overlooked some great investments that would have saved us a lot of money in big events like hurricanes. Rather than creating a whole new framework for evaluating resilience that exists outside reliability, let's explore whether we can evaluate reliability in a way that accounts for investments that might not otherwise be captured.

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[22] An idea explored at length by Steven Allen Mitnick in *Lines Down*, Franklin Square Publishing, 2013. Another metric for evaluating the likelihood of customer impact is CEMI (customers experiencing multiple interruptions) measures the percent of overall customers that have experienced more than a specific number of interruptions.

Remember our proposed definition of resilience? ***Resilience****: robustness and recovery characteristics of utility infrastructure and operations, which avoid or minimize interruptions of service during an extraordinary and hazardous event*. How does this fit into a reliability framework that currently prioritizes blue sky availability and post-event restoration investment? Actually, it fits right smack dab in the middle. Figure 2 below shows how:

Figure 2: Resilience In The Context Of Reliability

When?	**Before / without an event**	**During an event**	**After an event**
	Service Quality	***Resilience***	
What?	Availability: how well does it work under normal conditions?	Robustness: How hard is it to knock down?	Recovery: How quick can it get back up?
How is it measured?	Frequency (SAIFI, MAIFI, using only blue-sky conditions)	Variable avoided lost load value outage metrics, **to be developed** (more work may be needed in this space)	Duration (CAIDI, SAIDI, including major events)
Investment example	O&M, expenditures managing vegetation, siting and positioning favoring ease of access	Undergrounding, siting and infrastructure positioning above flood areas	Paying mutual assistance partners for crew time and expenses, advanced metering infrastructure to alert the company about outages

When we include resilience in how we treat reliability investments, we consider conditions and investments to overcome those conditions that didn't show up before. Using this way of thinking, what kinds of resilience challenges are captured that were otherwise missing?

- Non-traditional hazards (Example: sophisticated terrorist attacks)
- Large-scale catastrophe events that resist restoration (Example: pervasive malware attacks on control systems)
- Events with the capacity to induce long-term outages (example: extremely large geomagnetic disturbances)
- Cascading failures (example: interdependent, systemic failures)

Why? Thinking about resilience as an aspect of reliability allows us to explicitly consider large scale events and non-traditional hazards that were sometimes cut out of the math before. It allows for variable pricing for duration and a better understanding of scale by adapting to risk-based frameworks that capture interdependencies and likelihood. By assimilating resilience into the factors that assure reliability, regulators won't be charged with setting new criteria for utility performance.

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7. How Should Regulators Review Resilience?

Even if electric sector policymakers agree that resilience describes actions, which minimize or avoid service interruptions in extraordinary events, the evaluative frameworks (SAIDI and her sisters) are still letting us down. Before smarter minds develop the fix for evaluative frameworks for resilience, we will identify precisely what needs to be fixed.

We don’t evaluate reliability under **non-blue-sky conditions**, but for resilience considerations, we may be better off if we did. Those large-scale events that create long outages for large numbers of customers are the knockout punch that really cost an outsized amount of money for utilities and create the worst experience for ratepayers. When developing resilience parameters, we have to ask whether we are taking into account extra-normal circumstances, and if so, whether to the appropriate degree. To that extent, **scale measurement** must take into account how big the catastrophe is. If the catastrophe is big enough, does the measurement always scale accordingly, or does it warp? With a large enough scale, it may be necessary to recalibrate the measurement so that the math still works. And lastly, **variable or compounding outages** must hold a value in resilience measurements. We have to take into account the value of lost service on day one of an outage versus day thirty.

Adapting SAIDI, CAIDI, SAIFI, MAIFI, ICE and other calculations to address these areas will help utilities offer smarter resilience proposals and help regulators make better-informed prudence decisions that support those investments.

This sounds pretty good, but there is one further consideration to make. A good investment in one area may create **trade-offs elsewhere**. For example, undergrounding power lines may create value for robustness, but may reduce the speed of recovery. Making field instrumentation easy to access may be great for availability and rapid restoration, but if this instrumentation is exposed to the elements or mischief-makers it may reduce robustness. A matrix evaluation that measures the pros and cons of a proposed project across these three categories may yield improved understanding of the trade-offs.

Figure 3. Matrix evaluation of two hypothetical reliability / resilience investments

Example 1: unique encrypted passwords for all utility “smart” distribution devices		
	Resilience	
Availability	Robustness	Recovery
Poor: more likely errors will occur through everyday user mistakes	Good: More resistant to malicious software or hackers	Poor: more likely that password management and use will slow restoration efforts
Example 2: wooden distribution poles for power lines		
	Resilience	
Availability	Robustness	Recovery
Good: repairs and maintenance are simplified, and do not require excavation crews	Situational, but usually poor: more susceptible to wind, vegetation, and fires; less susceptible to floods	Good: materials are inexpensive and easy to replace.

In the previous examples, an investment that improves the robustness of the system may degrade its performance in availability or recovery, and vice versa.

Making everything resilient would probably break the bank, and it's unnecessary. Far better are investments that deliver lower-cost service and improve system performance. State regulators will want to approve investments that deliver the best system improvements and ratepayer value, but those may not always be the cheapest investments. Drawing a metaphor from a car, a hand-brake costs less than antilock brakes, but there are cases where the safety benefits of the latter may deliver higher value than always depending on a hand-brake. Likewise, investments in system visualization which help outage management or in distribution system redundancy with large benefits in the event of single line failures may be expensive items, but they may ultimately deliver bill reductions and other economic benefits to ratepayers. Sophisticated evaluations of the benefits of avoiding outages may deliver a clearer picture of the value case for robustness and recovery characteristics than strict line-item cost evaluation.

Money isn't everything though, and a single-minded focus on the investments with the highest cost-effectiveness may mask other societal and customer benefits that are important to commissioners and other policymakers. For this reason, it may be important when evaluating resilience to **differentiate between and within customer classes**. For simplicity's sake, we've bundled lost load into big groups, but because utility ratepayers are people, they're all different. Commercial and industrial load losses are generally higher per hour than residential load losses, and it might – or might not - be important to regulators to avoid having residential customers pay for system hardening to prevent a manufacturing plant from losing an extra shift of production. Even residential customers display a wide variety: when these customers lose power, the utility will be able to return many to service quickly it will take longer to restore service to a smaller group.[23] Outage management strategies that help eliminate long outages for smaller groups of residential customers may have a smaller economic payoff but may still be worth making a priority. Commissions may decide that the smartest approaches to investing in resilience may be those that not only differentiate between classes, but also within classes, with a balance between cost considerations and duration minimization for the longest-out customers.

If we can't afford to make everything resilient, how do we prioritize *what* to make resilient? The answer lies in risk-based methodologies to determine what will cost the most if we lose the service. The analysis for valuation of lost kWh's uses three structures. The **first** is the scale of the impact: how many customers are affected? The existing systems we have deal with that quite well. The **second** is the duration of the interruption. As we described earlier, the fact that you'll pay more for service the longer you go without it shows it has at least an arithmetic, and potentially exponential, increasing value to lost hours of service. Because they may never be used, if you were looking at these two factors alone, you'd have to conclude that resilience investments should prioritize the events and consequences that have the worst outcomes for large numbers of customers, no matter what the duration. Because evaluation frameworks like CAIDI and SAIDI already do a pretty good job of ensuring investments in widespread restoration for large numbers of customers, a large percentage of customers can lose service, but not for a very long period of time. What's overlooked is the compounding value effect of events that last a long time. So, **any new evaluative effort focused on resilience should prioritize those investments that best reduce long duration outages,** particularly for large numbers of customers.

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[23] For example, according to AP, after Superstorm Sandy New York utilities restored power to at least 95 percent of customers 13 days after the peak number of outages was reported. New Jersey reached that same level in 11 days and West Virginia in 10 days. But even at that time, 5% of customers had yet to have power restored. http://bigstory.ap.org/article/power-outage-time-after-sandy-not-extraordinary

But wait! Duration and scale are only two of the factors. The **third** is that the value of lost load varies by which customer is responsible for the load. Analysis of the value of lost load from the utility perspective has shown that it can range from $1,000/MWh for residential customers to more than $10,000/MWh for commercial and industrial users.[24] That's only how it looks from the utility perspective. An evaluation currently underway by NARUC for the Maryland PSC is exploring whether the value of lost load for customers in suburban Maryland after the 2012 derecho event was substantially higher than it was for the utility serving those customers. The utility costs only included things like new poles and visiting mutual assistance crew costs, while the customers lost business, productivity and the contents of their refrigerators. It makes sense that the real value of load is variable within customer groups and even across time. Anyone who remembers the power outage during Superbowl XXXV will tell you that the value of lost load was much lower the night before the Ravens beat the 49ers than it was the night of the game. Although it may never be possible to evaluate this perfectly, one recommendation to the reader may be to explore the possibility of an evaluation of the value of lost load as seen from a customer perspective, similar to the work done for Maryland.[25]

Harmonizing these three factors may require a new analytic framework – one that adapts to account for scale and duration, but also dynamically measures the compounding value of lost load, avoided before an event or incurred after an event, which will produce a variable value. We would suggest that a solution for this new analytic framework is dynamic, and may borrow features of a probabilistic risk assessment. NARUC has engaged experts to start figuring out what this might look like, but it's probable that it will take a conversation between States, companies and other stakeholders to create the tools to explore this effectively. One key participant may be consumer advocates, who would provide the perspectives that help commissions understand ratepayer value when the lights are on, and also when they aren't.

8. Resilience and National Disaster

As disasters increase in scale, so do the benefits of resilience. The 2011 Great East Japan Earthquake was a global tragedy whose effects were amplified by the reactor disaster at the Fukushima Daiichi nuclear power plant complex. Greater resilience at that site may have yielded outsized benefits. Understanding what the most damaging consequences are and prioritizing resilience investments in a spectrum that at least explores possible events of unthinkable consequence may yet provide outsized benefits in future catastrophes.

One way to determine what highest-consequence events might be best managed with a resilience investment is to take advantage of a tool utilities already use: contingency planning. This tool plays an iterative and repeating "what if" game, where the system operator models what the system does if different system components stop working. *What if we lose the most important line? What if we lost the two most important lines? What if we lose two important lines and the most important substation?* Generally, "N minus 1" or "N minus 2" planning is the rule, where operators are prepared to adapt to the loss of the most and second-most important assets on their system.[26] For planning purposes, utilities

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[24] The Regulatory Assistance project and Synapse Energy Economics, Workshop on Risk in the Electricity Industry, a training provided to the Mid-Atlantic Conference of Public Utility Commissioners in Hershey PA on June 14, 2013.

[25] This report will be available December 2013 at www.naruc.org/SERCAT

[26] For example, the NERC Transmission Planning (TPL) Series of standards uses this iterative method.

and regulators may want to explore whether going further out into worse contingencies (say, “N minus 20”) can be helpful in identifying the most critical systemic points of failure.

State Energy Offices are also a great locus for contingency planning experience. The DOE’s support of the work the National Association of State Energy Officials (NASEO) does in support of State energy assurance planning is a great resource for regulators.[27] As part of this effort, NASEO provides assistance, education and outreach to support energy assurance planning, response, and smart grid efforts in all 50 States. This effort is sponsored and supported by the U.S. Department of Energy's Office of Electricity Delivery and Energy Reliability (OE).[28] NASEO’s Energy Security Committee serves as the focal point of the program and committee members participate in planning and implementation activities aimed at facilitating peer exchange, offering expert input into state activities and facilitating regional coordination.

One final area to consider is whether there are restoration or survivability priorities that exceed the usual order for a utility or the jurisdictional borders of a State commission. The Japanese nuclear power plant example is instructive here, but in each utility service territory – or in its neighbor – there may be some hidden gem for which resilience holds extraordinary value. Does the National Emergency Management Training Center rate a higher or lower service resilience priority than the bio-defense labs at Ft. Detrick? Both are in Frederick County, MD, which borders on Pennsylvania and Virginia. Does reliability assurance in those States have an outsized value if it prevents cascading failures in Maryland? Do those asking about reliability have a way to ask about, measure or value those interdependencies? Do we have a way to coordinate if something important is discovered? More work may be needed on this front.

9. Resilience in Action

Reading through this paper, you might think that States and utilities haven’t even begun to think about resilience or taken any smart action. In fact, the opposite is true: a lot of very good thinking and planning has gone into a number of resilience efforts in recent years. States’ experience regulating for reliability provides a rich spectrum of activities and findings. Each of NARUC’s members offer guidance in the ways they have ruled on rates, terms and conditions for reliability. We have selected a few examples for you from New Jersey, Texas, Ohio, Florida, Maryland and Pennsylvania.

STATE	PROJECT	SIGNIFICANCE
New Jersey	PSE&G’s “Energy Strong” campaign.[29]	Utility cost-recovery plan
Texas	An Examination of Transmission and Regional Electricity Planning and Communication as it Relates to Reliability.[30]	NARUC and DOE- funded study for State needs
Ohio	Electric Reliability Performance Data.[31]	Reliability performance data from PUC’s regulated entities

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[27] For further information see: www.naseo.org/energyassurance.

[28] The DOE’s Infrastructure Security and Energy Restoration is also an important security and resilience partner in this effort, with a number of resources available online at: http://energy.gov/oe/mission/infrastructure-security-and-energy-restoration-iser.

[29] (PSEG 2013)

[30] (Mott MacDonald 2012)

[31] (Public Utilities Commission of Ohio n.d.)

STATE	PROJECT	SIGNIFICANCE
Florida	Florida PSC's annual Electric Utility Distribution Reliability Reports.[32]	Annual reliability reports from PSC's regulated entities
Maryland	Derecho Multi-State Outage and Restoration Report. Case No. 9298	Catastrophic storm impact evaluation
Pennsylvania	Post-Storm Reports – Hurricanes Irene and Sandy, and Post-Sandy PUC Policy Statement Proceeding	Evaluations of the utilities' response during Hurricanes Irene and Sandy, including lessons learned and best practices.

These examples show that States and utilities are already pretty good at evaluating and incentivizing resilience investments, but each has largely done it alone. Our hope in highlighting some of these outcomes is to pull together resources for State public utility commissioners to benefit from and build on their work.

In Section 7 (*How Regulators Should Evaluate Resilience*) we explored some concepts that Commissions might want to keep in mind when confronted with a proposal to invest in something that the petitioner calls "resilience." Another additional option would be for commissions to proactively inquire about resilience efforts undertaken by utilities and explore their understanding of the difference between resilience investments and investments that are focused on improving traditional reliability concepts.

10. Conclusion

Resilience is something we all want in our utility systems and commissions and utilities are hard at work addressing reliability and resilience for the systems they oversee. In many cases, they are already considering prudent investments that would fall under the definition of resilience that we've presented in this paper.

To better accommodate resilience into the world of regulatory review, however, we need to sharpen its definition and provide a more rigorous set of analytic tools to evaluate it. In this paper we've argued that resilience can be defined as the robustness and recovery characteristics of utility infrastructure and operations, which avoid or minimize interruptions of service during an extraordinary and hazardous event. Using that definition, there seems to be a home for resilience within how we review reliability. The frameworks we use to evaluate reliability aren't perfect in this space, and more work needs to be done to accommodate resilience within them, but with a little improvement of those frameworks, a number of good investments that improve service and deliver ratepayer value may get approved that currently might not meet cost-effectiveness muster.

Finally, because coming through an event without losing service becomes far more valuable the worse the event is, there may need to be some additional considerations brought to mind for commissions. Resilience is most valuable in dealing with severe hazards and non-traditional threats. More work may be needed to help commissions identify, prioritize and manage these risks.

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[32] (Florida Public Service Commission 2013)

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Commissions can take action on resilience today. When confronted with a proposal to make a resilience-oriented investment, commissions can:

- Explore and identify resilience issues, and how resilience is distinct from traditional reliability;
- Ask questions to understand trade-offs between investments that create availability, robustness and recovery;
- Explore the effectiveness of traditional reliability evaluative frameworks (SAIDI, SAIFI, CAIDI, etc.) in assuring resilience investments, particularly in the area of system robustness, and determining whether improvements are needed in how these frameworks are applied;
- Discuss with utilities and others whether new tools are useful for motivating, evaluating and incentivizing cost-effective resilience investments;
- Undertake evaluations of the difference between the utility costs of outages and the lost value to customers to better understand the impacts of severe events and have context to evaluate minimizing or avoiding their impacts (such as the work done in Maryland);
- Explore contingency analysis and other tools to understand high-impact outcomes to help prioritize and direct resilience investments;
- Work with State Energy Offices and other experts in energy assurance to understand interdependencies, regional considerations and other triggers that can complicate high-impact events; and
- Engage consumer advocates and others to assure that the best resilience efforts – those that enhance reliability and security, which avoid or minimize the impacts of severe and non-traditional hazards while delivering ratepayer benefit – are captured and prioritized for incorporation into essential utility systems.

Regulators want to be as smart as possible in evaluating utility proposals in resilience. If these investments bring large enough benefits, they may be worth seeking out proactively. All of this may require new tools, new partnerships and the generation of new understandings about how we use and value utility services. It’s a conversation that’s already taking place across the commissions and we hope this paper will help State commissions become even better participants in it.

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