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ELECTRICITY POLICY INSIGHTS

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Toward Resilience

Defining, Measuring, and Monetizing Resilience in the Electricity System

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Executive Summary

Resilience—the electric grid's ability to resist, absorb, and recover from high-impact, low-probability external shocks—is an important, yet wide-ranging and potentially amorphous concept. Many different actions can help the grid defend against, absorb, or recover from high-impact, low-probability shocks. However, some potential actions will do little to address specific threats and have been suggested for what appears to be political reasons. Moreover, many actions that can significantly enhance electric system resilience come at substantial cost. Systematically and transparently evaluating the cost of a potential resilience-enhancing action and its expected impact on the probabilities and consequences of grid outages is critical to evaluating whether that action is worthwhile from an economic efficiency perspective or whether it is misguided. To ensure that we make only efficient and cost-beneficial investments, decisionmakers must adopt a clear and useable definition of resilience, identify potential actions that improve resilience, and conduct an economic analysis of the social value of those actions. Only by engaging in this type of analysis can policymakers ensure that they do more than simply pick winners based on political preferences.

This report aims to assist policymakers in understanding grid resilience and evaluating potential interventions aimed at improving it. The following key insights can help policymakers improve the resilience of the electric system by acknowledging and responding to real threats in a systematic, transparent, and accountable way.

Defining and measuring resilience are necessary first steps.

- Grid resilience is a broad concept that can be simplified into a four-part framework. A resilient electric system is one that has the ability to (1) avoid or resist shocks, (2) manage disruption, (3) quickly respond to a shock that occurs, and (4) fully recover and adapt to mitigate the effects of future shocks.
- Resilience can be measured based on the performance of the system or its components (e.g., number of customer outage hours, monetized value of lost economic productivity). It can also be based on the attributes of the system or its components (e.g., how hardened the distribution system is to high winds, the extent to which replacement transmission components are readily available, the extent to which a generator is vulnerable to fuel-supply disruption). Attribute-based measures are easier to develop but also are potentially more misleading. Because of interactions among different threats and components of the electric system, improving one attribute may or may not improve resilience as a whole. Moreover, many of the attributes that have been suggested in recent federal policy discussions—such as whether a plant has historically operated to serve baseload demand or whether a plant was utilized during an extreme weather event—do not have a demonstrated connection to resilience. Performance-based metrics more directly measure resilience, are more reflective of the multi-faceted nature of resilience, and are more useful than system or resource attributes in quantitative analysis (such as cost-benefit analyses of potential resilience interventions).
- Investments to improve the resilience of individual components of the electric system—generation resilience, transmission resilience, distribution resilience—should all be considered, but must be measured with respect to how they improve overall *electric system resilience*.

Resilience policies and investments should be evaluated using a cost-benefit analysis framework.

- Policymakers should use a systematic, transparent framework for evaluating potential interventions, to ensure that the benefits of resilience-enhancing investments and policies justify the costs.
- A framework developed by Sandia National Labs is analytically intensive but can provide critical insight when comparing potential resilience interventions. This framework involves specifying threats, defining performance-based resilience metrics, using computer-modeling simulations to understand and monetize probabilistic baseline levels of resilience, and comparing those levels with monetized probabilistic estimates of resilience after potential interventions.
- The benefits identified using this framework can be compared to the costs of the policy or investment, including the costs to the utility of making investments, costs to customers that result from market rules that change energy prices, costs associated with any countervailing resilience risks, and environmental costs that result from changes to the grid mix.

In general, sufficient legal authorities exist at the state and federal levels to implement cost-beneficial resilience improvements.

- Because most customer outages are the result of disruptions to the distribution system, substantial focus on resilience should be on states, who have the authority to regulate distribution system investments and policies. States have numerous authorities to require resilience improvements.
- The federal role in enhancing resilience is restricted but important. The Federal Energy Regulatory Commission can use its authority over transmission investments, reliability standards, planning and coordination, and electric market rules to implement any identified cost-beneficial improvements to the bulk power system.
- The Department of Energy is vested with authority to respond to grid emergencies in the unlikely circumstance that existing market rules and reliability standards prove insufficient to respond to a high-impact, low-probability event. That authority must be exercised within the confines provided by Congress and subject to judicial review.

The Trump Administration's proposals to provide cost-based financial support to coal and nuclear plants do not reflect the best-practices for policy intended to support electric system resilience outlined in this report.

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Introduction

Grid resilience—the electric grid's ability to resist, absorb, and recover from high-impact, low-probability external shocks—has concerned electric utilities and grid planners for decades. However, a recent series of extreme weather events and cybersecurity incidents, and political efforts by the Trump Administration to prop up certain favored generation sources, have brought a renewed focus to this critical electric sector issue.

In the United States, Superstorm Sandy in 2012 and the Polar Vortex in 2014 kicked off the recent focus on grid resilience as a critical infrastructure priority, resulting in congressionally mandated studies,[1] federally directed policy changes,[2] new state energy policies,[3] and private-sector investment and innovation.[4] A series of high-impact, low-probability events during the summer and fall of 2017 brought grid resilience back into the news, prompting discussion of policy changes to prepare for events such as hurricanes,[5] wildfires,[6] cybersecurity incidents,[7] and high-profile power failures.[8]

The Trump administration's attempts to promulgate policies that support coal and nuclear power plants under the pretense of enhancing resilience have also drawn attention to the issue. In September 2017, the United States Department of Energy (DOE) issued a controversial and high-profile directive to the Federal Energy Regulatory Commission (FERC) to consider and act on a proposal to provide economic support to power plants that maintain 90-days' worth of on-site fuel (primarily coal and nuclear plants).[9] DOE justified the need for this support by claiming these plants provide essential grid resilience benefits that wholesale electric markets fail to sufficiently value. FERC ultimately rejected DOE's proposal but initiated a proceeding to request additional information from grid operators on how to think about and enhance resilience.[10] More recently, President Trump ordered DOE to develop policies to forestall retirement of coal and

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1 Nat'l Acad. of Sci., Eng'g & Med., Enhancing the Resilience of the Nation's Electricity System vii (2017), https://www.nap.edu/catalog/24836 [hereinafter NAS] (describing the report's origin in a 2014 Congressional mandate that the Department of Energy conduct a "national-level comprehensive study on the future resilience and reliability of the nation's electric power transmission and distribution system").

2 *Order on Technical Conferences*, 149 FERC ¶ 61,145 (Nov. 20, 2014).

3 2015 New York State Energy Plan at 34-35, https://energyplan.ny.gov/-/media/nysenergyplan/2015-overview.pdf (discussing extreme weather events that contributed to the development of New York's "Reforming Energy Vision" energy policy).

4 Magdalena Klemun, *5 Market Trends That Will Drive Microgrids Into the Mainstream*, Green Tech Media (Apr. 9, 2014), https://www.greentechmedia.com/articles/read/5-market-trends-that-will-drive-microgrids-into-the-mainstream (showing microgrid investment was driven by recent extreme weather events).

5 This includes a series of hurricanes in the Gulf of Mexico that caused significant power outages, resulting in damage and lost economic opportunity in Texas and Florida. *See* Karma Allen & Maia Davis, *Hurricanes Harvey and Irma May Have Caused Up to $200 Billion in Damage, Comparable to Katrina*, ABC News (Sep. 11, 2017, 8:09 PM), http://abcnews.go.com/US/hurricanes-harvey-irma-cost-us-economy-290-billion/story?id=49761970; Arelis R. Hernandez et al., *SinLuz Life Without Power*, Washington Post (Dec. 14, 2017), https://www.washingtonpost.com/graphics/2017/national/puerto-rico-life-without-power/.

6 Ivan Penn, *Power Lines and Electrical Equipment are a Leading Cause of California Wildfires*, Los Angeles Times (Oct. 17, 2017, 2:05 PM), http://beta.latimes.com/business/la-fi-utility-wildfires-20171017-story.html

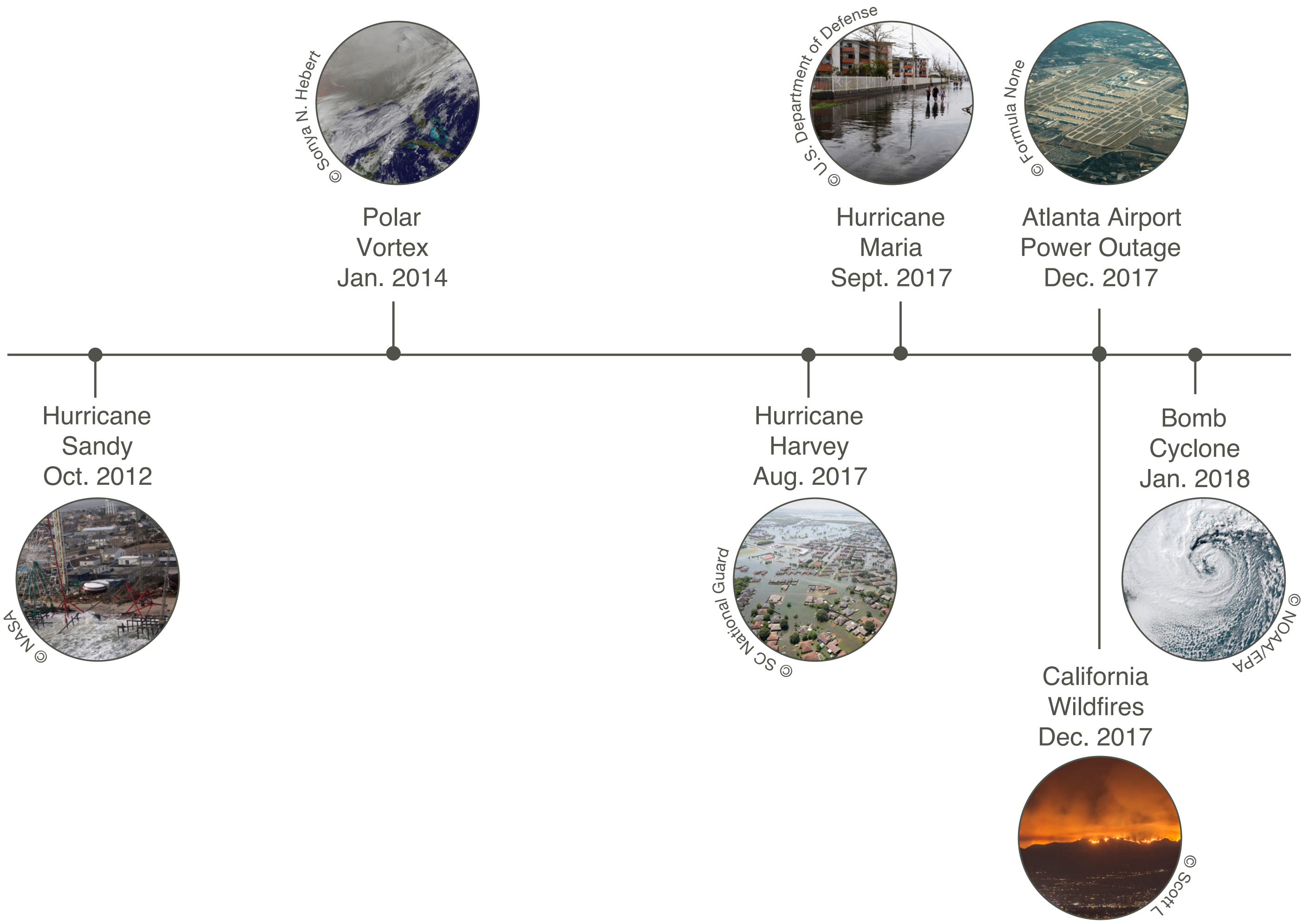
7 Michael Riley et al., *Russians Are Suspects in Nuclear Site Hackings, Sources Say,* Bloomberg (last updated July 7, 2017, 2:55 AM), https://www.bloomberg.com/news/articles/2017-07-07/russians-are-said-to-be-suspects-in-hacks-involving-nuclear-site.

8 Taylor Barnes & Jacey Fortin, *Power Failure at Atlanta Airport Snarls Air Traffic Nationwide,* NY Times (Dec. 17, 2017), https://www.nytimes.com/2017/12/17/us/atlanta-airport-power-out.html?hp&action=click&pgtype=Homepage&clickSource=story-heading&module=first-column-region&region=top-news&WT.nav=top-news.

9 *Grid Resiliency Pricing Rule*, 82 Fed. Reg. 46,940 (Oct. 10, 2017) [hereinafter "DOE NOPR"].

10 *Grid Reliability and Resilience Pricing, Order Terminating Rulemaking Proceeding, Initiating New Proceeding, and Establishing Additional Procedures*, 162 FERC ¶ 61,012 (Jan. 8, 2018) [hereinafter "FERC Resilience Order"].

Timeline of recent resilience threats



nuclear plants, asserting that planned retirements present national security concerns by "impacting the resilience of our power grid," which is used by military installations and defense-critical infrastructure.[11]

Recent events—particularly the devastation brought by long-term blackouts in Puerto Rico caused by Hurricane Maria in September 2017—have shown how damaging sustained power outages can be for U.S. citizens. And, while the DOE resilience proposal and the presidential order to DOE to keep coal and nuclear plants operational have been the subject of widespread criticism,[12] good-faith efforts to understand and improve the resilience of the electric grid at the local, state, regional, and federal levels are critical to the United States' continued prosperity.

If DOE, FERC, state and local governments, utilities, and grid operators are interested in truly improving resilience, they have many potential options. The process will require a systematic and considered focus; economic investment by ratepayers, utilities, and governments; and sustained and deliberate coordination and planning between utilities, grid operators, and regulators.

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[11] Brad Plumer, *Trump Orders a Lifeline for Struggling Coal and Nuclear Plants*, NY Times (June 1, 2018), https://www.nytimes.com/2018/06/01/climate/trump-coal-nuclear-power.html.

[12] Jeff St. John, *Behind the Backlash to Energy Secretary Rick Perry's Demand for Coal-Nuclear Market Intervention*, Greentech Media (Oct. 5, 2017), https://www.greentechmedia.com/articles/read/behind-the-backlash-to-energy-secretary-rick-perrys-demand-for-coal-nuclear; Gavin Bade, *How Trump's 'Soviet-style' Coal Directive Would Upend Power Markets*, Utility Dive (June 4, 2018), https://www.utilitydive.com/news/how-trumps-soviet-style-coal-directive-would-upend-power-markets/524906/.

Resilience is a wide-ranging and potentially amorphous concept. A variety of actions can help the grid defend against, absorb, or recover from high-impact, low-probability shocks; however, many potential actions that do so come at substantial cost. For example, it is expensive to harden existing systems (that is, make the system more resistant to potential physical disruption) or build infrastructure that is needed only if existing infrastructure fails or is destroyed. In some cases, those costs may exceed the benefits of avoiding or quickly recovering from grid outages, and making such investments would not be beneficial to society. Therefore, the cost of resilience-enhancing actions, and their expected impact on the probabilities and consequences of grid outages are critical to evaluating whether an action is worthwhile from an economic efficiency perspective. Ensuring that we make only efficient and cost-beneficial investments will require a clear and useable definition of resilience, categorization of attributes that improve resilience, and economic analysis of the social value of those attributes. Only by engaging in this type of analysis can policymakers ensure that they do more than simply pick winners based on political preferences.

This report aims to assist policymakers in understanding grid resilience and evaluating potential interventions aimed at improving it. The report first provides a definition of resilience grounded in academic literature. It then outlines a framework to identify socially optimal resilience investments. Next it outlines the authorities that states and federal agencies have for improving grid resilience, consistent with the jurisdictional divides established by the Federal Power Act. Finally, it applies the insights developed throughout the report to recent proposals from the Trump Administration to provide financial support to coal and nuclear generators based on asserted resilience attributes.

Key Institutions with a Role in Grid Resilience

State Public Utility Commissions - State regulators, commonly called "public utility commissions" or "public service commissions," are responsible for regulating local distribution utilities, setting retail electricity rates, and deciding on other state-level policies, such as distributed energy compensation, renewable portfolio standards, and energy efficiency programs.

Federal Energy Regulatory Commission (FERC) - FERC is a federal regulatory agency responsible for ensuring just and reasonable rates for wholesale electricity and interstate transmission. It maintains the authority to regulate the market rules implemented by operators of wholesale electricity markets. FERC is also responsible for ensuring reliable operation of the bulk power system—the system of large electric generators and high-voltage transmission lines.

Department of Energy (DOE) - DOE plays a limited role in resilience. Its primary electric-system responsibilities consist of analysis, funding new technologies, issuing regulatory proposals for FERC's consideration, and ordering specific actions in the case of electric-system emergencies.

National Electric Reliability Corporation (NERC) - NERC is a non-profit corporation designated by FERC to ensure reliable operation of the bulk power system. NERC collects information on power system outages, conducts reliability analyses, and develops and enforces reliability standards.

Independent System Operators (ISOs)/Regional Transmission Organizations (RTOs) - ISOs/RTOs operate the wholesale electric system in two-thirds of the country, including operating competitive electricity markets. ISOs/RTOs ensure that supply and demand of the bulk power system are balanced using complex economic and engineering algorithms that take into account the location of both generators and demand, the costs of generation, and congestion in the transmission system. ISO/RTO-operated markets are also responsible for regional analysis, planning, and coordination of transmission and reliability.

Understanding Resilience

In order to improve electric system resilience, it is necessary to first have a common understanding of resilience, including what resilience is and how to measure it. This section starts with the basics, including the definition of resilience and how to measure it, and puts those concepts together into a useful conceptual model. It then draws implications of these concepts to give more nuance and provide a deeper understanding of grid resilience.

The Basics: Defining and Measuring Electric System Resilience

Defining Electric System Resilience

The concept of "system resilience" originates in the academic literature on ecological systems. Here, resilience was first defined as "a measure of systems and of their abilities to absorb change and disturbance and still maintain the same relationships between populations or state variables."[13] Since then, this concept has been applied to a variety of contexts and so has been incorporated into system planning across many disciplines. While the specific definition in each discipline varies, all definitions consider **the ability of a system to resist, absorb and adapt, and recover after an external high-impact, low-probability shock.**[14]

Over the last decade, a number of government entities have developed definitions of resilience for U.S. infrastructure in general, and for the electric system in particular.[15] These definitions have been broadly consistent with the academic literature and with each other. In its order rejecting DOE's resilience proposal and initiating a new proceeding to consider resilience in ISO/RTO markets, FERC synthesized these different efforts to arrive at a useable definition of resilience as

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13 C. S. Holling, *Resilience and Stability of Ecological Systems*, 4 Ann. Rev. Ecol. Syst. 1, 14 (1979).

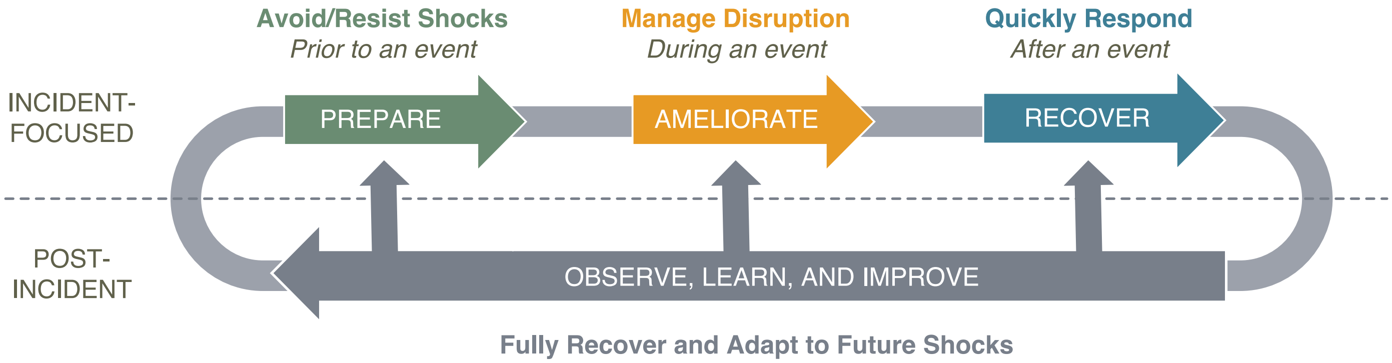
14 Mathaios Panteli & Pierluigi Mancarella, *The Grid: Stronger, Bigger, Smarter?*, IEEE Power Energy Mag., May–June 2015, at 58, http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=7091066; Min Ouyang & Leonardo Dueñas-Osorio, *Multi-dimensional Hurricane Resilience Assessment of Electric Power Systems*, 48 Struct. Saf. 15, 15–24 (2014), http://dx.doi.org/10.1016/j.strusafe.2014.01.001; Eric Vugrin et al., Sandia Nat'l Labs., Resilience Metrics for the Electric Power System: A Performance-Based Approach (2017), http://prod.sandia.gov/techlib/access-control.cgi/2017/171493.pdf; Dep't of Energy, Transforming the Nation's Electricity System: the Second Installment of the Quadrennial Energy Review 4–3 (2017), https://energy.gov/sites/prod/files/2017/02/f34/Quadrennial%20Energy%20Review--Second%20Installment%20%28Full%20Report%29.pdf [hereinafter "DOE QER"]; Henry H. Willis & Kathleen Loa, RAND Corp., Measuring the Resilience of Energy Distribution Systems, 1–25 (2015); Cen Nan & Giovanni Sansavini, *A Quantitative Method for Assessing Resilience of Interdependent Infrastructures*, 157 Reliabity Engineering & Sys. Safety 35 (2017), http://dx.doi.org/10.1016/j.ress.2016.08.013; Dep't of Energy, Staff Report on Electricity Markets and Reliability 63 (2017), https://energy.gov/sites/prod/files/2017/08/f36/Staff Report on Electricity Markets and Reliability_0.pdf [hereinafter "DOE Staff Report"].

15 In 2013, President Obama signed Presidential Policy Directive/PPD 21: Critical Infrastructure Security and Resilience, which establishes national policy on critical infrastructure security and resilience. PPD 21 defines resilience of critical infrastructure (including the electric system) as "the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions." Presidential Policy Directive/PPD-21, *Critical Infrastructure Security and Resilience*, The White House (Feb. 12, 2013), https://obamawhitehouse.archives.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil [hereinafeter "PPD-21"]. This definition was echoed by DOE in the Second Installment of the Quadrennial Energy Review, a comprehensive analysis of trends and set of recommendations for modernizing the nation's electricity system to lower costs, reduce environmental effects, ensure reliable access to electricity. DOE QER at 4-4 (defining residence as "the ability to prepare for and adapt to changing conditions, as well as the ability to withstand and recover rapidly from disruptions, whether deliberate, accidental, or naturally occurring.")
The National Academy of Sciences defines resilience as encompassing a process for "lessen[ing] the likelihood that [electricity] outages will occur" and "coping with outage events as they occur to lessen their impacts, regrouping quickly and efficiently once an event ends, and learning to better deal with other events in the future." NAS at 10.

it relates to the electric system: "The ability to withstand and reduce the magnitude and/or duration of disruptive events, which includes the capability to anticipate, absorb, adapt to, and/or rapidly recovery from such an event."[16]

The characteristics highlighted in the FERC definition can be divided into a four-part framework developed by the National Infrastructure Advisory Council. A resilient electric system is able to: (1) avoid or resist shocks, (2) manage disruption, (3) quickly respond to a shock that occurs, and (4) fully recover and adapt to future shocks. In its 2017 report *Enhancing the Resilience of the Nation's Electricity System*, the National Academy of Sciences adopted this framework and developed a useful graphic for visualizing it, presented in Figure 1.

Figure 1: Four-part framework for conceptualizing resilience



Adapted from: NAT'L ACAD. OF SCI., ENG'G & MED., ENHANCING THE RESILIENCE OF THE NATION'S ELECTRICITY SYSTEM 11 (2017), https://www.nap.edu/catalog/24836 .

Measuring Resilience

Resilience must be measured in order for policymakers and utilities to understand the electric system's current level of resilience, and evaluate potential interventions aimed at improving it. This requires a set of consistent resilience "metrics."[17]

The most useful type of resilience metrics are "performance-based." Performance-based metrics use quantitative data on either electric-system performance or the consequences of non-performance in the event of a high-impact, low-probability disruptive event.[18] These metrics can be based on the direct or indirect consequences resulting from such an event, depending on the goals and concerns of policymakers and grid operators. For example, a metric may focus on the direct consequences of a disruption to the generation, transmission, or distribution of electricity, such as the amount of energy services delivered to customers or the percentage of critical-customer energy demand served.[19] Alternatively, a performance-based metric may focus on indirect consequences or broader social perspectives, such as the availability of critical services that are at risk in the event of electric system outages (such as a potable water supply) or the general level of economic activity.[20]

[16] FERC Resilience Order, 162 FERC ¶ 61,012 at P 23.
[17] Panteli & Mancarella at 59; Nan & Sansavini at 38.
[18] Vugrin at 13.
[19] *Id.* at 19-20.
[20] *See* Watson.

A Less Useful Alternative Approach: Attribute-Based Resilience Metrics

Attribute-based resilience metrics are an alternative to performance-based metrics.[21] Attribute-based metrics identify properties of systems generally thought to be resilient and categorize the extent to which an evaluated system possesses those properties, using expert surveys. The political discussion surrounding grid resilience has focused on system attributes—e.g., number of generators with on-site fuel, whether a system is an islanded micro-grid—rather than performance measurements.

Argonne National Laboratory has developed an attribute-based methodology for grading the resilience of critical infrastructure, which can be applied to the electric grid.[22] Table 1 provides examples of electric-system attributes that can contribute to resilience for each resilience characteristic discussed in the four-part framework.

Table 1: Example Attributes of Resilient Systems, by Characteristic[23]

Avoid/Resist	Manage	Respond	Recover/Adapt
Deployment of Advance Warning Technologies	Fuel Security including Fuel-less Resources, Fuel Storage, Availability of Fuel Delivery Infrastructure	Ability to Reroute Around Damaged Resources	Ease of Coordination
Hardened/Weatherized	Ability to Separate/Island	Available Substitute Resources	Investment
Regular Maintenance/ Vegetation Management	Ability to Load Shed or Ration	Stockpiled Replacement Resources	Process for Learning from Past Failures
Quantity of Resources Available	Redundant Resources		Number of / Magnitude of Mutual Aid Agreements

For each attribute, a system or component is assigned a numeric score. For example, a distribution system with underground wires may be assigned a high "hardened" score, and each identified attribute can be similarly categorized. This data is then aggregated into a numerical resilience score using subjective weighting and simple arithmetic.

Attribute-based metrics may be appealing because they require less data collection than performance-based metrics, and they may be more easily understandable for casual observers. However, these metrics are more subjective, creating risks that improvements to the attribute will not translate into measurable or predictable improvements in resilience. For example, recent political discussion has focused on "fuel security" as a critical resilience attribute, but a recent analysis of the 2018 cold weather event known as the "bomb cyclone" concluded that coal units had higher forced outage rates than natural gas units, despite the fact that coal units are generally thought to have higher "fuel security" attributes than gas units.[24] In addition, attribute-based metrics, particularly when evaluated one-by-one, are less useful than performance-based metrics for accurately measuring changes in system resilience. For example, a system that is incredibly hardened but lacks redundancy, warning systems, and regular maintenance would be fragile. While a system with a moderate amount of each might be quite resilient.

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21 Vurgin at 12-13.

22 F.D. Petit, et al., Argonne Nat'l Lab., Resilience Measurement Index: An Indicator of Critical Infrastructure Resilience (2013), http://www.ipd.anl.gov/anlpubs/2013/07/76797.pdf.

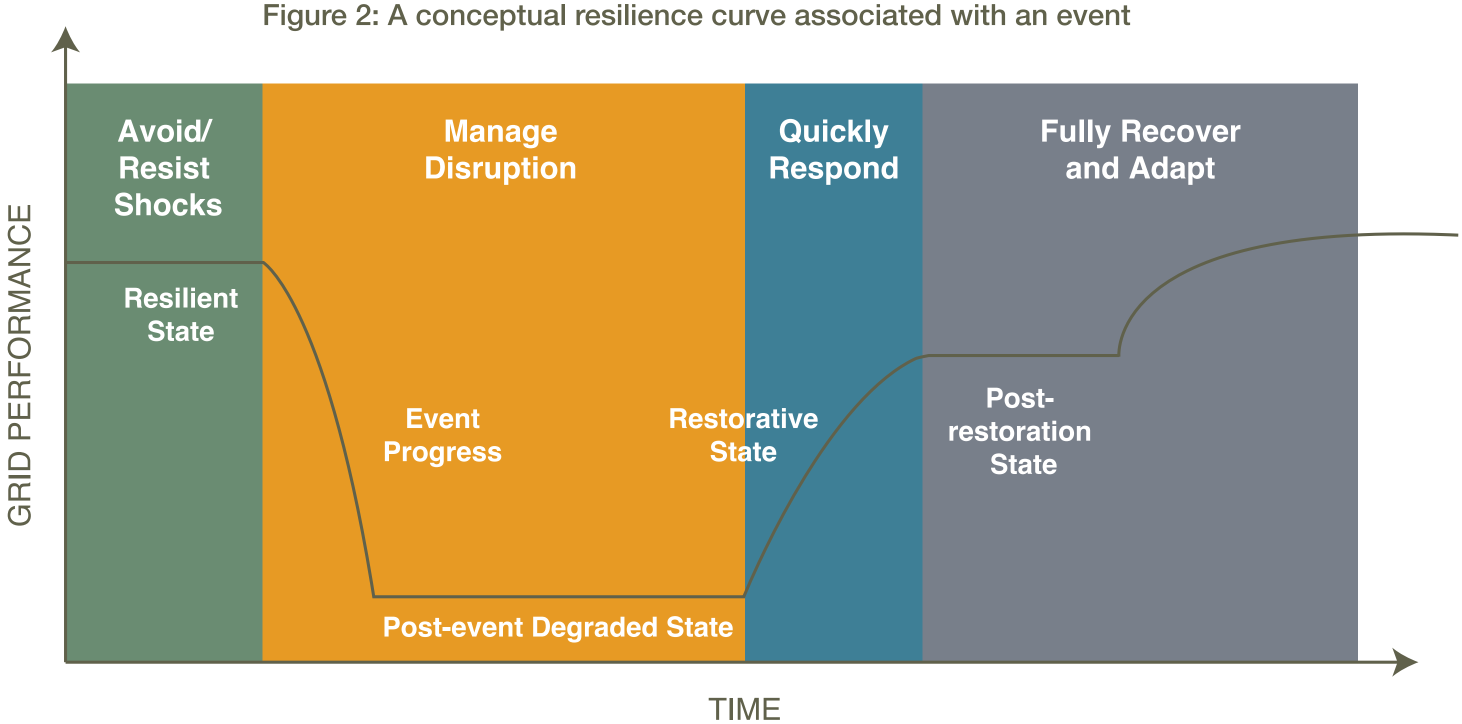
23 This table is adapted from Watson at 29.

24 PJM Interconnection, Strengthening Reliability: An Analysis of Capacity Performance (2018), http://pjm.com/-/media/library/reports-notices/capacity-performance/20180620-capacity-performance-analysis.ashx?la=en.

Putting it Together: The Phases of Electric System Resilience

The four characteristics of a resilient electric system outlined above can be conceptualized as four distinct phases of resilience in the event of a high-impact, low-probability shock, with different metrics and appropriate policy responses applied at each phase. Figure 2 shows a conceptual resilience curve that outlines the phases of resilience before, during, and after a high-impact, low-probability shock. In Figure 2, the vertical axis represents the performance of the system across time, before and after a high-impact, low-probability event.[25]

Figure 2: A conceptual resilience curve associated with an event



Adapted from: Mathaios Panteli & P Mancarella, *The Grid: Stronger, Bigger, Smarter?*, IEEE Power Energy Mag., 59 (2015)

This conceptual graph illustrates that the performance of the system, as measured by the chosen metric, will change over time as the system encounters each phase and exhibits the characteristics of resilience: the ability to (1) resist shocks when an event occurs, (2) manage shocks that disrupt the system, (3) respond to shocks by getting basic systems and services back online, and (4) fully recover from the shock and adapt for the future.

(1) The green area demonstrates an initial level of system performance in the period before an external shock. At this stage, the system's resilience depends on the capability of the system to **prevent and resist any possible hazards, and to reduce the initial damage if a hazard occurs**.[26] During this period, any resource or action that can reduce the probability of a high-impact, low-probability event or any initial damage would improve resilience. For example, when evaluating resilience in the face of a Category-5 hurricane, storm hardening efforts currently underway in many states reduce the probability of outages and increase the grid's ability to resist damage during the hurricane, increasing resilience. As another example, powering down nuclear plants in preparation for a hurricane can help prevent damage and ensure they remain available to provide electricity after the hurricane.

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[25] Panteli & Mancarella at 59; Cen Nan & Giovanni Sansavini at 38.

[26] Panteli & Mancarella at 60.

(2) Once the high-impact, low-probability event happens, the system starts degrading (as illustrated in the orange area). At this stage, the system's resilience depends on the operational flexibility and resourcefulness of the system (and its operators) to quickly **manage evolving conditions and reduce the consequence of the event**.[27] During this period, any resource or action that can reduce the level of degradation or slow the system's degradation can improve resilience. For example, in the context of a hurricane, islanding microgrids can help reduce outages during the storm by minimizing the extent to which a single point of failure in the transmission or distribution system knocks out power for critical services, such as hospitals.

(3) Once the event ends, the system enters into a restorative/recovery mode (as represented in the blue area). At this stage, the system's resilience depends on whether it has a capacity to **enable a fast response** and on the amount of time required to repair the damages.[28] During this period, any technology or action that can expedite the recovery process would improve resilience. This is when on-site fuel can play a limited role in the event of a hurricane that has disrupted fuel transportation networks, such as pipelines. But, as the Puerto Rican grid's incredibly slow recovery from Hurricane Maria illustrates, the recovery capabilities of transmission and distribution generally serve as a bottleneck to power restoration and so tend to be far more important than generator resilience.

(4) Finally, the system enters into a post-restoration state and then an **infrastructure recovery period** (as represented in the grey area).[29] Whether the system can return to its initial resilience level depends on the severity of the event and the level of improvement and investment made in restoration.[30] While the system may return to normal operation during phase (3), full infrastructure recovery may take longer. For example, power may be restored quickly after a flood, even though replacing all the damaged equipment may take longer.[31] During this period, any technology or action that can reduce the time to fully recover would improve resilience. On the other hand, during this phase, the steady-state level of performance can exceed the level preceding the event if, for example, policymakers and grid operators operationalize lessons learned from the event or make investments that minimize risks of future events or of the magnitude of damage.

The transition times shown in Figure 2 are as important as the levels of the performance metric in characterizing the system's resilience.[32] It is important not only to minimize the consequence of, and hence the losses resulting from, the event but also to *ensure that the system degradation occurs slowly* and that *recovery occurs quickly*.[33]

Deepening Understanding: Grid Resilience Insights

A number of implications flow from this framework. First, resilience is a long-term, ongoing, and adaptive concept. Resilience is not achieved, but only improved. Second, resilience is about more than avoiding outages. A resilient electric system minimizes the frequency of unexpected post-shock outages. But even a resilient electric system can experience outages in the face of a high-impact shock. When outages occur, a resilient system is one that manages the consequences of outage events and recovers quickly.[34]

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27 *Id.*
28 *Id.*
29 *Id.*
30 *Id.*
31 *Id.*
32 *Id.*
33 *Id.*
34 NAS at 10.

In addition, the definitions and measures of resilience suggest three larger implications:

- Resilience should be evaluated with respect to the full electric system, not just of individual components;
- Resilience should be defined and measured with respect to specific threats; and,
- Resilience and reliability are distinct concepts with different metrics.

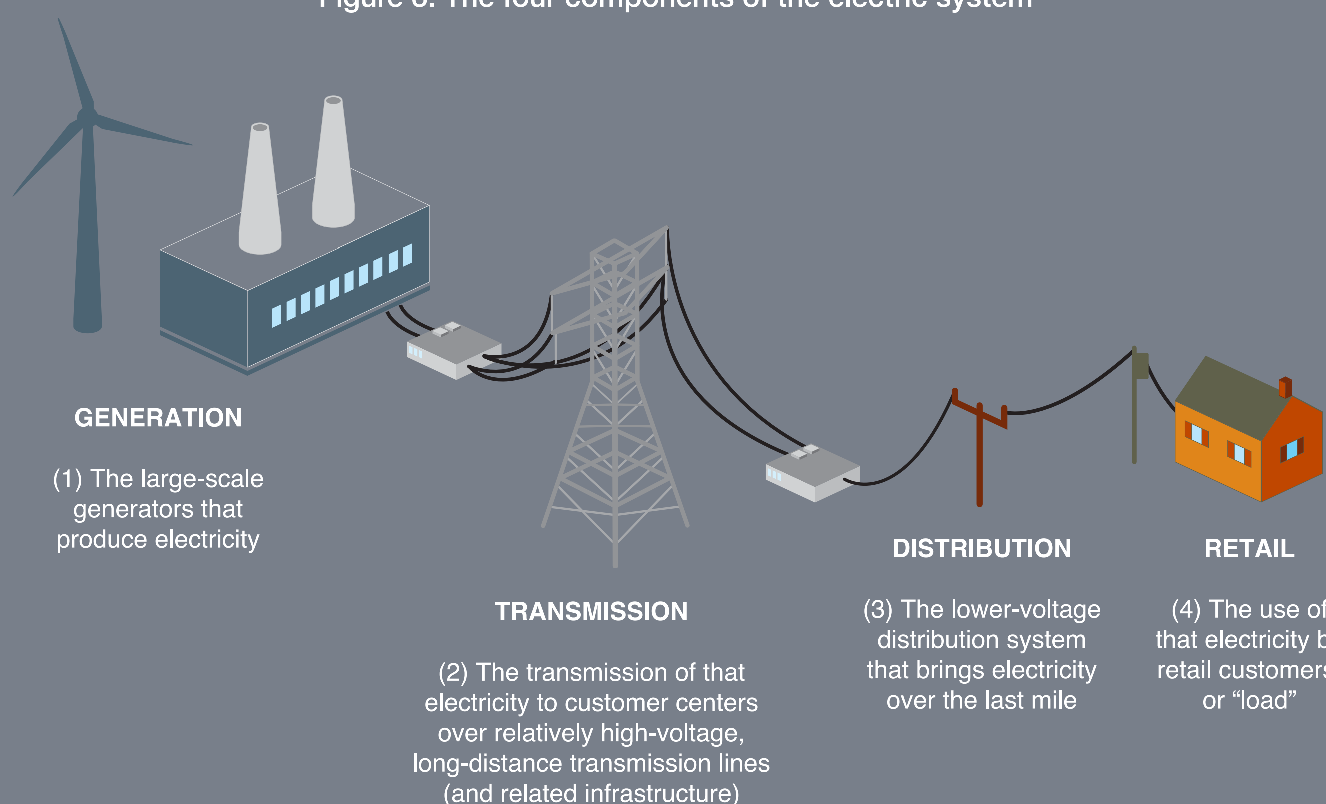
These are discussed in turn.

Resilience Should Be Evaluated with Respect to the Full Electric System

Individual components of the electric system may be vulnerable to high-impact, low-probability external shocks. Poorly maintained distribution infrastructure can cause or be disrupted by fire; a generating plant managed by poorly trained staff may be unprepared for a hurricane, resulting in permanent damage. In some cases, investments and policies that address the identified vulnerabilities of individual components in the electric system can enhance overall system resilience. This type of component-by-component resilience analysis can be characterized as:

- Generation resilience
- Transmission resilience
- Distribution resilience

Figure 3: The four components of the electric system



But resilience is not merely a sum-of-its-parts concept. Individually measuring or improving the resilience of each system component will not necessarily improve the resilience of the entire system. For example, significant investment in generator weatherization may do relatively little to reduce customer outages in the face of a Category 5 hurricane if distribution systems are not also hardened. In fact, interventions that improve the resilience of one system component can reduce the resilience of another, mitigating, and potentially reversing, improvements to system resilience. For example, subsidizing a large centralized generator with on-site fuel in order to mitigate the potential for outages caused by fuel-delivery disruption can increase the consequences of a physical attack on the transmission infrastructure that supports the centralized generator. The net effect of resilience improvements will depend on the relative probabilities of potential high-impact shocks, and the interactions of system components in the face of such shocks.

Therefore, in addition to evaluating whether a particular intervention is economically justified with respect to the appropriate component, regulators, grid planners, and utilities should evaluate the effect of the intervention on the electricity system as a whole. We refer to that concept as "system resilience."

Resilience Should Be Defined and Measured with Respect to Specific Threats

The electric system faces a wide variety of potential high-impact, low-probability shocks that can cause significant customer outages. Relevant threats may include extreme weather (hurricanes, tornadoes, wildfires, drought, extreme cold); sea level rise caused by climate change; other natural events, such as earthquakes and tsunamis; targeted physical attacks on electric infrastructure; cyberattacks; severe geomagnetic disturbances; and electromagnetic pulse events.[35]

Potential Significant Causes of Electricity System Outages		
Extreme Weather Event	**Human-Caused Event**	**Other**
Drought and water shortage	Cyberattack	Volcanic event
Earthquake	Physical attack	Space-based electromagnetic event
Flood and storm surge	Intentional electromagnetic pulse	Fuel supply disruption
Hurricane	Major operation error	
Ice storm		
Tornado		
Tsunami		

Adapted from: Nat'l Acad. of Sci., Eng'g & Med., Enhancing the Resilience of the Nation's Electricity System, 50-69 (2017).

There is no overarching metric of resilience relevant for all known and unknown high-impact, low-probability disruptions; rather, the resilience of a system to one threat will likely be different from resilience to other threats. This is because the magnitude of vulnerability to one threat does not imply similar vulnerability to other threats. A system with weak cybersecurity defenses may have excellent physical security that protects against physical attacks. In addition, the risk of extended outages from different threats may even be inversely related; that is, actions taken in the name of grid resilience may improve the ability of the system to resist or recover from certain disruptive events yet undermine its ability to resist or recover from others. For example, putting wires underground may improve resilience against hurricane-force winds

[35] EPRI, Electric Power System Resiliency: Challenges and Opportunities 6-8 (2016), https://www.naseo.org/Data/Sites/1/resiliency-white-paper.pdf [hereinafter "EPRI"].

but may reduce resilience against earthquakes. Ensuring available on-site fuel may make the grid resilient to fuel-supply disruption but may expose the create new grid vulnerabilities related to significant flooding,[36] leakage,[37] or temperature variations that make stored fuel unusable.[38]

These differences mean that policymakers must prioritize threats. Because resilience focuses on low-probability events, "making every corner of our utility systems resistant to failure would prove cost-prohibitive."[39] Measures to improve electric system resilience should be undertaken selectively to address the specific threats that pose the greatest risk for a given geographic area and electric system component.

Resilience and Reliability are Distinct Concepts with Different Metrics

The definition of resilience is different from the related and often conflated concept of "grid reliability." NERC defines reliability to include two concepts:

- "Operational reliability" is the ability of the electric system to withstand sudden disturbances while avoiding cascading blackouts; whereas
- "Resource adequacy" is the ability of the electric system to generate and transmit adequate quantities of electricity to meet demand, taking into account scheduled and reasonably expected unscheduled system outages.[40]

Whereas resilience is concerned with the ability of the system to prevent and recover quickly from outages caused by high-impact, low-probability events, reliability focuses on limiting the occurrence or spread of outages caused by (relatively) low-impact, high-probability events such as power surges and sudden increases in demand.[41] For example, a Category 5 hurricane that destroys substantial portions of the transmission and distribution system creates a resilience problem when it results in long-term electric system outages for a substantial number of customers until infrastructure can be replaced or rebuilt. On the other hand, an unexpected power surge on a distribution line may create a reliability problem by overloading a key circuit, causing some customers to lose power for a relatively short period. Reliability problems can become resilience problems to the extent that, if not properly managed, they result in cascading blackouts and destruction of infrastructure that requires substantial recovery operations.[42]

Reliability interventions generally seek to lessen the likelihood of outages. Resilience is similarly concerned with lessening the likelihood of disruptive but less-common events, but it also recognizes that disruption will likely occur in the case of

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[36] Mark Watson, *Harvey's Rain Caused Coal-to-Gas Switching: NRG Energy*, S&P Global Platts (Sept. 27, 2017, 5:22 PM), https://www.platts.com/latest-news/electric-power/houston/harveys-rain-caused-coal-to-gas-switching-nrg-21081527.

[37] Robert Walton, *CAISO Considers Making Aliso Canyon Gas Reliability Measures Permanent*, UtilityDive (June 8, 2017) https://www.utilitydive.com/news/caiso-considers-making-aliso-canyon-gas-reliability-measures-permanent/444522/

[38] N. Am. Elec. Reliability Corp., Polar Vortex Review 3 (2014); *Centralized Capacity Markets in Regional Transmission Organizations and Independent System Operators, Winter 2013-2014 Operations and Market Performance in RTOs and ISOs*, 149 FERC ¶ 61145 at 8 (Apr. 1, 2014), https://www.ferc.gov/legal/staff-reports/2014/04-01-14.pdf.

[39] Miles Keogh & Christina Cody, Nat'l Assoc. Reg. Util. Comm'rs, Resilience in Regulated Utilities 1 (2013), https://pubs.naruc.org/pub/536F07E4-2354-D714-5153-7A80198A436D.

[40] NERC, Frequently Asked Questions 1 (2013), https://www.nerc.com/AboutNERC/Documents/NERC%20FAQs%20AUG13.pdf (Operational reliability is also sometimes called "security").

[41] Panteli and Mancarella at 60; Vurgin at 8. Watson at 16.

[42] The 2003 Northeast blackout serves as a good example of a reliability problem that, left untreated, became a resilience problem. *See* FERC, Reliability Primer 31-32 (2016), https://www.ferc.gov/legal/staff-reports/2016/reliability-primer.pdf [hereafter "FERC Reliability Primer"].

a high-impact event. It therefore also focuses on establishing systems to manage and quickly recover from the disruption. As such, the National Academies of Sciences have concluded that "resilience is broader than reliability."[43]

As different (if related) concepts, resilience and reliability must be measured separately. Reliability is a static concept measured by well-defined and consistent metrics.[44] The two most frequently used metrics are measures of the *duration* of system outages (System Average Interruption Duration Index (SAIDI)) and the frequency of system outages (System Average Interruption Frequency Index (SAIFI)).[45]

However, these metrics are not generally appropriate for directing useful resilience decision making. They fail to consider that the impact of an interruption increases the longer the duration of the disruptive event.[46] And regulators often exclude major events when using these metrics because the effect of those events can swamp the smaller events that reliability interventions are generally created to address.[47] Because of the differences between the concepts, the metrics for reliability are not suitable for measuring resilience.[48]

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43 NAS at 1.
44 Panteli and Mancarella at 60; Vurgin at 8; Watson at 16.
45 *See* Keogh at 6.
46 *Id.* at 7-8.
47 *Id.*
48 *Id.* at 11-12.

Evaluating Resilience Interventions

Resilience of the grid to high-impact, low-probability events is a "public good." Public goods are typically underprovided by the market.[49] During a blackout, no generator is able to sell energy. As a result, when a resilience investment prevents or reduces the time of a blackout, all generators that would have sold power benefit. Similarly, given that no consumer can receive energy during a blackout, all consumers benefit from investments that forestall or mitigate a blackout, regardless of whether they pay directly for that service. Resilience investments made by utilities do not necessarily take into account all potential benefits to other entities, so they often will yield a sub-optimally low level of investment needed to facilitate the socially desirable level of resistance, management, response and recovery from high-impact, low-probability shocks. And, therefore, government must play a critical role in ensuring an efficient level of grid resilience.

One of the key challenges of an open-ended and multifaceted public good such as resilience is that regulators and utilities must determine the optimal level and type of resilience interventions. Resilience interventions could include physical improvements, such as hardening the distribution and transmission networks or weatherizing power plants;[50] operational improvements, such as using advanced awareness systems or adaptive islanding;[51] or increased deployment of distributed energy resources and microgrids.[52]

As discussed above, resilience is not binary; the grid is neither "resilient" nor "not resilient." Resilience exists on a spectrum. The grid can maintain different levels of resilience against different types of threats (weather, cyberattack, physical attack, geomagnetic disturbance) at different phases (resistance, continued operation, response, recovery). Improving any of these aspects requires the investment of time and resources; therefore, society must consider how much resilience is the appropriate amount.

Key Term: Public Good

A "public good" is a good or service that is non-rival and non-excludable. Non-rivalry means that the good or service being enjoyed by some does not prevent others from enjoying it simultaneously. Non-excludability means that it is not possible to prevent individuals from enjoying the benefits of the good or service even if they do not pay for it. Public goods are generally underprovided by the market because market participants cannot capture enough value individually to justify investing in the good at the socially efficient level. In order to ensure economically efficient levels of public goods, government intervention—such as direct investment, subsidy, or regulation—is necessary.

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49 NAS at 14.

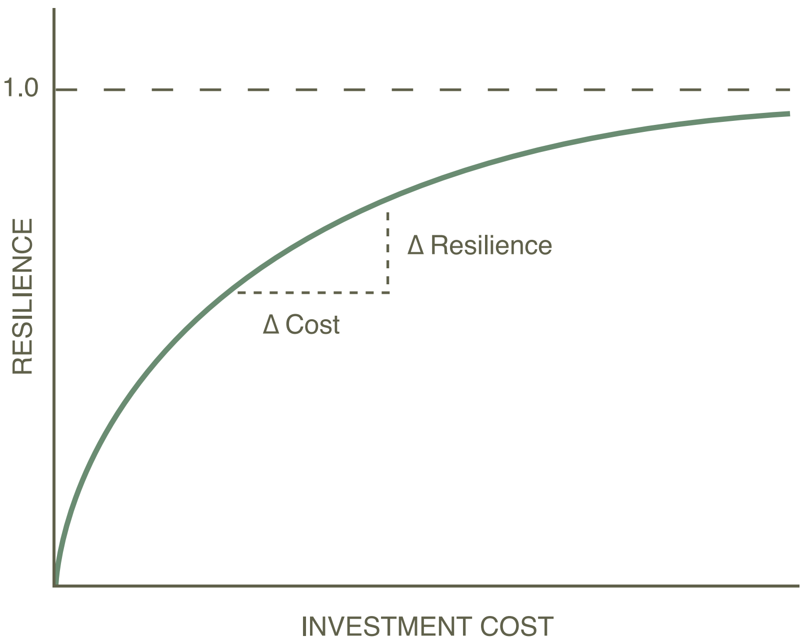
50 Panteli and Mancarella at 60.

51 Yi Ping Fang et al., *Resilience-Based Component Importance Measures for Critical Infrastructure Network Systems*, 65 IEEE Transactions on Reliability 502, 502–512 (2016), http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=7407429; Mathaios Panteli et al., *Boosting the Power Grid Resilience to Extreme Weather Events Using Defensive Islanding*, 7 IEEE Transactions on Smart Grid 2913, 2913–2922 (2016), http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=7407429; Eric D. Vugrin et al., *Optimal Recovery Sequencing for Enhanced Resilience and Service Restoration in Transportation Networks*, 10 Int. J. Critical Infrastructures 218 (2014), http://www.inderscience.com/link.php?id=66356.

52 NAS at 77-78.

The tradeoff between a given level of resilience and the investment needed to achieve that level of resilience is conceptually represented in Figure 4. This figure shows that a change in investment (ΔCost) will yield a change in resilience (ΔResilience) and that a 100% level of resilience is not achievable.[53]

Figure 4: Incremental cost of resilience



Adapted from: Jean-Paul Watson et al., Sandia Nat'l Labs., Conceptual Framework for Developing Resilience Metrics for the Electricity, Oil, and Gas Sectors in the United States 53 (2015).

Also, because of the variety of threat types and potential interventions, resource allocation among threats and technological solutions is critical. Government entities and utilities, therefore, need a decision framework that helps them decide which investments or projects to improve resilience are worthwhile and which are not.

In the second installment of its Quadrennial Energy Review, DOE suggests that cost-benefit analysis should be used to evaluate resilience investments.[54] In its recent compliance filing in FERC's resilience docket, the California ISO also advocated using cost-benefit analysis to assess potential resilience interventions.[55]

Using cost-benefit analysis to evaluate resilience policies and investments has two main advantages:

- First, cost-benefit analysis can help policymakers and utilities develop policies and make investments that maximize social welfare. Investments are socially efficient when the incremental cost of achieving the level of resilience—that is, the last dollar needed to achieve a particular level of resilience—is equal to the incremental

53 Engineers who study resilience represent the performance of a system over the course of an event using formulas where the resilience metrics span the range of 0 (lowest level of performance during an event) to 1 (return to steady-state level of resilience). Yi Ping Fang at 65. This is reflected as the Y-axis in Figure 4.

54 DOE QER at 7-22.

55 Comments of California Independent System Operator Corporation at 8, *Grid Resilience in Regional Transmission Organizations and Independent System Operators*, Docket No. AD18-7-000 (March 9, 2018).

resilience benefit—that is, the benefit of the last "unit" of resilience achieved. When choosing among conflicting options, the efficient investment would maximize net benefits to society.[56] This approach can be used regardless of whether the investments will be made by government entities or by utilities at the direction of regulators.

- Second, evaluating potential policies and investments using a systematic and evidence-based framework can help to ensure that proposals are actually effective (and cost-effective) in enhancing resilience, rather than just pretext for providing financial support to favored industries. For example, policymakers can use cost-benefit analysis to evaluate whether proposals to limit retirement of coal and nuclear plants would achieve their goals of reducing the expected costs of a cyberattack on natural gas pipeline infrastructure and reducing outages at defense-critical facilities such as military bases. Such analysis is particularly important for policy proposals, such as this, which would impose substantial costs, upend electricity markets, and potentially fail to achieve resilience goals, according to substantial expert criticism.[57] Cost-benefit analysis can provide the public and courts a transparent basis to evaluate proposals to determine whether the means chosen to enhance resilience match the specific threats identified.

Conducting cost-benefit analysis requires an evaluation of the incremental benefits and incremental costs of various resilience-improving policies and investments. The rest of this section outlines methods for evaluating these benefits and costs, and then highlights examples of state policies and studies that have put similar methodologies into practice.

Incremental Benefits of Resilience Interventions

To determine the efficient level of different resilience policies or investments, decisionmakers must first understand the expected benefits of such actions. Resilience policies and investments are valuable because they allow society to avoid or mitigate costs that would be imposed by a high-impact, low-probability event. For example, an investment that reduces 1000 customer outage hours from a hurricane provides society with benefits equal to the economic value of avoiding those outage hours. Calculating the benefits of resilience investments and policies involves quantifying the probability-weighted costs of disruptions, and how those costs change based on the investments and policies being considered. Therefore, resilience benefits are a function of the probability of each particular high-impact, low-probability event; the social cost if the event were to occur; and the extent to which the investment reduces the event's probability or impact.

In this section, we lay out a streamlined version of a framework for calculating the benefits of resilience investments and policies that was developed by Sandia National Laboratory as part of the DOE Metrics Analysis for Grid Modernization Project.[58]

[56] Office of Mgmt. & Budget, Circular A-4 at 10(Sept. 17, 2003), *available at* https://www.whitehouse.gov/sites/whitehouse.gov/files/omb/circulars/A4/a-4.pdf [hereinafter "Circular A-4"].

[57] *The Electric Grid of the Future: Hearing Before the Energy Subcomm. of the H. Sci. Comm.* (2018) (testimony of Robert E. Gramlich President, Grid Strategies LLC), https://science.house.gov/sites/republicans.science.house.gov/files/documents/HHRG-115-SY20-WState-RGramlich-20180607.pdf.

[58] Vugrin. Sandia produced a useful example of how this framework can be used to evaluate the benefits of different resilience interventions, including investments in line-burying and flood walls, and policy responses such advanced planning in the event of a hurricane. *See* Wastson et al at 73-80.

Step 1: Characterize Threats

First, policymakers must identify and characterize the specific threats against which the system should be resilient; examples include a hurricane exceeding a specific category, earthquakes exceeding a certain magnitude, a cyberattack that disables physical infrastructure control systems (called "SCADA systems"), and extreme cold or heat for specified durations.

Selecting relevant threats for which the policymaker is responsible will involve a combination of judgment and probabilistic analysis about the events most likely to significantly disrupt the electric system. In many instances, the threats identified will differ by region. The benefit of protecting against hurricane-force winds is likely greater in Tampa than in Los Angeles, whereas the benefit of improving distribution system resilience with respect to wildfires or earthquakes may be greater in San Francisco than in Houston. The probability of human-caused threats, such as cyberattacks or physical security attacks, will differ by region—attacks are more likely in Paris, France than Paris, Texas. Moreover, due to higher population density and economic output, the magnitude of impact and therefore the benefit of an intervention may be greater in New York City than in Duluth.

This step involves not only the identification of types of disruptive events but also a detailed specification of threat scenarios against which resilience improvements will be measured (e.g., the magnitude and location of an earthquake along with the number and magnitude of aftershocks). These scenarios should include probability estimates for the threats, which will be incorporated into later steps.

Step 2: Define Resilience Metrics

Next, policymakers should define the specific resilience metrics that will be used to measure the existing level of system resilience given the threats identified in Step 1, and the potential level if investments or policy changes are made.

In order to be useful in quantitative analyses of resilience, metrics should be performance-based and have the following features:

- Measurable in terms of the *consequences* expected to result from particular threat types.
- Reflect uncertainty (e.g., the expected consequence or the probability of the consequence occurring exceeds an acceptable level).[59]
- Use data from computation models that incorporate historical experience or expert evaluation.

Metrics can be direct (e.g., the cumulative number of customers or hours without power after an event) or indirect (e.g., the number of critical services without power for more than the time they typically have backup power). These metrics should then be monetized for use in a holistic cost-benefit analysis, such as the cost of electric system repair and the economic value of lost load.

For example, in a study of how on-site renewable energy and storage systems can improve the resilience of electricity delivery to buildings in New York City, researchers at the National Renewable Energy Laboratory and the City University

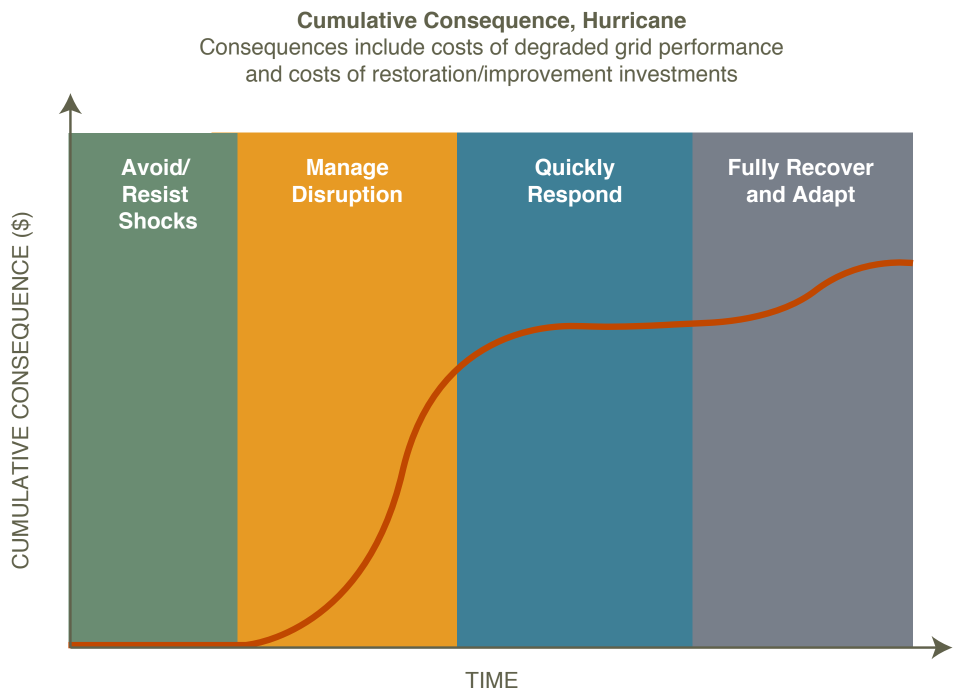
[59] Vugrin at 16-17.

of New York developed a resilience metric—the "value of resiliency."[60] This metric was calculated as the Value of Lost Load multiplied by the increased amount of "critical load" that could be served during a grid outage due to installation of on-site renewable energy and storage.[61]

Step 3: Quantify Baseline Resilience

This step involves the quantification of the baseline level of resilience—how the identified threats are expected to affect generation, transmission, distribution, and customer infrastructure, without any policy intervention. This specification can include which assets may be lost or degraded as well as repair/replacement time and cost. Ranges can be used to incorporate uncertainty. Policymakers and planners can then use system-level computer models to more fully evaluate the systemic effects of that infrastructure disruption. These simulations can facilitate calculation and quantification of the expected consequences of each hazard over time. These consequences should be expressed in terms of the monetized resilience metrics developed in Step 2. As illustrated in Figure 5 the lost economic value caused by power outages and the cost of infrastructure repair can be summed over time to produce a cumulative assessment of the consequences of a threat.

Figure 5: Calculating cumulative consequences of a threat



Adapted from: Jean-Paul Watson et al., Sandia Nat'l Labs., Conceptual Framework for Developing Resilience Metrics for the Electricity, Oil, and Gas Sectors in the United States 39 (2015).

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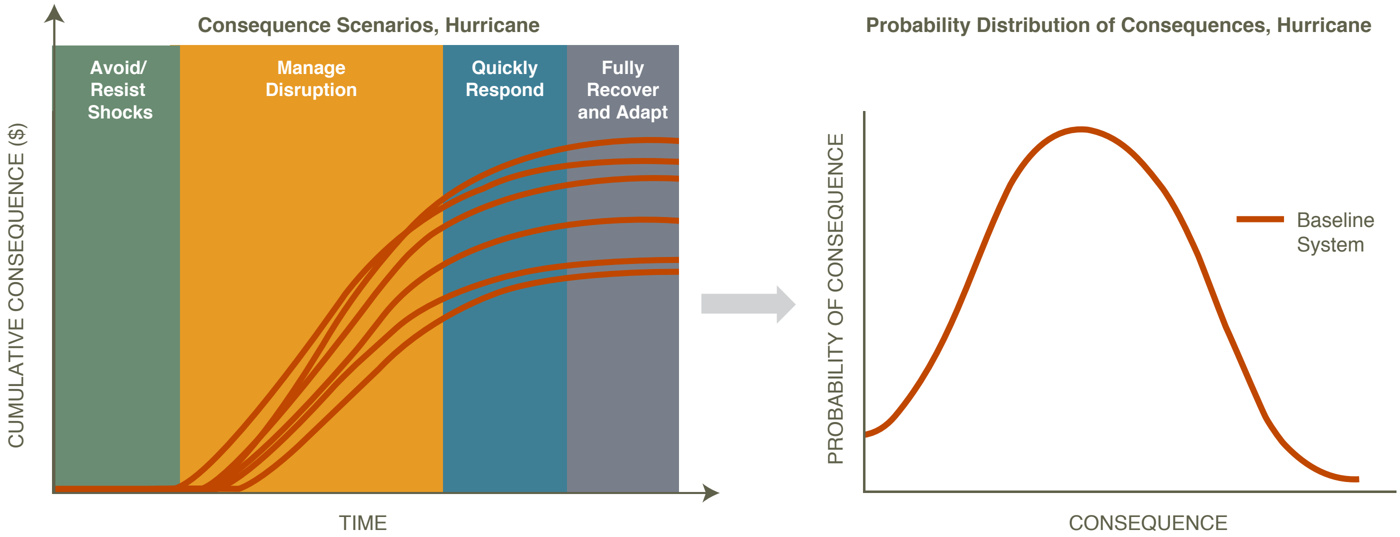
60 *See* Kate Anderson et al., *Quantifying and Monetizing Renewable Energy Resiliency*, 10 Sustainability 933 (2018), http://www.mdpi.com/2071-1050/10/4/933/htm#B13-sustainability-10-00933.

61 The researchers used a Value of Lost Load of $100 per kWh. Modeling showed that the renewable energy plus storage system under consideration would allow a building to sustain load for three times longer than a diesel backup generator; and so valued the resilience benefit of that system at $781,200. *Id.* § *See also The Interruption Cost Estimate Calculator 2.0*, ICE Calculator, https://icecalculator.com/home (last visited July 31, 2018) for an online tool developed by Lawrence Berkeley National Lab to estimate interruption costs or improvement benefits.

Because resilience is concerned with high-impact, low-probability events, it is important to take into account uncertainty in what level of disruption a given event will cause. In the baseline analysis, regulators can use the computer models to simulate different scenarios that reflect changes in threat significance or other key variables. These various simulations can be combined to produce a probabilistic value of the consequence of a threat. This is demonstrated in Figure 6.

Figure 6: Probabilistic Consequence of a Threat



Adapted from: Jean-Paul Watson et al., Sandia Nat'l Labs., Conceptual Framework for Developing Resilience Metrics for the Electricity, Oil, and Gas Sectors in the United States 39 (2015).

Step 4: Characterize Potential Resilience Interventions

Once the baseline resilience is identified, the goal is to calculate the value of resilience improvements achievable through particular interventions. These interventions could come in the form of mandated or direct investments in the generation, transmission, or distribution systems (such as fuel storage, hardening, or vegetation management), or they could be regulatory policies, such as requiring coordination among grid operators and utilities; changing market rules to provide market participants performance or investment incentives; or mandating specific actions, such as cybersecurity practices.

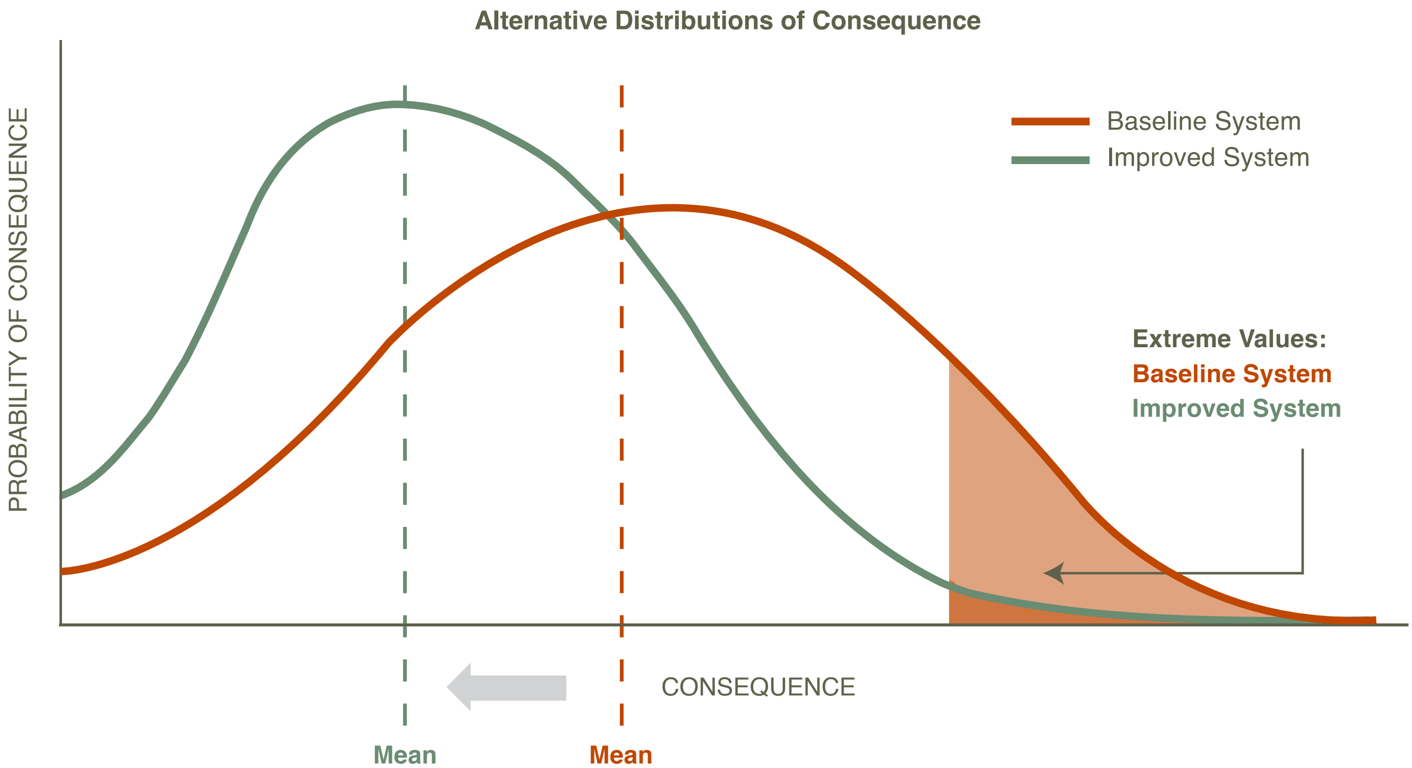
Once a menu of potential interventions is identified, the effects of interventions can be characterized. Some interventions enhance resilience by reducing the probability of specified threats. For example, strict password security protocols can reduce the likelihood that hackers penetrate utility control systems. While quantification of the change in threat probability of an event may be particularly difficult, policymakers can, nonetheless, make reasonable assumptions. Other interventions enhance resilience by reducing the magnitude of disruption that will occur in the face of identified threats. For example, an intervention might reduce the time needed to deploy new infrastructure by maintaining an infrastructure reserve or by facilitating islanding of a slice of the electric system to prevent cascading blackouts.

Step 5: Evaluate Resilience Improvements from Interventions

Evaluating the benefits of each potential intervention involves repeating Step 3, but with appropriate changes made to the electric system simulation models based on the particular policy or investment characterized in Step 4. The monetized savings between the baseline resilience metrics and the improved resilience metrics constitute the benefits of the intervention.

Figure 7 graphically demonstrates how a baseline level of resilience and resilience after an intervention can be compared.

Figure 7. Comparing resilience consequences of baseline and intervention scenarios.



Source: Jean-Paul Watson et al., Sandia Nat'l Labs., Conceptual Framework for Developing Resilience Metrics for the Electricity, Oil, and Gas Sectors in the United States 40 (2015).

Limitations

While this framework establishes a pathway for quantifying the benefits of resilience interventions, it carries substantial information requirements. This methodology requires understanding the probability distributions and likely damage functions of the underlying high-impact, low-probability events. We have limited information on these events due to their nature; incorporation of uncertainty into the analyses is therefore critical. In addition to quantifying baseline resilience, the methodology requires sufficient data to predict the extent to which investments and policies will change the probabilities and consequences of threats.

Incremental Costs of Resilience Interventions

There are a number of cost categories when evaluating potential resilience interventions. OMB Circular A-4 provides guidance to federal agencies regarding the estimation of costs and benefits of agency decisions and can serve as a useful guide for the consideration of the costs of resilience interventions.[62] Circular A-4 directs agencies to consider private-sector compliance costs, administrative costs, losses in consumer and producer surpluses, costs associated with countervailing risks, and health and safety costs.[63] Resilience investments and policies can impose costs in all of these categories.

Resilience investments and policies have direct, monetary costs on entities responsible for building or improving infrastructure. These may include project costs to improve or harden existing electric system infrastructure, build new transmission or distribution lines, or stockpile components; investments in cybersecurity and physical security; and costs related to planning or coordination exercises.

Policies that improve resilience by changing market rules can also result in additional consumer costs through increases in the price of electric energy and capacity. Because of the complex relationship between firm and consumer behavior affected by market rule changes, calculation of these costs may require the use of power sector and electric market modeling.

Resilience interventions can entail additional costs related to increases in countervailing risks. Interventions that improve resilience of one phase (resistance, continued operation, response, or recovery) may ultimately undermine the resilience of another phase. For example, putting transmission lines underground may significantly improve the resistance of transmission to disruption, but it will also make recovery more difficult if disruption occurs (e.g., due to flooding). As such, regulators and utilities should also evaluate an intervention's associated trade-offs, and the total effect on electric system resilience across phases. Costs associated with countervailing resilience risks can be calculated using the framework outlined above.

Some resilience interventions may also have environmental costs. Policy changes and infrastructure investments can alter the incentives to operate various power plants with different environmental performance, such as different rates of air pollution emissions. Similarly, investments in new infrastructure can result in environmental impacts associated with project development. These environmental effects can be quantified and monetized as environmental costs.

Relevant Examples from States

While methodologies to quantify the costs and benefits of resilience improvements have not been widely used in regulatory proceedings, there are some recent examples that can serve as a basis for policymakers.

New York State discusses a methodology for quantifying resilience benefits in the Benefit-Cost Analysis Framework associated with the state's Reforming Energy Vision proceeding.[64] Utilities use the Benefit-Cost Analysis Framework

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62 *See* Circular A-4.

63 *Id.* at 26, 28, 37.

64 Order Establishing the Benefit Cost Analysis Framework, Case No. 14-M-0101 at Appendix C 2 (N.Y. PSC 2016) http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7bF8C835E1-EDB5-47FF-BD78-73EB5B3B177A%7d.

when evaluating certain types of utility expenditures (on distribution projects, distributed energy resources, and energy efficiency programs).[65] While the general method outlined by New York offers a good conceptual example of how state regulators can approach valuing the benefits of resilience, the specific metrics used by utilities appear to better reflect reliability than resilience.[66] New York is not alone; many utilities estimate the value of lost load due to a high-impact, low-probability event using the Interruption Cost Estimate calculator. However, research suggests that this tool, developed primarily for evaluating reliability improvements, is not appropriate to use for evaluating potential resilience improvements.[67] Research is underway to further develop a resilience-focused value of lost load metric.[68]

In the wake of several significant hurricanes, the Public Utility Commission of Texas commissioned a cost-benefit analysis of vegetation management programs, ground-based patrols, infrastructure hardening, and deployment of new technologies.[69] This analysis used a probabilistic hurricane model as well as two primary metrics for evaluating resilience benefits: the avoided cost to repair or replace existing infrastructure, and expected changes in gross domestic product (GDP) for hurricane-prone areas.

Academic researchers are using similar techniques to estimate the resilience value of certain interventions. For example, a group of researchers associated with the National Renewable Energy Laboratory and the City University of New York published a study evaluating the net resilience benefits at the building scale of pairing renewable energy systems with existing backup diesel generators.[70] These existing approaches can serve as a model for regulators and utilities.

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65 *Id.* at 1-2.

66 *See, e.g.,* New York State Electric & Gas Corp., BCA Handbook Version 1.1 55-59 (2016), http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7BF0CC59D0-4E2F-4440-8E14-1DC07566BB94%7D.

67 EPRI at 46.

68 Anderson, 10 Sustainability 933.

69 Quanta Tech., Cost-Benefit Analysis of the Deployment of Utility Infrastructure Upgrades and Storm Hardening Programs 45-66 (2009), http://www.puc.texas.gov/industry/electric/reports/infra/utlity_infrastructure_upgrades_rpt.pdf.

70 Anderson, 10 Sustainability 933.

Addressing Resilience within the Federal System

The electric grid is an interconnected whole; however, under U.S. law, the grid is subject to divergent and sometimes overlapping regulatory control by federal and state entities. Any needed grid resilience improvements will require action at different levels of government as well as coordination among regulators, grid operators, and utilities. However, that there is bifurcated jurisdictional authority does not imply that there are gaps. Sufficient authorities exist at the federal and state levels to allow for cost-beneficial resilience-enhancing actions, including investments, policies, planning and coordination.

This section begins with a brief overview of the jurisdictional divide in responsibility between state and federal regulators. It then identifies specific regulatory authorities and tools that states have to enhance electric system resilience and makes some recommendations for improvements. Finally, it identifies authorities that the federal government has to enhance electric system resilience and makes recommendations for which authorities are appropriate under different circumstances.

A Brief Overview of the Electric System Jurisdictional Divide

The Federal Power Act gives the states regulatory responsibility over both retail sales of electricity and electric utilities responsible for local distribution infrastructure.[71] In addition, it provides states authority over electric generators (though not over the wholesale sale of the electricity that they produce), including the ability to enact policies that create preferences for certain power sources over others such as renewable portfolio standards. States also have regulatory responsibility over small generators that are interconnected with the distribution system rather than the transmission system, including responsibility for setting the rates paid for electricity generated from these distributed sources.[72]

On the other hand, the Federal Power Act provides the federal government—and FERC, in particular—responsibility to regulate wholesale sales of electricity, interstate transmission of electricity, and the facilities used for that interstate transmission.[73] In two-thirds of the country, federally regulated ISOs/RTOs manage electricity markets that must constantly balance supply and demand under a set of rules approved by FERC.

In addition, in 2005, Congress enacted Section 215 of the Federal Power Act,[74] which gave FERC, in partnership with NERC,[75] the additional responsibility of ensuring the reliable operation of the "bulk power system."

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71 Federal Power Act (FPA) § 201, 16 U.S.C. § 824 (2015).

72 Robert R. Nordhaus, *The Hazy "Bright Line": Defining Federal and State Regulation of Today's Electric Grid*, 36 Energy L.J. 203, 207-08 (2015).

73 FPA § 201(b)(1), 16 U.S.C. § 824(b)(1).

74 FPA § 215(a)(1), 16 U.S.C. § 824o(a)(1).

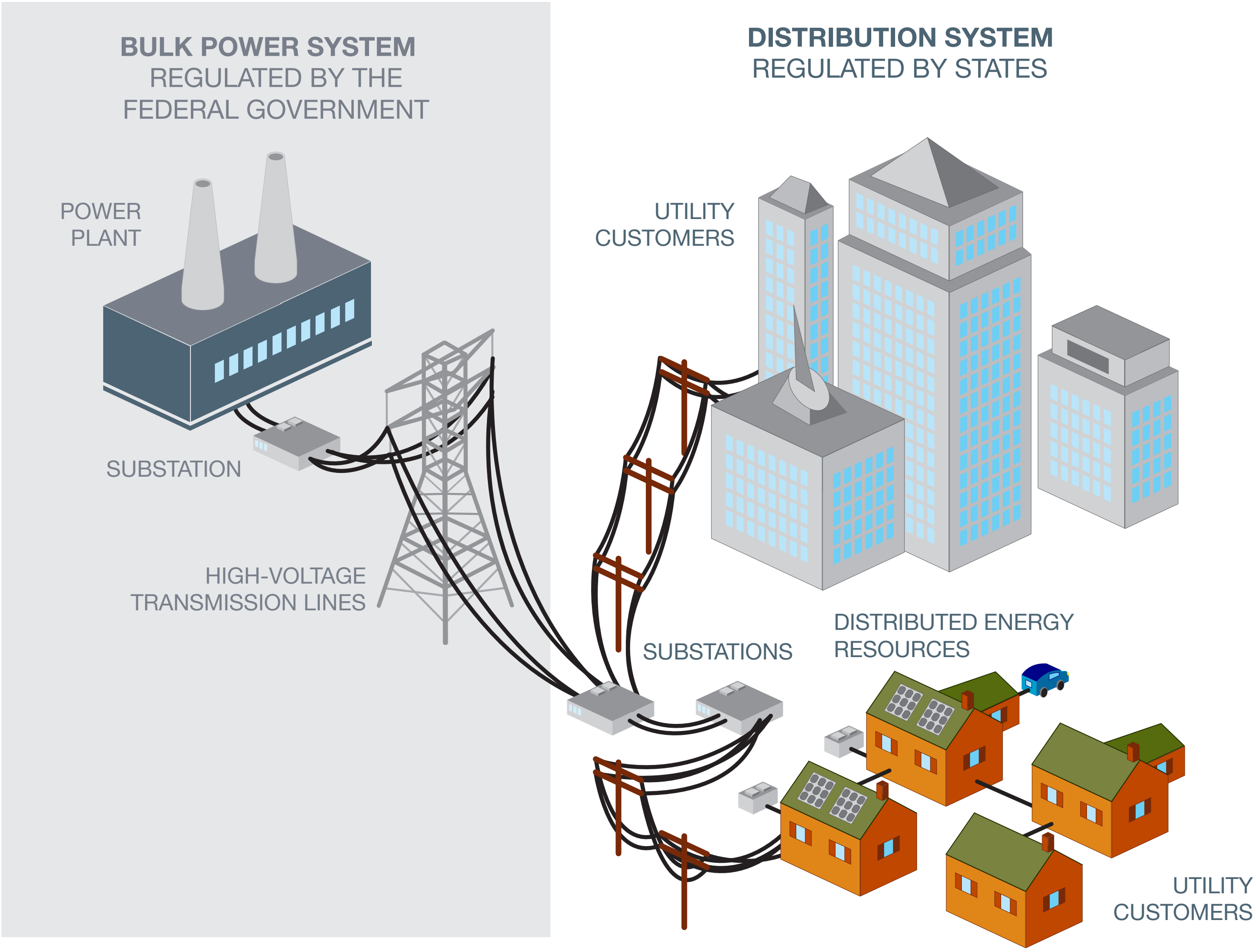
75 NERC is also responsible for initiating compliance and enforcement actions for mandatory reliability standards, and for *assessing* reliability and resource adequacy, particularly in the face of extreme events. FERC Reliability Primer at 65-71.

Key Term: Bulk Power System

The “bulk power system” includes transmission and related infrastructure and electric generators whose energy is needed to maintain transmission system reliability.[76] The Federal Power Act specifically excludes facilities used in local distribution from the definition of “bulk power system.”[77] Figure 8 illustrates the jurisdictional divide between the bulk power system, which is the responsibility of FERC, and the distribution system, which is the responsibility of the states.

Figure 8: Regulatory domains of the electric grid

The electric grid is divided between the bulk power system, subject to FERC and NERC jurisdiction, and the distribution system, subject to state and local regulatory jurisdiction.



[76] FPA § 215(a)(1), 16 U.S.C. § 824o(a)(1).
[77] FPA § 215(a)(1), 16 U.S.C. § 824o(a)(1).

FERC's responsibility under Section 215 of the Federal Power Act is limited to ensuring *operational* reliability—the ability of the system to withstand sudden disturbances without resulting in cascading blackouts.[78] It does not extend to ensuring resource adequacy—the availability of sufficient generating capacity to meet peak electric demand.[79] Under the FERC regulations issued pursuant to Section 215, NERC proposes—either on its own initiative or at the direction of FERC—mandatory reliability standards to be implemented by bulk power system entities such as generators, transmission owners, or regional entities known as "reliability coordinators."[80] FERC will approve a proposed standard so long as it meets statutory and regulatory criteria, including that the standard is a technically sound and efficient means of achieving a reliability goal; was developed initially by industry experts; was based on sound engineering and technical criteria; and is clear and unambiguous regarding its requirements.[81]

Regulation of resource adequacy is, in practice, split between the federal government and states.[82] States have traditionally had authority over resource adequacy. In regions that do not rely on ISOs/RTOs to manage electricity markets, states retain that authority. Over the past 20 years, the federal government has increased its regulatory influence over resource adequacy in some circumstances. A number of ISOs/RTOs have developed "capacity markets"—market-based constructs for meeting resource adequacy needs. The ISO/RTO rules governing these capacity markets fall under FERC's jurisdiction. Other ISO/RTOs have developed resource adequacy constructs that are explicitly designed to reflect shared power between states and federal regulators.[83]

In addition, the Department of Energy retains some authority to coordinate energy-sector information sharing and best practices for critical-infrastructure protection,[84] and to issue certain emergency orders in the face of a grid emergency.[85]

States' Role in Improving Electric System Resilience

Because states have exclusive jurisdiction over distribution-level facilities, which are the source of the vast majority of customer outages from unexpected events,[86] states have focused on grid resilience for some time. States, particularly those that have faced highly disruptive events, have invested significant resources in analyzing opportunities for improving system resilience. We outline three types of opportunities for states to improve electric system resilience.

Directing Distribution Utilities to Make Resilience Investments

The primary way that states can and do improve grid resilience is by directing public utilities under their regulatory authority to invest in key physical and operational systems, and to ensure that utilities can recover the costs of such investments.

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78 NAS.

79 FPA § 215(i)(2), 16 U.S.C. § 824o(i)(2).

80 For many regions the relevant ISO/RTO serves as both grid operator and reliability coordinator.

81 FERC, Reliability Primer at 55-56.

82 Nordhaus, 36 Energy L.J. at 210.

83 *See* Brian R. Gish, *Ensuring Resource Adequacy in Competitive Electricity Markets*, POWER (March 1, 2012), http://www.powermag.com/ensuring-resource-adequacy-in-competitive-electricity-markets/?printmode=1 (describing resource adequacy requirements in the Midcontinent Independent System Operator market).

84 PPD-21 (detailing DOE authority and responsibilities for energy sector critical infrastructure protection).

85 FPA § 202(c), 16 U.S.C. § 824a(c); FPA § 215A, 16 U.S.C. § 824o-1.

86 FERC & NERC, Regional Entity Joint Review of Restoration and Recovery Plans 1 (2016)

Several well-identified interventions that states can undertake to improve resilience include:

- improving vegetation management;[87]
- targeted undergrounding of critical distribution lines;[88]
- load-reduction strategies;[89]
- targeted hardening of distribution lines and substations against storm and physical damage, including through the use of innovative pole and line designs;[90]
- adopting regulation and customer communication plans that facilitate the preparation of selected assets prior to an event to reduce damage in the case of extreme weather events;[91]
- developing strategies for selective restoration and load prioritization to most efficiently restore power and recover from high-impact events;[92] and,
- requiring and overseeing more regular testing of backup power generation equipment at critical facilities.[93]

Additionally, states should consider the extent to which climate change will exacerbate resilience concerns and incorporate climate change directly into resilience-related cost-benefit analyses and risk assessment.[94]

States have indeed adopted many of these strategies as part of their mandate to ensure electric service for customers.[95] Examples include:

- A number of Northeast states require utilities to submit vegetation management plans for Public Utility Commission approval.[96]
- In Washington D.C., the Public Service Commission is responsible for considering a triennial plan filed jointly by the local distribution utility and the District's Department of Transportation for the undergrounding of priority distribution infrastructure.[97]
- Since Hurricane Wilma in 2005, the Florida Public Utility Commission directed distribution utilities to invest in strengthening of distribution lines, pole replacements, and vegetation management. These investments significantly reduced customer outages during Hurricane Irma in 2017.[98]

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87 EPRI at 35.
88 *Id.*
89 *Id.* at 36.
90 *Id.* at 40.
91 NAS at 115.
92 *Id.* at 103.
93 *Id.* at 96-97.
94 *See* Justin Gundlach & Romany Webb, Sabin Center for Climate Change Law, Climate Change Impacts on the Bulk Power System: Assessing Vulnerabilities and Planning for Resilience 1-25 (2018), http://columbiaclimatelaw.com/files/2018/02/Gundlach-Webb-2018-02-CC-Bulk-Power-System.pdf.
95 For an overview of state approaches to resilience, see Edison Elec. Inst., Before and After the Storm: A Compilation of Recent Studies, Programs, and Policies Related to Storm Hardening and Resiliency 1-132 (2014), http://www.eei.org/issuesandpolicy/electricreliability/mutualassistance/Documents/BeforeandAftertheStorm.pdf.
96 Lee R. Hansen, State of Connecticut, Utility Tree Trimming in Other States,(2011), http://www.cga.ct.gov/2011/rpt/2011-R-0459.htm.
97 D.C. Pub. Serv. Comm'n, In the Matter of the Application for Approval of Triennial Underground Infrastructure Improvement Projects Plan (Nov. 12, 2014), https://edocket.dcpsc.org/apis/pdf_files/e8c918a0-d080-4982-83a6-a649d7f64966.pdf.
98 Alison Silverstein et al., Grid Strategies LLC, A Customer-focused Framework for Electric System Resilience 58 (2018), https://gridprogress.files.wordpress.com/2018/05/customer-focused-resilience-final-050118.pdf.

Rules to Encourage Resilience-Enhancing Distributed Energy Resources

States can also use their distinct role in regulating distributed energy resources (DERs) to enhance grid resilience. DERs, including rooftop solar, electric batteries, backup generators, microturbines, and demand response, can enhance resilience in several ways.[99] Because DERs are generally located close to load, they reduce customers' reliance on vulnerable distribution infrastructure. This is particularly true when DERs can operate as islanded microgrids, allowing them to supply limited power to critical loads during large grid outages of long duration.[100] DERs are nonetheless generally interconnected with the distribution system and so can provide redundant generation supplies in the case of a generation, transmission, or distribution disruption that limits traditional sources' ability to supply energy. Because they are typically much smaller and more geographically dispersed than traditional power plants, DERs can reduce the risk that a single point of generation or transmission system failure will have a significant impact on customers.

Additional interventions related to DERs can improve resilience, including:

- revising utility-DER interconnection agreements to include resilience characteristics such as encouraging the use of enhanced inverters and islanding capability;[101]
- developing customer rate structures that compensate DERs for the quantified resilience value they provide;[102]
- encouragement of islanded microgrids for critical load,[103] including establishing special rates to encourage the development of private microgrids that provide resilience benefitis;[104] and,
- establishing contractual agreements and special rates with DER-owning customers that would permit the utility to use the DERs to supply critical loads during a high-impact event.[105]

Motivated in part by the increased frequency of extreme weather events, many states across the country have recently been ramping up their grid-modernization efforts. While the exact policies differ, many states are looking to advance their resilience goals by increasing the deployment of advanced technology and DERs, such as energy storage and microgrids.[106]

In the aftermath of Superstorm Sandy, New York and New Jersey invested significant resources in DERs and microgrids to reduce outages in the face of future natural disasters. In response to a 2016 report,[107] the New Jersey Board of Public Utilities initiated a process to add microgrids to the state and is currently completing the first step of funding feasibility studies for 13 municipal microgrids.[108]

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[99] Sherry Stout & Eliza Hotchkiss, Nat'l Renewable Energy Lab., Distributed Energy Generation for Climate Resilience (2017), https://www.nrel.gov/docs/fy17osti/68296.pdf. EPRI, Enhancing Distribution Resiliency: Opportunities for Applying Innovative Technologies 11 (2013), https://www.epri.com/#/pages/product/000000000001026889/.

[100] NAS at 106-107.

[101] *Id.* at 107.

[102] *Id.* at 108.

[103] EPRI at 44.

[104] NAS at 107.

[105] *Id.* at 108.

[106] Autumn Proudlove et al., N.C. Clean Energy Tech. Ctr., The 50 States of Grid Modernization: 2017 Review and Q4 2017 Quarterly Report 6 (2018), https://nccleantech.ncsu.edu/wp-content/uploads/Q42017_gridmod_exec_final.pdf.

[107] N.J. Board of Pub. Utils., Microgrid Report (2016), https://www.nj.gov/bpu/newsroom/announcements/pdf/20161130micro.pdf.

[108] N.J. Board of Pub. Utils., Town Center Distrubted Energy Resource Micgrogrid Feasibility Study Incentive Program Application , https://www.nj.gov/bpu/pdf/commercial/TC%20DER%20Microgrid%20Feasibility%20Study%20Application.pdf.

As part of its comprehensive energy strategy known as Reforming the Energy Vision (REV), New York has adopted a series of measures to promote grid resilience through increased deployment of DERs.[109] This includes policies to pay DERs for avoiding needed distribution investments,[110] policies that enable new financing models,[111] and policies that reduce market barriers by facilitating community solar.[112] New York has also implemented policies to expand microgrids. NY Prize is a competition to help local communities develop their own microgrids to "enable the technological, operational, and business models that will help communities reduce costs, promote clean energy, and build reliability and resiliency into the grid."[113]

The Hawaii Public Utility Commission recently approved a Grid Modernization Strategy developed by Hawaii's largest electric utility, Hawaiian Electric Company, at the direction of the Commission.[114] That strategy is intended to "enhance the safety, security, reliability, and resiliency of the electric grid," especially due to the increase in significant weather events.[115] To meet these goals, the plan outlines several steps to facilitate DER integration, such as the deployment of smart meters, enhancement of monitoring technology using SCADA, and use of system inverters to provide greater resilience during voltage deviations.[116] In addition, in January 2018, the Hawaii State Legislature introduced a bill to establish a Homeland Security and Resiliency Council to "assess the resilience of the State's electric grid and other critical infrastructure to natural disasters and other emergencies and make recommendations."[117] In the first sentence of the text of the bill, the legislature references the urgent need for grid resilience in light of Hurricanes Irma and Maria, which struck Puerto Rico in 2017.[118] The goals of the legislation are to prevent the severity of damage to the electric grid from a natural disaster or emergency, enable faster recovery after an outage due to a natural disaster or emergency, and maintain critical loads at critical infrastructure during a natural disaster or emergency.[119] Versions of this legislation have passed both the Hawaii State House and State Senate. As of the time of writing, the two bills are being reconciled.

In 2017, Rhode Island initiated its Power Sector Transformation Initiative, tasking the Public Utilities Commission with reviewing several potential avenues to modernize the grid and designing a new regulatory framework for the state's electric system.[120] The Rhode Island Commission's Phase I report offers seven recommendations with significant resilience implications: microgrid control, fault location and isolation, automated feeder and reconfiguration, remote monitoring, adaptive protection, outage notification, and dynamic event notification.[121]

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[109] *See generally* N.Y. State Energy Planning Bd., 2015 New York State Energy Plan (2015), https://energyplan.ny.gov/Plans/2015.aspx.

[110] N.Y. Dept. of Pub. Serv., Staff Report and Recommendations in the Value of Distributed Energy Resources Proceeding, Docket No. 15-E-0751 36-38 (describing demand reduction value and locational system relief value), http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7b59B620E6-87C4-4C80-8BEC-E15BB6E0545E%7d/

[111] N.Y. State Energy Plan at 32-33.

[112] *Id.* at 27.

[113] *NY Prize*, nyserda.ny.gov, https://www.nyserda.ny.gov/All-Programs/Programs/NY-Prize (last visited June 14, 2018).

[114] Haw. Pub. Util. Comm'n, Instituting a Proceeding Related to the Hawaiian Electric Companies' Grid Modernization Strategy, Docket No. 2017-0226 (2018), https://www.hawaiianelectric.com/Documents/about_us/investing_in_the_future/dkt_2017_0226_2018_02_07_PUC_decision_and_order_35268.pdf

[115] Hawaiian Elec. Cos., Modernizing Hawai'i's Grid For Our Customers 2, 18 (2017), https://www.hawaiianelectric.com/Documents/about_us/investing_in_the_future/final_august_2017_grid_modernization_strategy.pdf.

[116] *Id.* at 80.

[117] SB2910, 29th Leg., Reg. Sess. (Haw. 2018).

[118] *Id.*

[119] *Id.*

[120] RI Public Utilities Commission, *Power Sector Transformation Initiative*, Nov. 8, 2017, 5:11 PM, http://www.ripuc.org/utilityinfo/electric/PST_home.html.

[121] Div. of Pub. Utils. & Carriers, Office of Energy Res. & Pub. Utils. Comm'n, R.I. Power Sector Transformation 65-66 (2017), http://www.ripuc.org/utilityinfo/electric/PST%20Report_Nov_8.pdf.

In March 2017, the Illinois Commerce Commission (ICC) launched NextGrid: an 18-month study to transform the state's grid to be more flexible.[122] NextGrid is designed to be a collaborative process among different working groups comprised of various stakeholders. One working group is dedicated to "Reliability, Resiliency, and Cyber Security" and is tasked with studying solutions to the impacts of feasible risks and attacks both in the present and future.[123]

In 2017, the New Orleans City Council adopted a series of amendments that required utilities to evaluate how the deployment of DERs could increase grid reliability. The objective of the rule change was to "support the resiliency and sustainability of the Utility's systems in New Orleans" and provide the residents of New Orleans with reliable electricity at the lowest cost.[124] To do so, the amendments also require the local utility, Entergy, to determine the appropriateness of implementing new technologies and incorporating renewable energy sources, storage options, and DER.[125]

Local Resilience Rules

Several states have established mandatory standards for enhancing distribution-system reliability. As discussed above, reliability and resilience are distinct concepts, and these reliability standards are generally not designed to address specific resilience concerns. For example, when state regulators establish allowable reliability metrics against which distribution system performance is measured, they often exclude outages caused by major events.[126]

Nonetheless, many states can take advantage of the legal structure and existing institutions tasked with ensuring distribution-level reliability to develop equivalent resilience standards. To the extent that a state identifies a particular resilience vulnerability that can be cost-effectively addressed across utilities, it can consider adoption of a local rule mandating certain performance criteria or operational practices.

Unlike at the federal level, however, there is no single entity tasked with developing distribution-level standards. Institutions that could be responsible for distribution system resilience standards range from Public Service Commissions to customer-owned and publicly owned utilities, and, where they exist, state reliability organizations. For example, the New York State Reliability Council implemented a requirement that natural gas-fired generators interconnected with the ConEd system in New York City must be capable of also burning fuel oil in the case of natural gas supply disruptions.[127] This standard was intended to help address concerns of prolonged outages caused by a disruption in the supply of natural gas.

The Federal Role in Improving Electric-System Resilience

While no part of the Federal Power Act specifically directs any federal agency to improve electric system resilience, existing authorities are, nonetheless, sufficient to address any threats to the bulk power system and to allow the federal

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[122] Ill. Commerce Comm'n, Re Illinois' Consideration of: the Utility of the Future: "NextGrid": Grid Modernization Study (2017), https://nextgrid.illinois.gov/resolution.pdf.

[123] Ill. Commerce Comm'n, *Working Groups*, https://nextgrid.illinois.gov/WorkingGroups.html, (last visited June 14, 2018).

[124] Council of the City of New Orleans, Resolution Amending the Elec. Util. Integrated Res. Plan Rules, R-17-410, at 4 (2017), http://www.all4energy.org/uploads/1/0/5/6/105637723/2017_08_10_ud-17-01_cno_r-17-429_amend_electric_utility_irp_rules.pdf.

[125] *Id.*

[126] NAS at 28.

[127] DOE Staff Report at 91.

government to play an expansive coordinating role. The Federal Power Act places the primary regulatory responsibility over the bulk power system with FERC. Thus, FERC, and the entities it regulates, will have the primary role in evaluating and adopting policies to enhance the resilience of the bulk power system over the long-term. Nonetheless, the Federal Power Act and some other statutory provisions reserve limited authority for other entities, including DOE and NERC.

This section highlights the legal authorities that federal agencies have to ensure the resilience of the bulk power system:

- FERC can use its authority over transmission rates to encourage cost-beneficial investments in the transmission system;
- FERC, in partnership with NERC, can establish reliability standards that have resilience co-benefits;
- Federal agencies can encourage, require, and facilitate better resilience-related coordination and planning by ISOs/RTOs, reliability coordinators, and other entities;
- FERC can work with ISOs/RTOs to evaluate and, if justified, approve wholesale electricity market changes to enhance generation system resilience by compensating generators for well-defined resilience attributes; and,
- DOE and FERC can exercise their authorities to order specific actions in the face of grid emergencies.

Using these authorities to implement every potential intervention that could improve resilience is not feasible; interventions carry costs and other important tradeoffs that must be considered. Thus, when possible, each of these authorities should be exercised only after the relevant agency has determined that the benefits of a proposed action will exceed the costs, using a methodology like that outlined above.

The authorities described in this section are sufficient for the federal government to evaluate and, if necessary, implement cost-beneficial bulk power system resilience improvements and to facilitate resilience-related coordination among federal agencies, regional entities, state regulators, and private utilities.

Is Immediate Federal Resilience Action Needed?

This report focuses on tools that can be used to evaluate potential resilience improvements and the legal authorities that can be used to implement those improvements, when they are needed. There is, of course, a threshold question: are immediate resilience improvements needed?

Many experts that have studied the resilience of the electric system, including the National Academy of Sciences,[128] the Department of Energy,[129] and the Electric Power Research Institute,[130] have identified potential areas for improvement and made recommendations for investments and policy design changes that could be worthwhile. Where they implicate federal authorities, these proposals would be a reasonable place for regulators to start in evaluating cost-beneficial areas for improvement.

However, notwithstanding the potential for cost-effective improvements, it is important to recognize that there is no record supporting concerns about an imminent resilience threat. In rejecting the Department of Energy's proposal to provide cost-of-service payments to certain coal and nuclear plants in the name of grid resilience, FERC recognized that neither the DOE proposal, nor comments supporting the proposal provided a record sufficient to justify a finding that there is a national resilience emergency rendering current electricity markets unjust and unreasonable, let alone one that required substantial out-of-market compensation.[131] This finding was consistent with NERC's 2018 State of Reliability Report, which it released with the headline "*Grid Shows Improved Resilience*, Decreased Protection Systems Misoperations and Advanced Risk Management."[132] FERC did, however, initiate a proceeding to collect more information from ISOs/RTOs to evaluate the state of grid resilience in these wholesale markets.[133] In response to this proceeding ISOs/RTOs submitted information on the state of resilience in wholesale markets, efforts underway to ensure grid resilience, and opportunities for future improvement. These filings make clear that while grid resilience is a critical issue worthy of continued attention, there is no reason to believe any mandatory, national or even regional action to address acute resilience concerns are needed at this time.[134]

FERC Can Establish Transmission-Compensation Rules that Enhance Resilience

FERC's jurisdiction over interstate transmission gives it a role to play in ensuring the resilience of the transmission system. Most outages associated with high-impact, low-probability events occur due to disruptions of the distribution and transmission systems.[135] Investments in the transmission system, if they are cost-beneficial, have the potential to

[128] *See generally* NAS at 134-140.

[129] *See generally* DOE QER at 7-21 to 7-24.

[130] *See generally*, EPRI at 14-44.

[131] FERC Resilience Order, 162 FERC ¶ 61,012 at P 15.

[132] NERC, Media Release: Grid Shows Improved Resilience, Decreased Protection Systems Misoperations and Advanced Risk Management (June 21, 2018), https://www.nerc.com/news/Headlines%20DL/SOR%202018%20Media%20Release.pdf.

[133] FERC Resilience Order, 162 FERC ¶ 61,012at PP 18-19.

[134] *See, e.g.,* Comments of California Independent System Operator Corp., ISO New England Inc., Midcontinent Independent System Operator, Inc., New York Independent System Operator, Inc., and Southwest Power Pool, Inc., *Grid Resilience in Regional Transmission Organizations and Independent System Operators*, Docket No. AD18-7-000 (filed May 8, 2018). One notable exception may be Puerto Rico, where post-Hurricane Maria rebuilding is underway. The Department of Energy recently compiled recommendations for improving the resilience of the island's electric system. U.S. Dep't of Energy, Energy Resilience Solutions for the Puerto Rico Grid (2018), https://www.energy.gov/sites/prod/files/2018/06/f53/DOE%20Report_Energy%20Resilience%20Solutions%20for%20the%20PR%20Grid%20Final%20June%202018.pdf. The analytical tools and authorities outlined in this report could be useful as Puerto Rico works to rebuild its electric system.

[135] *See* Trevor Houser, John Larsen & Peter Marsters, The Rhodium Group, *The Real Electricity Reliability Crisis* (Oct. 3, 2017), https://rhg.com/research/the-real-electricity-reliability-crisis-doe-nopr/ [hereinafter Rhodium Group Outage Analysis] (showing that only 0.00858% and 0.000007% of major electricity disturbances were caused by generation inadequacy and fuel supply emergencies during 2012-2016).

enhance each phase of grid resilience, including its ability to absorb and resist shocks, manage disruptions as they occur, quickly recover, and respond and adapt to future shocks.[136]

FERC has authority over the rates and tariffs of transmission providers and can use this authority to ensure that transmission developers will be compensated for providing services that enhance the resilience of the transmission system. For example, FERC has already issued an order that requires utilities to have spare transformers, which provide significant system-restoration benefits while reducing the cost needed for all utilities to maintain spare transformers.[137] The National Academy of Sciences has identified mechanisms by which FERC can use its existing transmission authority to cost-effectively expand the availability of spare transformers through a national transformer reserve.[138]

In addition, FERC can use its transmission ratemaking authority to encourage, either directly or through ISOs/RTOs, cost-beneficial investments that will enhance transmission-system resilience, including hardening of vulnerable assets against extreme weather such as flooding or earthquakes; burying of key transmission lines; shielding of critical transmission equipment against electromagnetic attack; and more regular and innovative vegetation management.[139]

FERC Can Approve Reliability Standards that Have Resilience Co-benefits

FERC can use its existing authority to implement mandatory operational, planning, and performance requirements that improve grid resilience when doing so is a co-benefit of actions that enhance reliability. FERC's existing reliability standards have mandated planning, coordination, and investments that have generally supported a resilient electric system.

Under Section 215 of the Federal Power Act, FERC and NERC are responsible for issuing reliability standards—enforceable requirements intended to ensure the operational reliability of the bulk power system. While reliability and resilience are different concepts,[140] protecting against reliability risks can often have significant resilience co-benefits.

Many of the reliability standards that have been proposed by NERC and approved by FERC establish planning, analytical, or operational requirements that also improve the resilience of the bulk power system at each of the phases, including by (1) avoiding and resisting damage to the electric grid during a high-impact, low-probability event, (2) enhancing coordination during the event to manage damage that does occur, (3) speeding up the recovery of the system after such an event, and (4) analyzing past events to identify areas for future recovery and adaptation. For example, the following reliability standards have significant resilience co-benefits:

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[136] Hardening key weak points on the transmission system can increase the system's ability to absorb and resist shocks. New software and hardware systems are in development that, if deployed, may be able to help grid operators manage disruptions as they occur by rerouting electricity around overloaded elements. *See* Pablo A. Ruiz et. al, Transmission Topology Optimization, *Increasing Market and Planning Efficiency and Enhancing Resilience through Improved Software*, Docket No. AD10-12-0009 (June 26, 2018) Ensuring availability of non-wires transmission assets such as transformers can reduce the time needed to replace damaged equipment. And new tools are being developed to help transmission planners target investments by identifying "weak" points on the system that can cause cascading failures, Yang Yang, Takashi Nishikawa & Adilson E. Motter, *Small vulnerable sets determine large network cascades in power grids*, 358 Science 6365 (2017), http://science.sciencemag.org/content/358/6365/eaan3184.

[137] *Order on Application for Blanket Authorization for Transfers of Jurisdictional Facilities and Petition for Declaratory Order*, 116 FERC ¶ 61,280 (2006).

[138] NAS at 117-19.

[139] EPRI at 25-34.

[140] Policy Integrity Comments on DOE NOPR at 11-12.

- CIP-014-2 (Physical Security), requiring identification of critical transmission substations and performance of physical security risk assessments;
- CIP-009-6 (Cyber Security – Recovery Plans for BES Cyber Systems), requiring development and implementation of recovery plans in the event of cybersecurity threats;
- TPL-001-4 (Transmission System Planning Performance Requirements), requiring assessment of the impacts of "extreme events" on the bulk power system and planning for "N-2" extreme events;
- FAC-008-3 (Facility Ratings), requiring ratings for how well facilities operate in emergency situations; and,
- EOP-010-1 (Geomagnetic Disturbance Operations) and TPL-007-1 (Transmission System Planned Performance for Geomagnetic Disturbance Events), requiring planning and emergency operation procedures in the event of a geomagnetic disturbance.

To the extent that analyses from the Commission, ISOs/RTOs, or NERC identify gaps that are not appropriately filled by mandatory standards, improvements to existing reliability standards or promulgation of new standards may enhance both reliability and resilience. For example, in 2016 and 2017, FERC and NERC conducted an extensive study of transmission-operator and reliability-coordinator system restoration plans and issued two reports outlining a host of improvements that could further enhance bulk power system recovery from sustained widespread outages.[141] Recently, FERC adopted an order directing NERC to develop a reliability standard that requires mandatory reporting of cybersecurity incidents, which is intended to improve resilience by giving regulators, grid operators, and utilities the information they need to learn and adapt.[142]

One benefit of improving resilience using FERC's reliability standard authority is that it covers a wider range of entities compared to FERC's jurisdiction over wholesale energy and transmission. For example, reliability standards apply to federal power agencies, municipal utilities, rural electric cooperatives, and Texas, which are all largely exempt from FERC's ratemaking jurisdiction.[143] Under its reliability standard authority, FERC can direct NERC to evaluate opportunities to expand existing reliability standards or propose new standards that improve operational reliability, with the co-benefit of improved system resilience. For example, FERC could evaluate the benefits and costs of adopting the currently voluntary NERC reliability guideline aimed at improving generation system resilience, the Reliability Guideline for Generating Unit Winter Weather Readiness, as a mandatory reliability standard.[144] This guideline outlines best practices for the development and implementation of plant-specific winter readiness plans. These plans provide plant owners the tools needed to anticipate, prevent, respond to, and recover from equipment outages caused by extreme cold. On the other hand, investigation may show that existing practices and standards are meeting resilience needs.[145]

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[141] FERC & NERC, Regional Entity Joint Review of Restoration and Recovery Plans 1 (2016), https://www.ferc.gov/legal/staff-reports/2016/01-29-16-FERC-NERC-Report.pdf [FERC & NERC Joint Review]; FERC, Further Joint Study Report: Planning Restoration Absent SCADA or EMS (PRASE) (2017), https://www.ferc.gov/legal/staff-reports/2017/06-09-17-FERC-NERC-Report.pdf. [FERC & NERC Further Joint Review]

[142] *Cyber Security Incident Reporting Reliability Standards*, Order No. 848, 164 FERC ¶ 61,033 (2018).

[143] FERC Reliability Primer at 6.

[144] NERC, "Reliability Guideline: Generating Unit Winter Weather Readiness—Current Industry Practices," August 2013, http://www.nerc.com/pa/rrm/ea/ColdWeatherTrainingMaterials/Relibility_Guideline_Generating_Unit_Winter_Weather_Readiness.pdf.

[145] Staffs of FERC and NERC and its Regional Entities, Recommended Study: Blackstart Resources Availability (2018), https://www.ferc.gov/legal/staff-reports/2018/bsr-report.pdf.

Federal Agencies Can Mandate or Facilitate Planning and Coordination Among Regional Entities

Given the fractured nature of regulatory and planning responsibilities across the federal system, a key opportunity for improving system resilience is increased coordination and planning. In filings as part of FERC's resilience docket, a number of ISOs/RTOs rightly identified planning and coordination as providing important resilience benefits and identified potential improvements.[146] The federal government is well positioned to lead this effort. Enhancing coordination and planning can improve all phases of grid resilience, including by identifying opportunities to avoid or resist damage, enhancing communication so that all responsible actors can manage disruption during a shock, coordinating deployment of resources to quickly responding to a shock after it occurs, and identifying lessons learned and investments needed to recover from and adapt to future shocks.

Transmission Planning and Coordination. FERC has designated regional organizations to be responsible for mandatory transmission planning. While transmission planning has long been a responsibility of ISOs/RTOs, FERC expanded transmission planning to regions without ISOs/RTOs in its Orders No. 890 and 1000.[147] Regional transmission planners are required to work with member transmission and generation owners to complete an Annual Transmission Planning Assessment.[148] This assessment requires planners to evaluate the transmission system against a wide range of contingencies, many of which have resilience implications. These assessments can be used to direct transmission investments using new tools that facilitate targeting high-value investments, such as a model developed for identifying "weak" points on the transmission system that can cause cascading failures.[149] Coordination of transmission planning can also help facilitate transmission-system resilience. Planning must already be coordinated with "appropriate state authorities."[150] FERC can also encourage or require regional transmission planners to coordinate planning across regions.

Reliability Planning and Coordination. NERC has delegated certain authority over bulk power system reliability to regional reliability coordinators.[151] Reliability coordinators already perform important planning and coordination functions that can be leveraged to analyze and recommend resilience improvements. For example, transmission operators are required to have reliability coordinator-approved plans for system restoration following a widespread outage or

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[146] Comments of Southwest Power Pool, Inc. on Grid Resilience Issues, *Grid Resilience in Regional Transmission Organizations and Independent System Operators*, Docket No. AD18-7-000 at 8-9 (filed March 9, 2018) [hereafter "SPP Resilience Response"] (discussing SPP's role in general system and contingency planning, including scenario planning that covers high-impact low-probability risks); PJM Resilience Response at 49-50 (identifying a number of ways to think about resilience in the transmission planning process); *id.* at 63-64 (operations plans including load shedding plans help ensure that outages are minimized when they do occur before recovery can begin); Responses of the Midcontinent Independent System Operator, Inc., *Grid Resilience in Regional Transmission Organizations and Independent System Operators*, Docket No. AD18-7-000 at 3-4 (filed March 9, 2018) at 3-4 (discussing importance of transmission planning to identify needed expansions in light of grid resilience).

[147] *Preventing Undue Discrimination and Preference in Transmission Service*, Order No. 890, FERC Stats. & Regs. ¶ 31,241 at P 435 (2007); *Transmission Planning and Cost Allocation by Transmission Owning and Operating Public Utilities*, Order No. 1000, FERC Stats. & Regs. ¶ 31,323 (2011).

[148] NERC Reliability Standard TPL-001-04 – Transmission System Planning Performance Requirement, Eff. Jan. 1, 2015; *See* SPP Resilience Response (describing use of Annual Planning Assessment to address resilience concerns).

[149] Yang Yang et al., *Small Vulnerable Sets Determine Large Network Cascades in Power Grids,* 358 Science 6365 (2017), http://science.sciencemag.org/content/358/6365/eaan3184.

[150] 18 CFR § 35.34(k)(7).

[151] FERC Reliability Primer at 27. Generally ISOs/RTOs serve as the reliability coordinator for their region. *See* http://www.nerc.com/pa/rrm/TLR/Pages/Reliability-Coordinators.aspx. Note that CAISO does not currently act as its own reliability coordinator.

blackout.[152] Similarly, reliability coordinators are required to have area restoration plans.[153] Where improvements to other resilience phases (limiting initial damage, continued operation during an event) can be justified as improving reliability, FERC and NERC can use their reliability authority to require similar coordination and planning applicable to those phases. FERC and NERC can then conduct a comprehensive assessment of relevant plans to identify weaknesses and make cost-beneficial recommendations for improvement, as they recently did in a series of reports assessing existing restoration and recovery plans.[154]

Other Planning and Coordination. The Department of Energy has been designated as the Sector Specific Agency for the energy sector pursuant to Presidential Policy Directive 21.[155] Under this directive, DOE plays an important coordinating role. It is responsible for day-to-day prioritization and coordination of energy-sector critical infrastructure protection activities; carrying out incident management responsibilities; providing support and facilitating technical assistance and consultations with the energy industry; and coordinating with the Department of Homeland Security, other agencies, and the energy sector to implement the directive.[156] In addition, the National Academy of Sciences has outlined several recommendations for DOE, FERC, NERC, and regional entities such as ISOs/RTOs to improve general system planning and coordination with the goal of enhancing resilience. Potential actions include expanding emergency preparedness exercises,[157] information sharing to disseminate resilience best practices,[158] and coordinating natural gas and electric sectors to reduce fuel disruption risks.[159]

FERC Can Approve Market Rules that Create Incentives for Generation-System Resilience

FERC can use its authority over wholesale electricity market rules to evaluate and, if they are just and reasonable, approve proposals from grid operators that align generator incentives with resilience-enhancing entry, exit, and operational behavior. Market-based solutions may be an appropriate tool where services that enhance generation system resilience can be identified and defined with specificity, and where analysis shows that procurement of these services will enhance electric *system* resilience to an extent sufficient to justify the costs. As PJM Interconnection, the grid operator for states in the Midwest and Mid-Atlantic, stated in a filing to FERC regarding resilience improvements in wholesale markets, such solutions, when available, are preferable to alternatives where customers are responsible for cost-based payment to certain identified resources: "assuming that resilience requirements can be clearly articulated, meeting them through market-based solutions that allow resources to compete to meet those requirements is the preferred way to ensure that these objectives are met at the lowest cost to consumers."[160] However, there are limited circumstances where new market rule changes for generators will provide substantial electric system resilience enhancements. Therefore, FERC should

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[152] NERC Reliability Standard EOP-005-2 - System Restoration from Blackstart Resources, Eff. May 23, 2011, http://www.nerc.com/pa/Stand/Reliability%20Standards/EOP-005-2.pdf.

[153] NERC Reliability Standard EOP-006-2 - System Restoration Coordination, Eff. May 23, 2011, http://www.nerc.com/pa/Stand/Reliability%20Standards/EOP-006-2.pdf.

[154] FERC Joint Review; FERC Further Joint Review.

[155] PPD-21.

[156] *Id.* Notably, however, this directive does not provide with DOE with any additionally regulatory authority.

[157] NAS at 134.

[158] *Id.* at 135.

[159] *Id.* at 135.

[160] Comments and Responses of PJM Interconnection L.L.C. at 68, *Grid Resilience in Regional Transmission Organizations and Independent System Operators,* Docket No. AD18-7-000 (filed March 9, 2018).

ensure that proposals justified on the basis of resilience are supported by substantial evidence that they will result in measurable enhancements to electric system resilience.[161]

FERC has authority to approve and require such market-based solutions. FERC has jurisdiction over rules and practices affecting wholesale electricity rates,[162] and is responsible for ensuring that those rates are "just and reasonable."[163] Courts have interpreted the Federal Power Act to provide FERC the authority to approve and police a wide variety of ISO/RTO market rules. These rules can ensure just and reasonable wholesale rates by creating incentives for market participants to provide efficient levels of desired generator attributes.[164] And because generation system outages, in the limited circumstances that they occur, impose substantial costs on market participants, market changes aimed at reducing the likelihood and consequence of outages caused by high-impact, low-probability events fits squarely within FERC's authority.

That FERC has authority to approve market changes to enhance resilience does not necessarily mean that additional rules are required. A number of market-based constructs and enhancements have already been implemented to facilitate procurement of generator or electric-system services that enhance the resilience of the generation system.

- **Ancillary Services Markets.** NERC has catalogued the "essential reliability services" needed to ensure operational reliability.[165] Some of these services are provided through market mechanisms—called "ancillary services markets." For example, in some ISOs/RTOs, existing market rules provide for compensation of ancillary services that affect reliability and resilience, such as contingency reserves[166] and black-start.[167]
- **Capacity Markets.** A number of ISOs/RTOs manage capacity markets, market-based constructs intended to meet resource adequacy requirements. While resource adequacy is primarily a reliability attribute, reserve margins can help the system avoid and manage system disruption by lessening the risk that disruption of certain generation assets by high-impact, low-probability events will result in long lasting, widespread outages.

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[161] Because resilience currently has high salience, there is some risk that advocates attempt to justify preexisting policy proposals using grid resilience even if they are not directly aimed at improving resilience. For example. in its response to FERC's information request on grid resilience, PJM advocated for certain energy market pricing reforms. *Id.* at 78-80. But these price formation reforms, whatever their merits, "do not include even an attempted nexus to bulk power system resilience." FERC Resilience Order, 162 FERC ¶ 61,012 at P 16 & n. 25.

[162] FPA § 205(a), 16 U.S.C. § 824d(a).

[163] *Id.*

[164] *Advanced Energy Mgmt. All. v. FERC*, 860 F. 3d 656 (D.C. Cir. 2017); *Connecticut Dept. of Pub. Util. v. FERC*, 569 F.3d 477 (D.C. Cir. 2009). *FERC v. Elec. Power Supply Assoc'n*, 136 S. Ct. 760 (2016).

[165] NERC, Essential Reliability Standards Working Group, Essential Reliability Services Working Group Sufficiency Guideline Report (2016), http://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/ERSWG_Sufficiency_Guideline_Report.pdf.

[166] EPRI, Wholesale Electricity Market Design Initiatives in the United States: Survey and Research Needs at 3-46 to 3-49 (2016), https://www.epri.com/#/pages/product/000000003002009273/ [hereafter "EPRI Market Design"]. Contingency reserves are reserves that may be needed in the case of unplanned outages of significant generation or transmission facilities.

[167] *See* Nitish Saraf et al., The Annual Black Start Service Selection Analysis of ERCOT Grid, 24 IEEE Transactions on Power Systems 1867 (2009). Black-start is the ability to supply initial power to generators so that they can be brought back online and is an important resilience attribute that is critical for system restoration. EPRI at 30. Note, however, that not all ISOs/RTOs procure black-start service through a competitive mechanism. For example, CAISO compensates black-start resources on a cost-of-service basis. *California Independent System Operator*, 161 FERC ¶ 61,116 (2017). Cost-based provision of resilience attributes may be appropriate when market-based solutions are not feasible; however, consistent with FERC's approach to reliability, the use of such mechanisms should be limited and, when possible, time-limited. *PJM Interconnection, LLC*, 110 FERC ¶ 61,053 at P 114 (2005) ("a transparent market process is preferable to cost-of-service rates that can cause high uplift payments . . . . [O]ur policy on reliability compensation will be to rely on markets and proper market design, and to use non-market solutions only as a last resort"); *New York Indep. Sys. Operator, Inc.*, 150 FERC ¶ 61116 at P 16(2015) ("RMR filings should be made only to temporarily address the need to retain certain generation *until more permanent solutions are in place*") (emphasis added).

- **Generator Performance.** Partially in response to FERC action taken in the aftermath of the Polar Vortex,[168] PJM and ISO New England have implemented market reforms to charge generators that are unable to meet their capacity obligations a penalty and make additional payments to those that can.[169] These initiatives can provide efficient incentives for generators to change their behavior in ways that avoid or reduce the consequence of expected outages caused by high-impact, low-probability events. For example, generators would be incentivized to invest in weatherization to protect against extreme weather events or to sign firm fuel contracts to protect against natural gas supply disruptions.

- **Removal of Market Participation Barriers.** FERC has adopted rules that require grid operators to provide for the participation of new technologies—such as demand response and energy storage—in existing energy, capacity, and ancillary services markets.[170] These market enhancements broaden the scope of resources that are able to provide the resilience-enhancing services beyond traditional generation resources.

It is conceivable that there are additional, measurable services that resources with particular attributes can provide that can be shown to increase resilience, or resource types that are excluded from providing existing services, To the extent that such services and resources are identified, changes to market rules could be appropriate if supported by analysis that the expected benefits of such changes justify the costs.

However, any use of these options is limited in important ways. First, electricity markets primarily affect the entry, exit, and operation incentives for generation resources. Only a very small proportion of electric-system outages are caused by failures of the *generation* system.[171] And additional generation is primarily useful for *resisting* and *avoiding* outages caused by insufficient generation, with limited utility for managing, recovering from, or adapting to high-impact, low-probability shocks. Therefore, even policies that enhance the resilience of the generation system provide limited opportunities to enhance *electric-system* resilience.

Second, market rules are best suited for facilitating the efficient procurement of specific generation resource attributes. As such, changing market rules to incentivize resilience is only appropriate where attributes have been shown to have a direct connection to resilience improvements—that is, that the attributes allow generators to provide services or products that will help the electric system withstand, respond to, or recover from a high-impact, low-probability shock. And to the extent that substantial evidence can demonstrate the connection between particular generator attributes, and resilience-enhancing capabilities, those attributes have to be defined with sufficient specificity to allow price formation. To-date, resilience-specific attributes (as distinguished from those that also facilitate provision of reliability services) have not been identified and defined. Market regulators, therefore, must be careful to ensure that the attributes identified actually support resilience. There is no evidence that many of the generator attributes highlighted as part of recent political discussions actually provide resilience benefits.

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168 *Order on Technical Conferences*, 149 FERC ¶ 61,145 (Nov. 20, 2014).

169 DOE Staff Report at 91-92. PJM instituted its Capacity Performance Proposal, which was approved by the Commission. *PJM Interconnection, L.L.C.*, 151 FERC ¶ 61,208 ("Capacity Performance Order"), *order on reh'g and compliance,* 155 FERC ¶ 61,157 (2015). The New York ISO identified, adopted, and implemented its Comprehensive Shortage Pricing enhancements. *New York Independent System Operator Inc.*, 154 FERC ¶ 61,152 (March 1, 2016). ISO New England identified its Pay For Performance capacity market design, to be implemented in 2018. Fuel Assurance Status Report of ISO New England Inc. at 5-9, Docket No. AD14-8-000 (Feb. 18, 2015).

170 *Electric Storage Participation in Markets Operated by Regional Transmission Organizations and Independent System Operators*, Order No. 841, 162 FERC ¶ 61,127 (2018) (providing for participation of energy storage); *Wholesale Competition in Regions with Organized Electric Markets*, Order No. 719, FERC Stats. & Regs. ¶ 31,281 (2008) (providing for participation of demand response in ancillary services and capacity markets).

171 *See* Rhodium Group Outage Analysis; Silverstein at 18-20.

Third, market rules designed to compensate for individual attributes may improve resilience against certain threats but exacerbate resilience against other threats. For example, a resilience proposal aimed at compensating "fuel security"[172] might, in practice, reward large central-station powerplants that have on-site access to fuel. Yet such resources often pose countervailing resilience concerns because unexpected outages of these resources place more strain on the electric system and they are often less resistant to extreme weather conditions. To the extent additional fuel-security payments increase reliance on such generators or slow the replacement of these resources with newer technologies, such payments may ultimately harm resilience on net. Use of narrow definitions of resilience attributes such as "fuel security" also risks under-compensating and, therefore, under-providing, the resilience improvements of generation resources *without* fuel requirements.

Therefore, it is not sufficient for policymakers merely to identify individual attributes that are nominally related to resilience as sufficient justification for market changes. Rather, FERC and ISOs/RTOs should first conduct holistic analyses that evaluate how any contemplated market changes would likely affect *system* resilience against multiple threats, in comparison to the impact of other potential changes.

Moreover, while cost-benefit analysis is an important tool to evaluate any resilience intervention, it is particularly important for market-based solutions. Market changes, if not done well, can impose substantial costs on consumers by distorting efficient entry, exit, and operational decisions. The potential that market changes will result in very large costs and low or ill-defined benefits suggests that a thorough cost benefit analysis should be required in order for FERC to make any determination that market changes intended to enhance resilience are "just and reasonable."

DOE Can Issue Emergency Orders to Address Rare and Unforeseen Events If They Occur

Notwithstanding all responsible planning, coordination, and investment, high-impact, low-probability events can cause significant outages and damage. Grid operators can implement the contingency plans they have developed to facilitate the speedy recovery from such outages. However, in the unexpected and rare case that existing plans and tariffs are insufficient to address recovery needs after a high-impact, low-probability event, federal regulators—specifically DOE and FERC—have been delegated emergency authorities by Congress that can be used under limited circumstances. While these authorities are broad, they come with important limits.

First, under long-standing authority codified in Section 202(c) of the Federal Power Act, DOE can issue emergency orders requiring the interconnection of electric facilities and the generation, transmission, and delivery of electricity.[173] These orders can be issued on DOE's own or after an application by the owner of generation, transmission, or distribution facilities affected by an emergency.[174] DOE can use this authority to enable grid operators to deviate from operations under existing market rules to facilitate recovery and restoration in the event of an emergency. Section 202(c) establishes the limits under which DOE may act. DOE's emergency authority is intended to address relatively short-term and unexpected events, not long-term changes to the electric system. Long-term changes should be handled in the

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[172] *See, e.g.*, PJM, Valuing Fuel Security (2018), http://www.pjm.com/-/media/library/reports-notices/special-reports/2018/20180430-valuing-fuel-security.ashx [hereinafter "PJM Fuel Security Proposal"].

[173] 16 U.S.C. § 824a(c).

[174] 10 C.F.R. § 205.370.

normal course.[175] Moreover, DOE's authority is not intended to address economic concerns of specific generators. The Federal Power Act and DOE's regulations encourage power-sector entities to use existing rates or negotiate mutually acceptable rates with other power-sector entities.[176] But Congress provided FERC, not DOE, the ultimate authority to determine "just and reasonable" compensation for compliance with emergency orders, "in accordance with its standard procedures."[177]

Second, in 2015, Congress delegated to DOE additional authority under Section 215A of the Federal Power Act to impose mandatory security measures to restore critical infrastructure in the case of grid-security emergencies.[178] Grid-security emergencies are limited to cyberattacks, electromagnetic pulse attacks, geomagnetic storms, and direct physical attacks that *have occurred* or pose an *imminent* danger.[179] Under this provision, after the President of the United States has declared a grid-security emergency, DOE can issue emergency orders to utilities, NERC, and regional entities to implement emergency security measures. Like with Section 202(c), this authority is not intended to address economic concerns of generators and authority to set "just and reasonable" compensation is delegated to FERC.[180]

These authorities provide needed flexibility so that relevant generators, utilities, grid operators, and regulators can respond to the particular circumstances caused by a disruptive event. But the emergency powers are appropriately circumscribed by Congress and the courts. Congress authorized DOE and FERC to use these authorities only under specific conditions during and immediately after an incident. Section 202(c) provides DOE authority to issue emergency orders only "*during* the continuance of any war" and "whenever the Commission determines that an emergency *exists*."[181] DOE may only order the "*temporary* connections of facilities" and the "generation, delivery, interchange, or transmission that will *meet* the emergency."[182] And DOE's authority to allow facilities to avoid environmental requirements is limited to a (renewable) 90-day period.[183] Section 215A sets strict time limits on DOE's authority. DOE may only issue emergency orders for periods of 15 days, and may only renew orders if the Secretary of Energy certifies that the emergency continues to exist or the measures continue to be required.[184] That is, these emergency authorities are aimed at the *manage* and *quickly respond* phases of grid resilience, rather than the *resist/avoid* and *recover/adapt* phases.

In addition, any DOE or FERC action is subject to judicial review.[185] This allows courts to exercise oversight in order to ensure that any emergency order issued by DOE has been justified through sufficient record evidence and limits DOE's ability to implement far-reaching emergency orders that are inconsistent with Congress's intent that they be used in limited circumstances.

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175 *See* FPA § 202(c), 16 U.S.C. § 824a(c) ("defining "emergency" as ""a *sudden* increase in the demand for electric energy, or a shortage of electric energy or of facilities for the generation or transmission of electric energy"); 10 C.F.R. § 205.371 (defining emergency using terms such as "sudden" "unexpected" or "unforeseen"); 10 C.F.R. § 205.375 (outlining factors to be considered when evaluating an energy supply shortage); *see also Richmond Power & Light v FERC*, 574 F.2d 610, 615 (D.C. Cir. 1978) ("That section speaks of "temporary" emergencies, epitomized by wartime disturbances, and is aimed at situations in which demand for electricity exceeds supply and not at those in which supply is adequate but a means of fueling its production is in disfavor").

176 FPA § 202(c)(1), 16 U.S.C. § 824a(c)(1) ("If the parties affected by such order fail to agree upon the terms of any arrangement between them in carrying out such order . . . . "); 10 C.F.R. § 205.376.

177 10 C.F.R. § 205.376; FPA § 202(c), 16 U.S.C. § 824a(c)(1).

178 *See* FPA § 215A, 16 U.S.C. § 824o-1.

179 FPA § 215A(a)(7), 16 U.S.C. § 824o-1(a)(7).

180 FPA § 215A(a)(6), 16 U.S.C. § 824o-1(a)(6).

181 FPA § 202(c)(1), 16 U.S.c. § 824a(c)(1) (emphasis added).

182 *Id.* (emphasis added).

183 FPA § 202(c)(4)(A), 16 U.S.c. § 824a(c)(4)(A).

184 FPA § 215A(a)(5), 16 U.S.C. § 824o-1(a)(5).

185 FPA § 313(b), 16 U.S.C. § 825l(b).

Key Takeaways for Proposals to Subsidize Coal and Nuclear Plants Based on Grid Resilience

The Trump Administration has used the concept of grid resilience to argue for policies to provide out-of-market financial support to existing coal and nuclear generators. First, in September 2017, DOE issued a Notice of Proposed Rulemaking ("DOE NOPR") requesting that FERC approve changes to ISO/RTO markets in the name of grid resilience.[186] The DOE NOPR, if adopted, would have guaranteed cost-based compensation to coal and nuclear plants that maintained substantial on-site fuel supplies, thereby shielding those units from competitive market forces. DOE justified this proposal on the grounds that retirement of these units would risk undermining electric system resilience and therefore result in unjust or unreasonable wholesale rates. FERC ultimately rejected the proposed rule, determining that DOE had not provided a sufficient record to support its proposal.[187]

More recently, President Trump issued a directive to DOE to limit the closure of coal and nuclear plants.[188] The Administration is contemplating action under Section 202(c) of the Federal Power Act and under provisions of the Defense Production Act of 1950. Under these authorities, the federal government would mandate that distribution utilities and grid operators purchase electricity from certain coal and nuclear generators. The Trump Administration has asserted that these emergency actions are needed to maintain national security; however, the underlying national security argument for coal and nuclear bailouts generally overlaps with the resilience concerns that motivated the DOE NOPR. Specifically, a leaked memo explains the Administration's concern that, without "fuel-secure" generation such as coal and nuclear, a high-impact, low-probability shock risks disrupting the electric system and leaving critical defense facilities without power. While the contours of a proposal have been reported in the press, no official action has been taken and DOE has not provided a timeline for when it will act in accordance with President Trump's directive.

The insights provided in this report can be useful in evaluating these policy proposals.

Urgent and Unprecedented Action Is Not Necessary or Appropriate Because There Is No Grid Resilience Emergency

With proper analysis and deliberate policymaking, regulators can identify investments or policies that would cost-effectively improve grid resilience. However, as is discussed in this report, the expert judgment of the entities responsible for the continued operation of the bulk power system—FERC, NERC, and the ISOs/RTOs—makes clear that there is not presently a national grid resilience emergency. To the extent that further analyses determine cost-beneficial resilience improvements, the existing authorities described above are available to craft the appropriate transmission investment, minimum standard, planning/coordination, or market-based compensation solution. The use of untested, ill-fitting "emergency" authorities—such as authority under the Defense Production Act designed to ensure that the federal

[186] DOE NOPR at 46,945.

[187] FERC Resilience Order, 162 FERC ¶ 61,012 at P 15.

[188] Brad Plumer, *Trump Orders a Lifeline for Struggling Coal and Nuclear Plants*, N.Y. Times (June 1, 2018), https://www.nytimes.com/2018/06/01/climate/trump-coal-nuclear-power.html.

government has priority in the purchase of needed materials and products—is, therefore, not necessary or appropriate to make national security-related grid resilience improvements.[189]

Policy Focused Narrowly on Certain Threats Obscures Resilience Consequences of Other Threats

The Trump Administration has asserted that it is responding to fuel supply and other disruptions caused by cyber and physical attack.[190] As explained above, adopting policy based on a limited threat assessment risks exposing the electric system to other threats. Even if coal and nuclear units were less exposed to *pipeline* cyberattack , they may be more or equally exposed to a direct cyberattack or an attack on transmission infrastructure.[191] Recent forced outage rates during extreme weather suggest that deepening dependence on older resources may also reduce resilience to those threats.[192] A holistic assessment of reasonable threats and analysis of the type describe in this report would be necessarily to determine whether the contemplated policy will enhance or detract from generation system resilience.

Proposals to Support "Fuel Secure" Generation Demonstrate Why Attribute-Based Resilience Metrics can be Misleading and Unhelpful

Both proposals would support resources because they possess "fuel security" attributes (defined in the DOE NOPR to mean on-site fuel storage, and in recent proposals to mean generation that is not dependent on natural gas pipelines). As explained above, attribute-based resilience metrics are less useful in evaluating resilience improvements than performance-based metrics. Thus, special care must be taken to ensure that if policy is designed to compensate for certain generator attributes, those attributes, in fact, enhance system resilience. Yet, there are no well-established studies that, relying on realistic assumptions, show that increasing the availability of generators with "fuel security" attributes will enhance the resilience of the electric system. Incentivizing plants with on-site fuel storage may reduce some risks of generation outages due to fuel supply disruption, but may increase other fuel disruption risks, including risk to the fuel stored on-site.[193] And by prejudging the importance of a single, narrow attribute, policymakers may miss alternatives such as hardening fuel transportation infrastructure or installing fuel-free resources that more cost-effectively or comprehensively enhance generation system resilience.

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[189] *See* 50 U.S.C. § 4511(a)(1) (permitting use of priority contracting and allocation authority only for actions "necessary or appropriate to promote the national defense"); *see also* Joint Trade Association Letter to Secretary Rick Perry Regarding Emergency Authorities at 6-10 (May 7, 2018), https://info.aee.net/hubfs/Trade_Letter_Legal%20Analysis_DOE_5-7-18.pdf.

[190] *See* Jennifer A Dlouhy, *Trump Prepares Lifeline for Money-Losing Coal Plants*, Bloomberg (June 1, 2018), https://www.bloomberg.com/news/articles/2018-06-01/trump-said-to-grant-lifeline-to-money-losing-coal-power-plants-jhv94ghl (citing a leaked DOE memo that describes cyber and physical threats to the electric and gas systems).

[191] *See* Rebecca Smith, *Russian Hackers Reach U.S. Utility Control Rooms, Homeland Security Officials Say*, Wall Street Journal (July 23, 2018), https://www.wsj.com/articles/russian-hackers-reach-u-s-utility-control-rooms-homeland-security-officials-say-1532388110 (describing compromised electric utility systems that could result in outages of transmission and generation systems).

[192] *See* Ariel Horowitz et al, Synapse Energy Economics, Comments on the United States Department of Energy's Proposed Grid Resiliency Pricing Rule at E-22 to E-25 (2017), http://www.synapse-energy.com/sites/default/files/Grid-Resiliency-Whitepaper-As-Filed-17-085.pdf.

[193] Mark Watson, *Harvey's Rain Caused Coal-to-Gas Switching: NRG Energy*, S&P Global Platts (Sept. 27, 2017), https://www.platts.com/latest-news/electric-power/houston/harveys-rain-caused-coal-to-gas-switching-nrg-21081527.

Additional Generator Attributes that Are Bad Resilience Metrics

In order to justify support for nuclear and coal plants, the Trump Administration has primarily pointed to narrow definitions of "fuel security" as the relevant resilience attribute. However, DOE has pointed to other generator attributes that are not good metrics for resilience as support for its proposals. These include:

The number of plants operating as baseload resources.[194] The term "baseload" refers to the minimum level of demand on an electrical grid over a span of time. "Baseload resources" is a technology-neutral term and refers to generation resources that would be most often called upon to meet baseload demand. Some generators—often coal and nuclear—have historically operated to meet baseload demand; however, that historical practice has generally been a reflection of plant cost structure rather than any technological capability to operate in the face of or in response to high-impact, low-probability events. Particularly before the recent drop in natural gas fuel prices, coal and nuclear plants had relatively low variable costs and relatively high startup and shutdown costs, and so had been most economic to meet baseload demand.[195] But as natural gas prices have fallen, efficient natural gas-fired plants have more often been the cost-effective option to meet baseload demand. And as demand remains relatively flat while the level of variable resources (such as wind and solar, which generate only when it is sunny or windy) increases,[196] the electric system may not need as many generators to run continuously and may instead benefit more from dispatchable resources that can supply electricity when the variable resources do not. Whether a plant has operated as baseload, therefore, is not a resilience attribute; it is just a feature of the cost structure of electricity generation. As a result, retirement of units that historically operated as baseload resources does not necessarily reflect reduced resilience of the generation system, let alone the electric system as a whole.

Change in generation by fuel type during a high-impact event.[197] Whether a certain type of generator increases its generation during a high-impact event does not necessarily reflect that it possesses attributes that would help it to perform during future such events. Rather, it may reflect the fact that high-impact events cause electricity prices to rise, and that the facility was likely to operate only during periods of high electricity prices due to high generating costs. For example, during the 2018 "bomb cyclone," coal units were available to meet unexpectedly high electricity demand because their relatively high costs meant they were not being dispatched before the event and therefore had unused generating capacity. Once electricity prices rose, it became economic to dispatch these plants. It was these market dynamics and not any particular resilience attributes of the plants that dictated their operation.[198]

Because Resilience Is a Feature of the Electric System, Focusing Only on Generation Resilience Is Improper

Trump Administration coal and nuclear support proposals have been targeted at improving *generation* resilience. Yet, even if policies to limit the retirement of existing coal and nuclear units did improve generation system resilience, such policies would not necessarily improve *system* resilience. Most outages result from disruptions in the distribution and

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[194] DOE NOPR at 46,943.

[195] *See* DOE Staff Report at 38.

[196] *Id.* at 16.

[197] Peter Balash et al., Nat'l Energy Tech. Lab, Reliability Resilience and the Oncoming Wave of Retiring Baseload Units 12-18 (2018), https://www.netl.doe.gov/energy-analyses/temp/ReliabilityandtheOncomingWaveofRetiringBaseloadUnitsVolumeIThe-CriticalRoleofThermalUnits_031318.pdf.

[198] *See* Karen Palmer et al., *Understanding Grid Resilience Implications for Market Design: Beyond the NETL Study*, UtilityDive (Apr. 24, 2018), https://www.utilitydive.com/news/understanding-grid-resilience-implications-for-market-design-beyond-the-ne/522052.

transmission systems, leading some analysts to advocate for a primary focus on distribution and transmission resilience policies and investments.[199] Resilience-focused policy should be evaluated with respect to system resilience, not the resilience of a single component of the system.

Resilience Policies Should be Evidence-Based and Justified Using Cost-Benefit Analysis

The Trump Administration proposals provide stark examples of the need for evidence-based policymaking to improve grid resilience. Neither the DOE NOPR, nor the contemplated DOE emergency action included a comprehensive analysis of the benefits or costs of the proposed actions. A number of analyses showed significant economic costs associated with the DOE NOPR. For example, the independent, nonpartisan think tank Resources for the Future developed a limited economic analysis of the DOE NOPR showing that the proposal would result in net economic costs of around $10 billion per year.[200] Modeling conducted by both The Brattle Group and by Energy Innovation Policy & Technology LLP arrive at similar cost estimates.[201] Yet, DOE presented no evidence that the expected value of resilience benefits of these actions would exceed $10 billion per year. Similarly, a preliminary analysis of the DOE emergency action by The Brattle Group estimated it would cost consumers $20 billion to $70 billion over two years in increased energy costs.[202] This increase would be in addition to the $4-$9 billion of welfare loss over two years caused solely by increased conventional pollution and greenhouse gas emissions, as estimated by a recent Resources for the Future analysis.[203] The Trump Administration should adopt federal policies to enhance resilience only if the benefits of doing so exceed the costs. The cost-benefit analysis framework described in this report provide the tools for doing so.

Resilience Improvements Based on Changing Generation Incentives Should Be Made Using Market-Based, Not Cost-Based Compensation

One feature of both the DOE NOPR and the emergency action DOE is currently contemplating is that they would provide targeted resources with compensation based on their costs of operation (cost-based compensation) rather than the value that they provide the system, as determined by the market (market-based compensation). As described above, the use of cost-based compensation will not provide efficient resilience-enhancing entry, exit, and operational incentives for generators, and might significantly distort the existing energy markets. Rather, market-based compensation schemes should be used for policy designed to enhance resilience by changing generator incentives. Grid operators are currently in the process of implementing or developing market-based systems to value the resilience benefits of fuel-security.[204] Getting the design details right for these schemes is critical, and many have criticized the methodologies and assumptions

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199 Silverstein et al. at 6.

200 Daniel Shawhan & Paul Picciano, *Costs and Benefits of Saving Unprofitable Generators: A Simulation Case Study for US Coal and Nuclear Power Plants*, RF WP 17-22 (Nov. 30, 2017), http://www.rff.org/files/document/file/RFF-WP-17-22.pdf.

201 Metin Celebi et al, Brattle Group, Evaluation of DOE's Proposed Grid Resilience Pricing Rule (Oct. 2017), http://files.brattle.com/files/11635_evaluation_of_the_does_proposed_grid_resiliency_pricing_rule.pdf; Robbie Orvis et al, The Department of Energy's Grid Resilience Pricing Proposal: A Cost Analysis (Oct. 2017), http://energyinnovation.org/wp-content/uploads/2017/12/20171025_Resilience-NOPR-Cost-Research-Note-UPDATED.pdf.

202 Metin Celebi et al, The Brattle Group, The Cost of Preventing Baseload Retirements (2018), https://info.aee.net/hubfs/Brattle_AEE_Final_Embargoed_7.19.18.pdf.

203 Daniel Shawhan & Paul Picciano, Retirement and Funerals: The Emissions, Mortality, and Coal-Mine Employment Effects of a Two-Year Delay in Coal and Nuclear Power Plant Retirements, RFF WP18-18 (2018), http://www.rff.org/files/document/file/RFF%20WP%2018-18.pdf.

204 *See, e.g.* PJM Fuel Security Proposal; *ISO New England Inc.*, 164 FERC ¶ 61,003 (2018) (ordering ISO-NE to develop a market-based fuel security construct).

that are being used to develop these market-based schemes.[205] But if done right, market-based compensation is preferable to cost-based compensation for the procurement of real resilience-enhancing grid services.[206]

Conclusion

States and the federal government have a range of authorities to direct investments, implement policies, and facilitate coordination in order to enhance electric system resilience. These authorities can be used to implement a wide variety of actions that help the grid defend against, absorb, or recover from high-impact, low-probability shocks. However, the exercise of these authorities should be consistent with the concept of resilience described in this report and should be evaluated using the cost-benefit framework presented here. By doing so, state and federal regulators will ensure that potential investments and policies enhance the resilience of the electric system as a whole, and that the resilience improvements caused by those policies are justified by their costs.

[205] Kathiann M. Kowalski, *Critics: PJM Fuel Security Plan Ignores Renewables, Won't Build Resilience*, Energy News Network (May 9, 2018), https://energynews.us/2018/05/09/midwest/critics-pjm-fuel-security-plan-ignores-renewables-wont-build-resilience/; Paul Peterson et al, Synapse Energy Economics Inc., Understanding ISO New England's Operational Fuel Security Analysis (2018), https://www.clf.org/wp-content/uploads/2018/05/Understanding-ISO-NE-OFSA1.pdf.

[206] *See* FERC Resilience Order, 162 FERC ¶ 61,012 at PP 11, 16 (rejecting DOE Resilience Pricing, in part, because it used disfavored cost-of-service compensation rather than market-based compensation); *ISO New England Inc.*, 164 FERC ¶ 61,003 at 3 (Glick, Comm'r, *dissenting in part*) (arguing that FERC's preliminary action on fuel security for a natural gas plant would cause "a parade of uneconomic generators seeking cost-of -service rate treatment under the guise of fuel security" rather than "reform [of] the ISO-NE market to address the drivers of whatever fuel security problem may exist"); *Constellation Mystic Power, LLC*, 164 FERC ¶ 61,022 at 1-2 (2018) (Powelson, Comm'r, *dissenting*) (arguing that FERC should have rejected an cost-of-service agreement for a facility in favor of waiting for stakeholders to develop a market-based solution to fuel security concerns).

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