Electric Power Resilience: The Challenges for Utilities and Regulators

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Few people doubt that the United States will continue to experience long-lasting electric power outages affecting a large number of people and businesses (e.g., outages from Superstorm Sandy, Hurricane Maria in Puerto Rico, and severe hurricanes in Florida).[1] Some industry observers believe that the resilience of the U.S. electric-power network is deficient, and if industry spends additional funds on improving its resilience, the benefits would outweigh the costs.[2]

Customers, the media, and the public have taken more interest in scrutinizing utilities' responses to weather-related disasters and cyberattack threats.[3] There is a full-court press at the federal, state, and local levels to bolster the resilience of electric power.[4]

The common perception is that the benefits are too large to ignore. This belief seems plausible on its surface. After all, the damages from a long power

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1. *See Resilience Strategies for Power Outages*, CTR. FOR CLIMATE & ENERGY SOLS. (Aug. 2018), https://www.c2es.org/site/assets/uploads/2018/08/resilience-strategies-power-outages.pdf [https://perma.cc/NZD9-ZV68].

2. *See Enhancing the Resilience of the Nation's Electricity System*, NAT'L ACADS. SCI., ENGINEERING, & MED. 13 (2017), https://www.nap.edu/catalog/24836/enhancing-the-resilience-of-the-nations-electricity-system [https://perma.cc/5SD3-8MC6]. Extreme weather and distribution-level problems are the primary factors in the duration of electric power interruptions, with bulk generation shortfalls accounting for only a tiny number of customer outages, especially extended outages. Thus, the emphasis is on spending more money at the distribution level to enhance resilience. *See* Alison Silverstein et al., *A Customer-focused Framework for Electric System Resilience*, GRID STRATEGIES, LLC 14-18 (May 2018), https://gridprogress.files.wordpress.com/2018/05/customer-focused-resilience-final-050118.pdf [https://perma.cc/V4JY-JE4P].

3. *See* CONG. RESEARCH SERV., IN10895, ELECTRIC RELIABILITY AND POWER SYSTEM RESILIENCE (2018), [https://perma.cc/R57Q-3G7G]; *Before and After the Storm*, EDISON ELECTRIC INST., at v. (Mar. 2014), http://www.eei.org/issuesandpolicy/electricreliability/mutualassistance/Documents/BeforeandAftertheStorm.pdf [https://perma.cc/KV3Y-ABMD]; *Hardening the Grid: How States Are Working to Establish a Resilient and Reliable Electric System*, NAT'L CONF. STATE LEGISLATURES (Apr. 2018), http://www.ncsl.org/Portals/1/Documents/energy/HardeningGrid_1_32298.pdf [https://perma.cc/EV45-CU7S].

4. *See Order Terminating Rulemaking Proceeding, Initiating New Proceeding, and Establishing Additional Procedures*, FED. ENERGY REGULATORY COMM'N (Jan. 8, 2018), https://www.ferc.gov/CalendarFiles/20180108161614-RM18-1-000.pdf [https://perma.cc/6SQB-YCB2]. See also *Before and After the Storm*, *supra* note 3, for a listing of state activities addressing issues related to electric power resilience.

outage can be devastating to a locale, affecting almost everyone.[5] Possible damages include economic and noneconomic components. An example of the latter is the inconvenience and discomfort caused by an outage. Imputing a dollar value on the noneconomic effects is difficult—not much more than a guess. Any event that causes prolonged power outages over a large area is extremely costly—both for restoration and to the economy, and in terms of citizens' health, safety, and general welfare.

Studies have shown that electricity outages, on a kilowatt hour (kWh) basis, have far higher costs than both the price of electricity and the cost of producing and delivering electricity.[6] Outage costs include spoiled food, lost productivity, lost business revenues, and inconveniences. On net, then, electric customers are worse off when they experience an outage, even when their electricity bills decline. This is no surprise for anyone that has experienced an outage, especially for a long duration.[7]

Both the utility provider and electricity consumers can mitigate the damages from extended power outages. Resilience should be an integral goal of utility planning to determine long-term investments and other measures. Through pricing, a utility can determine how much its customers are willing to pay for different levels of resilience. Customers can also self-insure and take other protective actions to mitigate the damage from long-term outages.

The widely recognized Coase Theorem favors the imposition of liability on those parties who are able to address a problem at the lowest cost.[8] It may be true that customers can more cost effectively make investments and take other adaptive actions to mitigate the effects of long-term power interruptions. But solely maximizing efficiency avoids the question of who should bear the

5. According to estimates by the Lawrence Berkeley National Laboratory, sustained power outages cost the United States around fifty-nine billion dollars annually, with businesses and industrial firms incurring about ninety-seven percent of the costs. Joseph H. Eto, *The National Cost of Power Interruptions to Electricity Customers—A Revised Update*, LAWRENCE BERKELEY NAT'L LAB. (Jan. 10, 2017), http://grouper.ieee.org/groups/td/dist/sd/doc/2017-01-10%20National%20Cost%20of%20Power%20Interruptions%20to%20Electricity%20Customers%20-%20Eto.pdf [https://perma.cc/AL9H-TKG9]. This supports the importance of electric utilities providing uninterruptible service and prompt service restoration when interruptions occur.

6. *Id*.

7. Assume a stylized model in which customers benefit from electricity usage at the amount U. Extended service interruptions occur at the probability p with an average damage of d (i.e., damage per unit of kWh interruption). Consistent with empirical research, d is much greater than the price of electricity. Michael J. Sullivan et al., E*stimated Value of Service Reliability for Electric Utility Customers in the United States*, LAWRENCE BERKELEY NAT'L LAB., at xxvi, tbl.ES-5 (June 2009), https://emp.lbl.gov/sites/default/files/lbnl-2132e.pdf [https://perma.cc/2NBH-GM3L]. On net, the benefit to a customer from electricity service equals $U – p \cdot d$. Because the average American customer relies heavily on electricity, service interruptions can impose a high cost on households and businesses. Overall, customers would be willing to pay up to this $U – p \cdot d$ for electricity. Customers should therefore be willing to pay a higher price for electricity that is more resilient, since they would suffer less damage from service interruptions. The ability to charge a higher price arguably should incentivize the utility to incur additional costs to improve its resilience. To the extent that customers place greater value on more resilient electricity than it costs the utility to provide it, they benefit (assuming cost-based rates), the utility stands to profit, and aggregate economic welfare improves.

8. Ronald Coase, *The Problem of Social Cost*, 3 J.L. & ECON. 1 (1960).

risk from an "equity" perspective.[9] At the other extreme lies strict liability. Under strict liability, the utility alone is responsible for all long-term service interruptions, irrespective of the cause and cost. Imposing all liability on a utility might both be inefficient and unfair to the utility and its shareholders. It presumes that either (1) the utility could prevent and mitigate the damage at a lower cost than customers could (an efficiency argument), or (2) fairness demands that the utility absorb all costs, since the occurrence and the actual consequences of service interruptions are largely under the utility's control. Each condition, or both, may fail to hold.

This Essay argues that, for an electric power system, achieving a socially optimal level of resilience poses more challenges to utilities and their regulators than achieving optimal reliability and thus requires a special form of regulatory analysis. A host of factors—flawed decision-making (e.g., probability neglect), ambiguity over the definition of resilience and the scope of activities to which it is relevant, the high uncertainty of the benefits from improving resilience, the difficulty of measuring resilience and establishing a benchmark, and the optimal institutional arrangement involving both utility planning and a consumer-driven approach—complicate the tasks of both utilities and regulators. This Essay discusses each factor in turn.

I. Differentiating Resilience from Reliability

A fundamental problem in developing policies that guide utility-resilience investments is the lack of a consensus on the definition of resilience and deficiencies in measuring and assessing resilience on various scales. Experts and other observers disagree over the scope of resilience. Should it include only actions to restore power service? Or does it encompass avoiding service interruptions as well? What most differentiates resilience from reliability is the attention paid to utility activities once a service interruption begins, a presumed longer interruption period, and a wide selection of mitigating actions.

A. Ambiguity Over the Definition of Resilience

Various definitions of resilience abound, differentiated by the nature and scope of actions directed at making a power system more resilient.[10] Often the term resilience is used loosely and inconsistently.

9. The Coase Theorem may also conflict with the legal determination of which party should bear the risk.

10. For different definitions of resilience, see MILES KEOGH & CHRISTINA CODY, NAT'L ASS'N REG. UTIL. COMM'RS, RESILIENCE IN REGULATED UTILITIES (2013); Karen Palmer et al., *Economic Approaches to Understanding and Addressing Resilience in the Bulk Power System: A Workshop Summary,* RESOURCES FOR THE FUTURE (June 2018), https://media.rff.org/documents/RFF_workshop_summary_final_0.pdf [https://perma.cc/C5WV-LVQH]; and *Toward a Practical Theory of Grid Resilience*, GRID MODERNIZATION LABORATORY CONSORTIUM, U.S. DEP'T ENERGY (Apr. 2018),

One generally accepted definition of resilience is that *it measures the performance of a system under threat or stress*, for example, power grid performance under severe weather conditions or a cyberattack. [11] According to this definition, a resilient power system possesses the capability to absorb a disruptive event and still continue to operate. If service is interrupted, resilience turns to the ability to mitigate the damage or social cost. Sources of system disruption from a major event are both natural (e.g., severe storms) and human (e.g., cyber and terrorist) threats. A resilient power system has the ability to withstand and recover from both malicious and inadvertent cyber and physical attacks.

The above definition of resilience contains two components. The first is s*tatic*, which is the ability of a power system to remain functional when shocked. The second is *dynamic*, which involves hastening the speed of recovery from a disruption.[12] The first component relates to keeping the lights on. The second involves restoring service quickly when the lights go out and, considering the economics, at the minimum cost to consumers and society. Static resilience and dynamic resilience are substitutable. By spending more money to prevent service interruptions, the operator can reduce the money spent on managing an outage and restoring service.

Utilities commonly engage in four broad activities related to resilience: (1) sustaining operation of the power system; (2) restoring service; (3) planning and preparing for future extended interruptions; and (4) adapting to future events based on past experiences.[13] The last activity, often overlooked, refers to the process in which, after a disruptive event happens, a utility learns from that experience. This can result in the utility modifying its future actions in response to a disaster, which will improve resilience and thereby reduce the duration of a service interruption.

The 2017 U.S. Department of Energy report on Electricity Markets and Reliability recapitulates the unique challenges associated with resilience:

Recent severe weather events have demonstrated the need to improve system resilience. The range of potential disruptive events is broad, and the system needs to be designed to handle high-impact, low probability events. This makes it very challenging to develop cost-effective programs to improve resilience at the regional, state, or utility levels. Planning, practice, and

https://gridmod.labworks.org/sites/default/files/resources/Theory of Grid Resilience final_GMLC_0.pdf [https://perma.cc/4XRW-FWZB] .

11. Henry H. Willis & Kathleen Loa, *Measuring the Resilience of Energy Distribution Systems*, RAND CORP. (2015), https://www.rand.org/pubs/research_reports/RR883.html [https://perma.cc/LS27-3KBW].

12. Adam Rose, *Economic Resilience to Natural and Man-Made Disasters: Multidisciplinary Origins and Contextual Dimensions*, 7 ENVTL. HAZARDS 383 (2007).

13. Richard J. Campbell, *Weather-Related Power Outages and Electric System Resiliency*, CONGRESSIONAL RESEARCH SERVICE (Aug. 28, 2012), https://fas.org/sgp/crs/misc/R42696.pdf [https://perma.cc/V4ZA-GVZV]; *supra* note 3.

coordination on an all-hazards basis and having a mix of resources and fuels available when a major disturbance occurs are both essential to fast response.[14]

The Edison Electric Institute has compiled a listing of recent studies, programs, and policies on grid hardening and resilience for distribution systems in response to large storms. It notes that no single solution exists to make all systems more resilient; rather, "utilities and their regulators must look at the full menu of options and decide the most cost-effective measures to strengthening the grid and responding to storm damages and outages."[15]

B. A Two-Part Definition of Reliability

The North American Electric Reliability Corporation (NERC) disaggregates reliability into two parts. The first, operating reliability, is "the ability of the electric system to withstand sudden disturbances," such as electric short circuits or unanticipated loss of system components.[16] Operating reliability identifies *short-term* operational aspects of the system, which overlap with maintenance of system functionality when confronted with an extreme event like a hurricane. It relates to that element of resilience that prevents the system from going down and interrupting service to customers.

The second part, adequacy, is "the ability of the electric system to supply the aggregate electric power and energy requirements of the electricity consumers at all times, taking into account scheduled and reasonably expected unscheduled outages of system components."[17] Reliability is generally measured by interruption metrics.[18] It is a binary concept of system performance: the lights are either on or they are not. Reliability, therefore, concentrates on a system's general capability to provide power with as few service interruptions as possible.

C. The Uniqueness of Resilience

14. *Staff Report to the Secretary on Electricity Markets and Reliability,* U.S. DEP'T OF ENERGY 12 (Aug. 2017), https://www.energy.gov/sites/prod/files/2017/08/f36/Staff Report on Electricity Markets and Reliability_0.pdf [https://perma.cc/4XLZ-XBPT].

15. *Before and After the Storm*, *supra* note 3, at v.

16. Letter from Gerry Cauley, President & Chief Exec. Officer, N. Am. Electric Reliability Corporation, to Rick Perry, Secretary U.S. Dep't of Energy 2 (May 9, 2017), https://www.eenews.net/assets/2017/10/03/document_ew_01.pdf [https://perma.cc/JAQ7-RHCC]. For the role of NERC in assuring reliable electric service, *see* the Federal Energy Regulatory Commission's document at https://www.ferc.gov/legal/staff-reports/2016/reliability-primer.pdf [https://perma.cc/FP3L-B92P].

17. Letter from Gerry Cauley, *supra* note 16, at 2.

18. The classic reliability metrics are the System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), Customer Average Interruption Duration Index (CAIDI) and Momentary Average Interruption Frequency Index (MAIFI). *See Electric Reliability: Problems, Progress and Policy Solutions*, GALVIN ELECTRICITY INITIATIVE (Feb. 2011) http://www.galvinpower.org/sites/default/files/Electricity_Reliability_031611.pdf [https://perma.cc/2UDD-PQFW].

Resilience, as discussed *supra*, focuses more on one-time extreme events with the potential for widespread and long-lasting damage. A more resilient system can better withstand an extreme event. With a disruptive event, the damage is smaller and recovery is faster. Moreover, resilience extends beyond the duality that characterizes reliability by allowing for intermediary positions between service and no service.

First, consumers experience benefits of resilience and reliability investments differently. Resilience-improving actions attempt to mitigate the damage done by extreme (i.e., not routine) circumstances. Customers enjoy most of the benefits from investing in resilience only after an extreme event. Indeed, with luck, in a given year, they may realize no benefits other than a perceived reduction in risk due to these investments—for example, comfort in knowing that they would suffer less damage if a severe storm happens. In contrast, because investments in reliability enhance routine operations and conditions, customers should see their benefits within a few years.

Second, improving resilience requires a greater diversity of activities because of resilience's broader scope. Resilience-improving conduct occurs over a broad time range. Some, like preparation and planning, occur before an event is on the horizon. Others, like the retention of service and service's quick recovery, only occur after an event happens.[19] Activities also vary in priority because of their greater benefits, lower costs, or both. For example, many observers consider two-way communication with customers during a long-term outage as critical *and* relatively low cost.[20] Customers can better adapt if they know how long a service interruption will continue. Their behavior will likely differ if, say, the estimated time to restoration is eight hours versus thirty minutes. Other commonly cited resilience improvements include more redundancy (e.g., spare parts), hardening of distribution lines (e.g., upgrading poles and structures with stronger materials), distributed energy resources (DER) and microgrids, remote-controlled switches, system design accommodating recovery, mutual assistance programs, security measures, a diversified and integrated grid, training and workforce development, smarter operation of distribution component, and better communications with customers. [21]

Finally, resilience improvements require more effort on the part of utility companies. To combat a major event, the utility may have to repair damaged

19. *Supra* notes 2 & 3 and accompanying text.

20. *See Enhancing Distribution Resiliency: Opportunities for Applying Innovative Technologies*, ELECTRIC POWER RES. INST. (Jan. 2013); *supra* note 2.

21. Campbell, *supra* note 13; *supra* note 2. Of course, just listing the options begs the question of which ones are most cost-effective in providing the most "bang for the buck." Some analyses develop a long list of recommendations for improving resilience that, if all executed, would be cost-prohibitive. They rarely provide guidance or systematic ranking as to which ones are most effective and economical, and whether any of them would pass a cost-benefit test. Regulators should demand that utilities choose and pick the most effective and economical actions because of their constrained resources and their obligation to their customers to hold rates down.

overhead lines, transformers, and substations.[22] It also may have to grapple with service interruptions throughout its system and for a large number of customers. These possibilities make resilience-based outages more challenging to confront and analyze than reliability-based (e.g., less than twenty-four hour) outages.[23]

Resilience is, however, not the sole purview of utility operators. A holistic perspective of resilience views how power operators, electric consumers, and the general economy respond to a disruption—even perhaps through utility-community joint efforts that require outside help from the government.[24] Holism also involves how electric consumers react to an extended service outage and what precautions they took prior to the outage to lessen the actual harm they otherwise would suffer.[25] These actions represent adaptive responses to a major threat.[26] Any regulatory policy should recognize that a utility and its customers, along with the community assisted by the government, can jointly contribute to mitigating the damages from an extended service interruption. These entities possess complementary expertise and skills that can efficiently

22. Phil Zahodiakin, *Making Distribution Grids Stronger, More Resilient*, 4 EPRI J., July/Aug.2016, at 4-8 http://eprijournal.com/making-distribution-grids-stronger-more-resilient [https://perma.cc/FWY3-GCHD].

23. According to one survey, state utility commissions make no distinction between reliability and resilience in their investments—they lump them together when evaluating investment proposals. Kristina LaCommare et al., *Evaluating Proposed Investments in Power System Reliability and Resilience: Preliminary Results from Interviews with Public Utility Commission Staff*, LAWRENCE BERKELEY NAT'L LABORATORY (2017), https://emp.lbl.gov/publications/evaluating-proposed-investments-power [https://perma.cc/USY3-4ZW2].

24. As a common practice, utilities rely on community and government assistance when an extensive power outage occurs. Utilities also generally update their customers on the status of the outage and how to best cope with it, for example not opening their refrigerators to prevent food spoilage and releasing the garage door. *See supra* note 2 and *Before and After the Storm*, *supra* note 3; M. Finster et al., *Front-Line Resilience Perspectives: The Electric Grid*, ARGONNE NAT'L LAB. (Nov. 2016), https://www.energy.gov/sites/prod/files/2017/01/f34/Front-Line Resilience Perspectives The Electric Grid.pdf [https://perma.cc/4SKL-GQQT]; *Are You Prepared for a Power Outage?* FEMA (Mar. 29, 2019), https://www.fema.gov/media-library/assets/images/161542 [https://perma.cc/L9YC-EUUQ]. For an example of one utility's (New Jersey Central Power & Light) strategy in preparing its customers for a possible outage from severe weather, see *JCP&L Preparing for Severe Weather Forecast; Critical Customers Notified*, PR NEWSWIRE (Oct. 24, 2018), https://www.prnewswire.com/news-releases/jcpl-preparing-for-severe-weather-forecast-critical-customers-notified-300737418.html [https://perma.cc/GX57-778N].

25. There is little discussion in the literature and in the regulatory arena of the role of electric consumers in taking responsibility for damages that they may suffer from an extended power outage. If utilities alone are responsible for the damages, this could create what analysts call a "moral hazard" problem," with customers forgoing potentially cost-effective behavior. (Although the "moral hazard" problem is a theoretical possibility, its seriousness requires an empirical analysis. The author is unaware of any such analysis.) Customers can take various actions to avoid or mitigate damages from an outage. Although customers have no legal responsibility to mitigate damages, it seems both unfair and inefficient to compensate customers for damages that they could have reasonably avoided or mitigated at a low cost. Just as utilities should be accountable in their actions, an argument is that customers should also have a duty to take reasonable actions in mitigating the consequences of an outage.

26. One measure of adaptation by businesses is the percentage decline in production relative to the percentage decline in electricity availability from the local utility. If a business suffers no decline in production, say, because it has a back-up generator, it has perfectly adapted, or its resilience is one hundred percent.

and equitably mitigate the damage done by extended outages to utility customers and the community.

II. Flawed Decision-Making

A. Probability Neglect

Evidence from different contexts has shown that "probability neglect," namely the sole focus on outcome and disregard for its probability, helps to explain excessive reactions to low-probability, catastrophic events.[27] That is, the responses to tragedies and other highly damaging events often occur right after outrageous incidents with high public exposure. The result is a failure to apply rigorous, analytical approaches to managing risks. Resilience of electric power is susceptible to this conundrum.

Because policymakers and system operators rightly fear extended service interruptions and blackouts—they would face the brunt of criticism—they may not think twice about burdening electric customers with the cost of avoiding them. They will tend to err on the side of excessive caution that translates into higher electricity prices for their customers.[28] The problem is that they may view improved resilience to be beneficial from their perspective when it is not from society's.

The mindset of many decision-makers and industry observers *seems to be*: we can't let this happen again, no matter how slim the chances are and the economics.[29] Moreover, their risk perceptions are exaggerated, derived from high-profile publicity given to such events. The policy discourse over electric power resilience exemplifies this flawed thinking.

Prudent decisions on resilience require consideration of the probability of events, whether calculated objectively with historical data or determined subjectively. Assessing the economics of improved resilience should account for the likelihood of the future frequency and duration of extended outages covering a large area. Otherwise, how can decision-makers conduct a valid cost-benefit review of costly investments and other actions?

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27. *See generally* Cass R. Sunstein, *Probability Neglect: Emotions, Worst Cases, and the Law*, 112 YALE L.J. 61 (2002).

28. This is a theoretical argument with the premise that long-term service interruptions would impose greater risks (e.g., public outcry) for decision-makers than slightly higher electricity prices. This tradeoff might differ from that of electricity customers and society.

29. One example is the U.S. Secretary of Energy's proposed rule to the Federal Energy Regulatory Commission in 2017 to promote electric power resilience as vital to national security. The Commission remarked that "the Proposed Rule would allow all eligible resources to receive a cost-of-service rate regardless of need or cost to the system. The record, however, does not demonstrate that such an outcome would be just and reasonable. It also has not been shown that the remedy in the Proposed Rule would not be unduly discriminatory or preferential." *Order Terminating Rulemaking Proceeding, Initiating New Proceeding, and Establishing Additional Procedures*, FEDERAL ENERGY REGULATORY COMMISSION 9 (Jan. 8, 2018), https://www.ferc.gov/CalendarFiles/20180108161614-RM18-1-000.pdf [https://perma.cc/6SQB-YCB2].

B. *The Precautionary Principle*

Analysts often refer to the precautionary principle in setting environmental, safety, and other public policies across different industries and contexts.[30] The precautionary principle warns that society is gambling when it acts to prevent a potential harmful event only under stringent conditions (e.g., a highly certain future). It assigns a benefit to prevention even with inconclusive risk. The application of the precautionary principle to electric power resilience seems appropriate. The reason is that, even though it becomes difficult to assign a probability to a catastrophic event and measure, with reasonable accuracy, the benefits from actions to enhance resilience, the event could cause severe damage to electric consumers and the regional area.

1. What Is the Precautionary Principle?

According to the precautionary principle, the optimal decision in a world of less-than-perfect certainty and large risk from the status quo calls for new action. Uncertainty exists where decisionmakers lack reasonably accurate estimates or forecasts for the benefits from enhanced resilience. The precautionary principle strategy mirrors a "min-max" approach—i.e., minimizing the maximum harm that can result from an adverse event[31]—which is most appropriate for situations where the outcomes can afflict substantial damage to property and human life, in addition to being highly uncertain.

Under the precautionary principle, even in the face of uncertainty, society should expend resources today to mitigate the chances of severe problems in the future.[32] The implication for resilience is that society should spend some amount of money today to enhance resilience and avoid a worst-case scenario, notwithstanding the high uncertainty over the benefits.

To wit, the precautionary principle says that society takes an inordinate risk when it attempts to prevent a potential harmful event only under certainty. It supports society erring on the side of caution in protecting the general public from risk, adopting a "better safe than sorry" stance that insures against catastrophic events. For resilience, the precautionary principle would recognize both the possible extensive damage to society from threats to the electric power grid and the inconclusive nature of the costs from service disruptions.

A conservative interpretation of the precautionary approach aligns with the "real options theory." According to this theory, decision-makers would "hedge" by deferring costly actions until they acquire more definitive

30. Christian Gollier & Nicolas Treich, *Decision-Making Under Scientific Uncertainty: The Economics of the Precautionary Principle*, 27 J. RISK MGMT. 77 (2003).

31. *See* Cass R. Sunstein, *The Paralyzing Principle*, REGULATION, Winter 2002-2003, at 32. This is especially applicable to utility investments in resilience. The frequencies and magnitudes of severe weather events are highly uncertain and the worst-case outcome reflects catastrophic damages of the highest magnitude.

32. Gollier & Treich, *supra* note 30.

information necessary to reduce the chances of making the wrong decision (e.g., overspending on resilience).[33] This wait-and-see posture can help avoid uneconomic actions. Decision-makers would delay undertaking a major initiative until they know more about the risk level of threats. This cautious approach would result in some spending today on enhancing resilience as an insurance against the possibility of a catastrophic outcome.

2. Critiques of the Precautionary Principle

The precautionary principle is not uncontroversial.[34] Critics note its shortcomings compared to a cost-benefit analysis that accounts for uncertainty and the risk aversion of the decision-maker. How much money should society spend today to mitigate the consequences of major threats to the electric power system? Should a utility spend a hundred million dollars or two billion dollars for mitigation? Unlike a cost-benefit analysis, the precautionary approach provides little guidance.

When people purchase insurance, they at least implicitly compare the premiums with the expected cost of an adverse event.[35] Should society not have an idea of the expected benefits from spending money today to reduce the damages from long-extended power outages? But the precautionary principle places the burden on those would devote little or no resources toward mitigating a hazard where reasonably accurate information about its consequences and the probability of its occurrence is nonexistent.[36] The default option is that society should act to avoid a risk with potentially catastrophic consequences, irrespective of the likelihood of the event. That is why a prominent scholar harshly said that the precautionary principle "offers no guidance—not that it is wrong, but that it forbids all courses of action, including inaction."[37]

Indeed, the precautionary principle may not represent an economically rational way to guide socially desirable policy, especially when it involves society spending large sums of money today. Assume that the utility spends substantial sums of money to improve its resilience. Although the investment would reduce the expected damages from a severe storm, that money might have been better spent on alternative utility activities designed to improve

33. For a discussion of real options theory and its application, see generally LENOS TRIGEORGIS, REAL OPTIONS: MANAGERIAL FLEXIBILITY AND STRATEGY IN RESOURCE ALLOCATION (1996); and *Real Options: Developments and Applications*, 38 Q. REV. ECON. & FIN. 533 (1998).

34. *See* RICHARD A. POSNER, CATASTROPHE: RISK AND RESPONSE (2004); Robert W. Hahn & Cass R. Sunstein, *The Precautionary Principle as a Basis for Decision Making*, 2 ECONOMIST'S VOICE (2005); *supra* note 31.

35. GARY S. BECKER, ECONOMIC THEORY 61-64 (1971).

36. DANIEL KAHNEMAN, THINKING, FAST AND SLOW 351 (2011).

37. TRIGEORGIS, *supra* note 33, at 33.

safety or reduce other risks. The benefits of the paths not taken constitute the opportunity cost of spending the money on resilience.[38]

So even if a course of action is tenable, rational behavior would limit spending for preventing the possibility of future harm from catastrophic events. In the face of uncertainty, the best policy may be to avoid the worst outcome irrespective of the probabilities for different scenarios. This rationale assumes a risk-averse society and severe damages from an event.

III. Uncertainty as a Complicating Factor

Uncertainty differs from risk in that the probability of occurrence is not quantifiable, thereby requiring subjective judgment by decision-makers.[39] Under uncertainty, a common approach is to describe various hazard scenarios or assign them a probability based on the decision-maker's personal assessment.

Uncertainty can warrant action, but decision-makers should exercise caution when doing so. When deciding to perform a costly action with uncertain benefits, economic or noneconomic, people often hesitate, and they hesitate rationally. Decision-makers need to continuously acquire better information, whether from credible modeling or more informal sources, to increase the chance that they take socially desirable actions in the face of uncertainty. This seems to be true for electric power resilience.[40]

To make socially optimal—or even effective—decisions on resilience requires reasonably accurate information about the true cost of service interruptions for both utility customers and the local area. As of today, methods that estimate willingness to pay (WTP) are inadequate to inform the benefit-cost analysis of "resilience investments."[41]

A. "Black Swans"

Analysts label power interruptions of long duration as a high impact, low probability (HILP) event, also known as a "Black Swan" event. A Black Swan

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38. The definition of opportunity cost is the alternative use of the money spent on resilience that has the highest social value.

39. In the real world, risky and uncertain situations are insurable. But uncertainty precludes decision-makers from relying on historical data to calculate the objective probability of an adverse event. This makes uncertain events more expensive to insure.

40. If decision-makers have better information on the benefits of enhanced resilience, they would then expect to deviate less from a decision where the marginal benefit differs from the marginal cost.

41. WTP is an economic concept used to value nonmarket goods such as cleaner air, more wildlife, fewer power outages, and lower obesity. For an application of the latter, see John Cawley, *Contingent Valuation Analysis of Willingness to Pay to Reduce Childhood Obesity*, 6 ECON. & HUMAN BIOLOGY 281 (July 2008), http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.594.8056&rep=rep1&type=pdf [https://perma.cc/7583-7V96].

event poses special challenges for decision-makers because of its (1) far-reaching impact; (2) poorly understood risk ("uncertainty"); (3) costly mitigation; and (4) the unclear role for industry, power customers, and government in sharing the responsibilities for mitigating the effects of a major event.[42]

HILP events can have macroeconomic and other societal impacts (e.g., nonmonetary inconvenience). The likelihood and magnitude of societal impact increases as an interruption endures for an extended period over a large area.[43] As the extent of an outage and the dispersal of its effects increases, the benefits of any actions to improve resilience become harder to measure.

B. Addressing Uncertainty

Decision-makers[44] face a high degree of uncertainty about the effects of major disruptions on an electric power system. Because of scant data to draw upon, predicting their frequency and the damage they might cause is pure speculation.[45] Compared with natural threats to electric grid reliability, such as extreme weather, cyber threats are more difficult to anticipate and address.

One source of greater uncertainty that has proliferated recently is more extreme weather, which some experts predict to worsen in the future.[46] Another relatively new source of uncertainty is cyberattacks; utilities have little clue when they will occur and with what likelihood.[47]

Uncertainty inevitably forces decision-makers to rely heavily on value judgment. These value judgments frequently are part of the evaluation of the

42. For a discussion of "Black Swan" events, see generally NASSIM NICHOLAS TALEB, THE BLACK SWAN: THE IMPACT OF THE HIGHLY IMPROBABLE (2010).

43. *See* Seth Guikema & Roshanak Nategchi, *Modeling Power Outage Risk from Natural Hazards*, OXFORD RESEARCH ENCYCLOPEDIA OF NATURAL HAZARD SCIENCE (June 2018) https://oxfordre.com/naturalhazardscience/view/10.1093/acrefore/9780199389407.001.0001/acrefore-9780199389407-e-52 [https://perma.cc/39RR-UP8X].

44. "Decision-maker" refers to utilities who create and execute strategies and tactics, and the regulators who approve them.

45. This fact is a rationale for using an analytical tool other than cost-benefit analysis, such as break-even analysis, see Section V.E.2, to evaluate investments in resilience. *See* Peter Fox-Penner & William P. Zarakas, *Analysis of Benefits: PSE&G's Energy Strong Program*, prepared for PSE&G (Oct. 7, 2013), http://files.brattle.com/files/936_analysis_of_benefits_-_pse_g's_energy_strong_program_fox-penner_zarakas_10_07_13.pdf [https://perma.cc/9VF6-SC85].

46. *See Resilience Strategies for Power Outages*, *supra* note 1.

47. KEOGH & CODY, *supra* note 10; *Electric Distribution System Cybersecurity Is Critical in Today's Interconnected Society*, EDISON ELECTRIC INST. (Apr. 2018), https://www.eei.org/issuesandpolicy/cybersecurity/Documents/EEI_Cybersecurity_Considerations_Distribution_Fin-April27-2018.pdf [https://perma.cc/PK7Q-Y8UN]; Lynne Holt & Mary Galligan*, State Public Utility Commissions' Role in Cybersecurity and Physical Security Issues: Trade-Offs and Challenges* (Public Utility Research Center, Working Paper, Dec. 12, 2017), https://bear.warrington.ufl.edu/centers/purc/docs//papers/1707_STATE_PUC_ROLE_Cybersecurity_12_12_17.pdf [https://perma.cc/QL5R-RBB7].

benefit side of "resilience" investments.[48] It also makes strict cost-benefit tests less feasible. [49] Analysis of resilience thus differs from evaluating reliability concerns, which are more accurately described as risks. The likelihood of inadequate capacity to meet demand is derivable from historical data for both system peak load[50] and power-plant outage rates. Reliability is also more precisely measurable and is less ambiguous in its definition.[51] An Electric Power Research Institute (EPRI) report summarizes the current state of cost-benefit analysis for electric power resilience, and demonstrates how much these analyses differ:

> In conventional cost-benefit analysis, prospective investments can be evaluated by comparing the costs and benefits expressed in present-value currency terms, which make comparisons straightforward. Resiliency investments are considered to avert the consequences of events characterized by low probability, uncertain timing, and high severity (while the costs are certain and large). If costs or benefits are not known with certainty, then the analysis must account for this from an expected risk perspective. Risk is traditionally defined as a function of the hazard (i.e., probability) and the consequence. Consequence can be further described as a function of exposure and vulnerability . . . . [T]here is no unifying perspective or framework for cost-benefit analysis of resiliency efforts, though there is much interest in advancing the state of the art. [52]

One way to handle uncertainty is to know the customer's implicit WTP for enhanced resilience in order to justify investments or other actions. While decision-makers cannot expect to eliminate uncertainty, they can incorporate it (e.g., by using subjective probabilities) into WTP calculations and cost-benefit analyses. The decision-maker can then better understand how uncertainty affects the cost-effectiveness of investments and other resilience-improving measures under different scenarios.

One unavoidable question is: how much is society willing to pay for increased resilience? The answer depends on the avoidance of lost welfare that

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48. Any calculated benefits, for example, would have a wide band of uncertainty causing ambiguous results. Investments and other actions that improve resilience may have additional benefits, such as energy efficiency, reliability, and economy.

49. Some state jurisdictions have required cost-benefit analysis prior to approving the inclusion of grid modernization expenditures in rates. These programs will likely include the development of performance metrics for reliability, and possibly for resilience, if these new capabilities are to provide the expected service improvements. For a review of state grid modernization programs, see *50 States of Grid Modernization 2018 Annual Review*, N.C. CLEAN ENERGY TECH. CTR. (Feb. 2019), https://nccleantech.ncsu.edu/wp-content/uploads/2019/02/Q42018-GridMod-Exec-Final2.pdf [https://perma.cc/53KS-KYA3].

50. Peak load is the highest electrical power demand over a specified time period.

51. For reliability, the margin of redundancy reflects three factors: historical experience, the value lost to customers from service interruptions, and the cost of power-supply reliability.

52. ELECTRIC POWER RESEARCH INST., ELECTRIC POWER SYSTEM RESILIENCE: CHALLENGES AND OPPORTUNITIES 45 (Feb. 2016), https://www.naseo.org/Data/Sites/1/resiliency-white-paper.pdf [https://perma.cc/4ZH4-KJ2J].

would otherwise occur. Lost welfare measures what analysts refer to as the "Value of Lost Load" (VOLL). VOLL estimates can help to set resilience targets and to allocate monies toward different measures to enhance resilience. A risk-averse society would be willing to spend more than the expected loss in welfare. The tough chore for decision-makers is to calculate the risk tolerance of different customers. For the utility-planning approach, discussed *infra* Section V.A, analysis requires aggregating the disparate risk preferences across utility customers into a single standard for society.

Knowing with reasonable accuracy how much customers and society would be willing to pay for avoiding long service interruptions, therefore, is critical for prudent decision-making. But presently, willingness-to-pay information is too imprecise to render much value.[53] For example, VOLL estimates are highly uncertain and specific to local conditions, outage duration, and scope. Besides, almost all studies focus on outages of twenty-four hours or less.[54] The benefits of investments in resilience to counter interruptions of long durations (e.g., multi-day service outages) are consequently dubious and much more uncertain than the benefits for investments in electric power reliability.

53. Utilities, government agencies, and others in the United States commonly use the Interruption Cost Estimate (ICE) Calculator as a tool for estimating interruption costs, or the benefits of reliability improvements. *Interruption Cost Estimate Calculator*, LAWRENCE BERKELEY NAT'L LABORATORY & NEXANT, INC., https://icecalculator.com/home [https://perma.cc/7FDM-9GW8]. The U.S. Department of Energy funds the ICE Calculator. *Id*. Utilities provide the ICE Calculator with cost estimates for power interruptions lasting at most 16 hours. *See id*. Although users can extrapolate the costs to longer interruptions, and use them as a guide, the estimates would be less accurate when a nonlinear relationship exists between kWhs of lost service and interruption costs. It is reasonable to assume that the costs per kWh of lost service during prolonged interruptions differ significantly from the costs of short interruptions. Long interruptions tend to inflict social costs by having a ripple or "multiplier" effect on the economy. *See Economic Benefits of Increasing Electric Grid Resilience to Weather Outages*, EXEC. OFFICE PRESIDENT (Aug. 2013), https://www.energy.gov/sites/prod/files/2013/08/f2/Grid Resiliency Report_FINAL.pdf [https://perma.cc/FT4J-PRYT]. This means that they would have a society-wide effect that extends beyond the costs to power customers. Applications of the the ICE Calculator generally consider only the direct costs to customers. *See* Peter H. Larson, *Projecting Future Costs to U.S. Electric Utility Customers from Power Interruptions*, LAWRENCE BERKELEY NAT'L LAB. 9-10 (Jan. 2017), https://www.ourenergypolicy.org/wp-content/uploads/2017/02/lbnl-1007027_1.pdf [https://perma.cc/M67T-6F92]. Therefore, it excludes the costs suffered by businesses not directly affected by an interruption. Overall, scaling up the estimates of short interruption would likely lead to inaccurate results. For a critique of the ICE Calculator, see *Electric Power System Resilience: Challenges and Opportunities*, ELEC. POWER RES. INST. 46 (Feb. 2016), https://www.naseo.org/Data/Sites/1/resiliency-white-paper.pdf [https://perma.cc/YQM8-7YWW].

54. VOLL per kilowatt-hour for residential customers can be more than two orders of magnitude above the price of electricity; for commercial and industrial customers, the order of magnitude is far greater. Sullivan, *supra* note 3. VOLL reflects what economists call "compensating variation" or "equivalent variation." *See* HAL R. VARIAN, MICROECONOMIC ANALYSIS Ch. 10 (1992). The former measures what customers would be willing to pay to avoid a service interruption, while the latter measures what customers would be willing to accept for having a service interruption. Surveys generally have shown the latter measure to be higher. *See supra* note 7, at 59. Customers feel they have an entitlement to continuous service, which is compatible with one of the tenets underlying behavioral economics and prospect theory. For a discussion of prospect theory, see generally Amos Tversky & Daniel Kahneman, *Advances in Prospect Theory: Cumulative Representation of Uncertainty*, 5 J. RISK & UNCERTAINTY 4, 297 (1992). Applying prospect theory to customers, their utility should pay them a nontrivial sum for agreeing to have their service interrupted because that would violate their basic right to electric service.

Uncertainty often causes suboptimal behavior. People sometimes act overconfidently by overstating the sureness of their decision, saying something like: "We just know that spending more money on resilience is cost-beneficial. We observe how damaging long-term power outages can be, so we can never throw too much money at trying to mitigate their effects." Others may rationalize inaction because of the high degree of uncertainty, stating, "Since we have highly imprecise estimates of what the benefits will be, we shouldn't throw any money at improving resilience until we get better estimates." Both responses can lead to irrational behavior and a socially undesirable outcome.[55] The arguments are akin to the policy issues facing climate change, with divergent positions taken.[56]

IV. Metrics for Resilience

A major if not central purpose of regulation is to induce high-quality performance from public utilities.[57] To achieve that objective, regulators should measure and evaluate utility actions. Performance depends on how well utility management uses available resources. Yet factors outside utility management's control also affect performance.[58]

The challenge for regulators is to determine what constitutes a well-performing utility.

What do they consider acceptable performance? Regulators must address this question if they are to exploit fully the information contained in performance metrics to take appropriate action, including those metrics relating to resilience. Measuring performance trends in the absence of a standard, for

55. Behavioral economics can explain this irrationality. *See* KAHNEMAN, *supra* note 36, at 55; RICHARD H. THALER & CASS R. SUNSTEIN, NUDGE: IMPROVING DECISIONS ABOUT HEALTH, WEALTH, AND HAPPINESS (2008).

56. Examples of divergent (or as some people would say, extreme) positions are (a) climate change is a hoax that poses no problem, and (b) we need to take immediate aggressive action to reduce greenhouse gas emissions or else catastrophe is inevitable.

57. The presumption is that when a utility performs well, for example, in controlling its costs and providing highly reliable and resilient service, it is advancing the interests of both its customers and society. If the generally agreed-upon goal of regulation is to serve the public interest, a better performing utility would then seem compatible with that goal.

58. A chronic problem for regulators is that they observe only a utility's performance, not the effect of management's effort on cost, service quality, and other outcomes affecting customer welfare. Because of this reality, if given the chance, utilities have an incentive to engage in strategic behavior, resulting in a zero-sum game where they benefit from higher profits or other managerial goals at the expense of their customers. *See* Paul L. Joskow, Incentive Regulation in Theory and Practice: Electricity Distribution and Transmission Networks (Jan. 21, 2006) (manuscript prepared for the Nat'l Bureau of Economic Research Conf.), https://economics.mit.edu/files/1181 [https://perma.cc/83KU-CSSU].

In the context of this Essay, regulators lack the ability to determine the minimum costs compatible with a certain level of resilience (if measurable). Utilities inherently have better information that motivates them to overestimate the cost of resilience. This incentive is more acute when utilities receive zero or minimal benefits from better managing their costs or improving their resilience. That is, the higher the allowed costs, the less risk there would be that unanticipated additional expenditures (e.g., cost overruns on underground distribution lines) would result in the utility earning a return on capital below its allowed return.

example, greatly constrains what actions regulators should take. How can they rightly penalize a utility without a benchmark against which to evaluate a utility's performance?[59]

A. Challenges to Developing Resilience Metrics

Developing metrics for resilience is inherently difficult but is critical for decision-making.[60] It involves measuring how well system operators prepare for and deal with rare events without any history (therefore, with significant uncertainty).[61] As amplified in one study:

> Reliability metrics measure grid operations during expected outages that could occur under relatively normal conditions. However, reliability metrics typically do not include outage information when low-probability, high-consequence events such as storms, earthquakes, and cyber-attacks occur. As the hazard landscape continues to change, historical data used for reliability calculations may not be suitable for characterizing future potential outages because emerging threats can differ significantly from historical precedents.[62]

59. A benchmark allows the regulator to compare an individual utility's performance with some predefined reference, either a peer group or the utility's own past performance. It focuses on outcomes, for instance the services provided by a utility per unit of labor or capital, or the frequency and duration of service interruptions. As an alternative, a benchmark would center on a utility's practices and uses of different technologies—i.e., has the utility adopted "best practices" in the form of state-of-the-art technologies and management processes? *See* Mehdi Farsi et al., *Benchmarking and Regulation in the Electricity Distribution Sector* (Ctr. for Energy Policy and Economics, Working Paper No. 54, 2007), http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.546.6782&rep=rep1&type=pdf [https://perma.cc/HCQ4-L2ET].

60. In the absence of quantifiable metrics, it becomes difficult for decision-makers (e.g., utility management and regulators) to know if a utility's "resilience" performance is falling short of, achieving, or surpassing predetermined objectives or targets. Metrics can empower regulators to grade utilities, mindful of limitations in their use for regulatory actions. Performance metrics can accompany special incentive mechanisms, management audits, and other detailed investigations to determine recovery of resilience-related costs for a utility. For examples of the different uses of performances metrics in the regulatory arena, *see* Ken Costello, *How Performance Measures Can Improve Regulation*, NAT'L REGULATORY RES. INST. (June 2010), http://nrri.org/download/2010-09-how-performance-measures-can-improve-regulation [https://perma.cc/KLE5-PQUD].

61. Conventional reliability metrics like the System Average Interruption Duration Index (SAIDI, the total duration of interruption for the average customer during a predefined period) are misleading because often they exclude data on service interruptions originating from major events. There are also inconsistencies in the definition of a "major event." U.S. Energy Information Admin., *EIA Data Show Average Frequency and Duration of Electric Power Outages,* TODAY IN ENERGY (Sept. 12, 2016), https://www.eia.gov/todayinenergy/detail.php?id=27892 [https://perma.cc/QY3B-695G]. Problems also arise from measuring the benefits of resilience with metrics traditionally used for reliability planning. Reliability metrics like average service interruption indices are ill-suited for characterizing resilience.

62. Eric Vugrin et al., *Resilience Metrics for the Electric Power System: A Performance-Based Approach*, SANDIA NAT'L LABS. 7-8 (Feb. 2017), https://prod-ng.sandia.gov/techlib-noauth/access-control.cgi/2017/171493.pdf [https://perma.cc/Z92B-VEG4].

According to the National Academy of Sciences, "[w]hile reliability metrics are relatively well established and widely used in electricity system planning and operation, the development of agreed-upon metrics for resilience lags significantly behind."[63] Decision-makers have found it difficult to assign standards to each of the activities advancing resilience, let alone measure their effectiveness. From the perspective of utility customers, a number of metrics are relevant. They relate to the frequency of long interruptions; the duration of long interruptions; the affected population; survivability (the provision of essential service); and lost welfare, like inconvenience and economic losses.

B. *Limitations of Resilience Metrics*

1. A Cautionary Note

Appropriate use of performance metrics, even where they accurately measure the outcome of utility actions, depends on the regulator's ability to separate the effects of external and internal factors on performance. For resilience, several factors are relevant, some internal to a utility's control and others outside utility management control. The challenge for regulators is to distinguish between these internal and external factors when deciding on whether a utility's actions are prudent. Without this separation, applying performance metrics for regulatory decision-making becomes more difficult, even counterproductive. One example is comparing two utilities' time to restore service after an outage. It may well be that the utility taking the longer time faces more challenging physical and environmental conditions. It would be unfair to penalize or reprimand that utility without considering those conditions. Regulators should therefore exercise caution in using performance metrics mechanically or as the sole source of information for evaluating a utility's performance.

Regulators should pay special attention, however, to those utilities exhibiting abnormal or "outlier" performance, which might lead to more detailed inquiry. A metric, therefore, can act as a guide to future regulatory scrutiny and remedial actions. Metrics function best as a gross indicator signaling a potential problem warranting further inquiry.

2. An Example of Metrics' Limits: The Utility of Input Metrics

For example, a serious limitation of input metrics (e.g., money spent on vegetation management) is that they provide no indication of how well a power system will operate in the event of a disruption or of the effectiveness of specific actions to enhance resilience.[64] The real indicators of a power system's

63. *Enhancing the Resilience of the Nation's Electricity System*, *supra* note 2, at 34.
64. *See id*.

resilience are the consequences that befall the system during and after a disruptive event. The utility can either estimate the consequences,[65] account for the inherent uncertainties, or measure consequences after an event.

Input metrics also fail to consider the tradeoffs between different processes or standards. Assume that a utility meets a mandated regulatory standard for hardening its infrastructure to mitigate damage from a severe storm. Perhaps the money invested in infrastructure could have been better spent on emergency and planning activities or on better communications with customers during an event. That is, the actual dollars spent by the utility could have been used for greater improvements of resilience; the opportunity cost of the infrastructure investments exceeded their benefits.

V. Alternative Institutional Arrangements

A "resilience" strategy should focus on the consumer. Later, this Part argues that focusing on the individual consumer is a more economically efficient and equitable approach than lumping all the customers together, such as under the utility planning approach, to make decisions on resilience.

The decision to spend money on improving resilience should hinge on the risk-adjusted expected value to consumers. In a market-based environment, the resiliency of electric service will depend more on the value that consumers place on different levels of resilience. Under this "bottom up" approach, pricing and market incentives become major factors. Overall, customer-oriented strategies incorporate flexible, market-based rules accommodating the demands of individual customers.

But with long-term and massive power service interruptions having spillover effects on the economy, there is a macroeconomic effect (and noneconomic effects like safety, health and inconvenience) with a sum cost greater than the aggregate costs suffered by utility customers. When an industrial firm has no electric service, the relevant cost to the firm is the loss of profits. In contemplating whether to purchase backup service, the firm compares the cost of that service to the benefits (which would be avoided profit losses). But this private benefit would fall short of the social benefit, which would include employees not losing work and wages and other economic and noneconomic benefits external to the firm. The total benefit to the local economy would exceed the benefits to the firm. Thus, the profit-maximizing firm would be underinvesting, since it would not internalize some of the benefits that would result from having backup service. In other words, society should be willing to pay more for avoiding a massive outage than what the sum of individual customers would be willing to pay. This gap would then call for

65. The estimates can represent expected or maximum consequences, along with their subjective probabilities.

some action to close it, action that should be taken by the government or by utilities.

A. Utility Planning Approach

1. Causes of Suboptimal Outcomes

From a public-interest perspective, the ultimate question is whether a "resilience problem" exists; namely, either utilities are spending too much on the resilience that they presently have (however it is measured), spending too little for enhancing their resilience, or are overly resilient today.

On one hand, deficient resilience can exist because of the net-positive externalities—for example, the social benefits, which may include public health and safety—exceed the benefits to electricity customers and the utility itself. On the other hand, utilities may be overspending on resilience because of excessive caution and probability neglect.

Utilities can also spend too much on the resilience desired because of the absence of a sequence of actions based on cost-effectiveness. Some analysts have questioned the cost-effectiveness of underground lines; for example, these lines can cost three to four times more than overhead lines of equal distances. Although underground lines can reduce the frequency of service interruption, outage duration is typically longer than with overhead lines because of the greater difficulty in repairing underground lines. Other measures (e.g., investment in an outage management system) taken by one utility can be cost-effective while the same measures may not be for another utility. One example is underground distribution lines in areas like Florida, where long-term, weather-related outages are more frequent than in other areas, would tend to be more economical.

Under conventional ratemaking, utilities may have an incentive to inflate their rate base to improve resilience (assuming that the authorized rate of return exceeds a utility's cost of capital[66])—in regulatory jargon, gold-plating[67]—by spending excessively to boost their profits. They may approach their regulators with key actions and investments to improve resilience without explicitly considering their costs or effectiveness. The likely outcome is utility customers paying for resilience at an amount more than either the benefits they receive or the amount they should pay, because of utilities' cost inefficiencies. For example, communicating better with customers during an outage may be less expensive than investing in new distribution hardware.

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66. Harvey Averch & Leland L. Johnson, *Behavior of the Firm Under Regulatory Constraint*, 52 AM. ECON. REV. 1052 (1962).

67. Edward E. Zajac, *Note on 'Gold Plating' or 'Rate Base Padding'*, 3 BELL J. ECON. AND MGMT. SCI. 1, 311-15 (1972).

2. Alternatives to Cost-Benefit Analysis

If a problem exists, what might utilities do? How do we know if improved resilience is net beneficial to society? These questions are tough to answer, especially when relying on conventional cost-benefit analysis. Other analytic approaches may provide a fuller picture.

One of these approaches, break-even analysis, asks the following question: if we know the costs of increasing resilience and the costs of electric outages to customers and society, how large does the probability of an event, combined with the effect of resilience investment on the costs of the event's consequences, have to be to balance benefits and costs? Break-even analysis becomes more valid when there is a high degree of uncertainty over the probability distributions of relevant outcomes. With high uncertainty, even when examining different futures, policymakers have little clue of the probability for each future.[68]

Another strategy would be to expend resources today to mitigate the small chance of a future disaster (i.e., the "fat tail" part of a probability distribution), even when the benefits are highly uncertain.[69] This resembles the earlier-described "min-max" strategy that aims to minimize the maximum harm that can result from an adverse event. Even a "fat tail" approach, however, might lead to underinvestment in resilience. Long-term service interruptions could result in damages far greater than what is presently considered likely. One policy implication is that instead of viewing "resilience" actions as a cost-benefit question, decision-makers should consider them as a form of insurance against a catastrophe that might happen, but with an unknown likelihood.[70] Yet this begs the question of how much utilities should spend in total and for each resilience-improving measure. These are the basic challenges facing both utilities and their regulators.

68. The costs of interruptions itself, of course, would be subject to a high degree of uncertainty. The alternative question then becomes how much would the expected benefits have to be to justify the costs. While the break-even approach is superior to conceding ignorance, it involves much judgment. As an illustration, if the costs to improve resilience is fifty million dollars, the utility can justify the action if it sets a lower-bound estimate of the benefits at a level greater than fifty million dollars. On the other hand, if the utility sets the upper-bound estimate at less than fifty million dollars, the utility should not act, as the benefits could not justify the costs. *See* William P. Zarakas et al., *Utility Investments in Resilience: Balancing Benefits with Cost in an Uncertain Environment*, 27 ELECTRICITY J. 5, 31 (2014); *supra* note 45.

69. See *supra* note 42 and accompanying text for a general discussion of "fat tails."

70. A similar conceptual issue has become part of the discussion over the optimal public policy for climate change. There is one notable difference: as of now, we have not experienced any catastrophic effect from climate change while we have encountered substantial welfare losses from long-term power outages. *See* Robert S. Pindyck, *Fail Tails, Thin Tails, and Climate Change Policy* (Nat'l Bureau of Econ. Research, Working Paper No. 16353, 2010), https://www.nber.org/papers/w16353.pdf [https://perma.cc/AD5R-F6RB].

B. Customer-Driven Approach

A customer-driven approach involves utilities offering customers service-differentiated pricing.[71] Such pricing has the potential to optimize the response to service interruptions by allowing utilities to charge a premium to customers who value uninterruptible service at the highest level. These customers, to the extent technically feasible, will have their service cut off only after the utility interrupted service to other customers.[72] Service-differentiated pricing considers explicitly a customer's WTP.[73] Evidence shows that customers suffer widely varying costs from power interruptions.[74]

For example, some retail customers are very tolerant of variations in power quality and power interruptions, while other customers are less accepting of these conditions. Customers would therefore be willing to pay different amounts for protection against interruptions.[75] One prime example is interruptible rates for customers who are willing to accept less reliable service in return for a lower rate.[76] Critical peak pricing and peak-time rebates also illustrate where customers are willing to tolerate lower reliability for savings on their electricity bills.[77]

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71. Individual electricity customers generally cannot choose their preferred level of resilience. This is because utilities rarely provide differentiated resilience; instead, they provide uniform resilience to their customers with some exceptions. One exception is interruptible service for customers who are willing to accept less reliable service for lower rates. For a discussion of interruptible rates, see SANFORD V. BERG & JOHN TSCHIRHART, NATURAL MONOPOLY REGULATION: PRINCIPLES AND PRACTICE 218 (1988). Another exception is critical customers, who receive preferential treatment during service restoration. *See* Public Utilities Commission of Ohio, *Electric Power Outages: A PUCO Guide to Being Prepared*, https://www.puco.ohio.gov/be-informed/consumer-topics/electric-power-outages-a-puco-guide-to-being-prepared/ [https://perma.cc/L7CH-TN69]; *supra* note 23.

72. One obstacle is the high transaction costs for the utility from providing higher/lower quality service to customers willing to pay more/less. It seems that this would be much more difficult to implement than simple interruptible service—but probably more feasible in view of present and emerging technologies.

73. *See* C.K. Woo et al., *A Review of Electricity Product Differentiation,* 114 APPLIED ENERGY 262 (2014).

74. Michael Sullivan et al., *Estimating Power System Interruption Costs: A Guidebook for Electric Utilities*, LAWRENCE BERKELEY NAT'L LAB. (July 2018), http://eta-publications.lbl.gov/sites/default/files/interruption_cost_estimate_guidebook_final2_9july2018.pdf [https://perma.cc/7SVE-K2EB].

75. But for customers to make efficient decisions, they will need to have some idea of the likelihood of future events that will interrupt electricity service for an extended period. They could acquire an historical record of service interruptions from their utility or base their decisions on personal experiences.

76. For examples of interruptible rates, see *Is-4 Electric Interruptible Service*, MADISON GAS & ELECTRIC CO. (2019), https://www.mge.com/customer-service/for-businesses/electric-rates/is-4-electric-interruptible-service [https://perma.cc/QAC9-HVB5]; and *Schedule No. 38; Noticed Interruptible Power Service*, EL PASO ELECTRIC CO. https://www.epelectric.com/files/html/Rates/TX_Tariff_Schedules/TX_Sch_No._38_Notice_Interruptible.pdf [https://perma.cc/4QC4-KMKP].

77. For examples of critical peak pricing and peak-time rebates see, respectively, *Get to Know Critical Peak Pricing (CPP)*, S. CAL. EDISON (2019), https://www.sce.com/business/rates/cpp [https://perma.cc/B9L7-QJN8]; and *Peak Time Rebates*, PORTLAND GENERAL ELECTRIC, https://www.portlandgeneral.com/residential/energy-savings/peak-time-rebates [https://perma.cc/75G5-KY8G].

In comparison, the central planning, or top-down alternative previously mentioned—whereby a utility makes network-wide investments to increase resilience for all customers—can be extremely expensive. It would also raise a "fairness" issue: those customers who impute a relatively low value on increased resilience would subsidize other customers.

One widely acceptable practice is to minimize service interruptions of critical services. This may require the use of distributed generation and microgrids for essential load like police and gas stations, hospitals, and cell towers, and taking nonessential loads offline. Another action may be to ensure that essential services have backup systems. There are different ways to maintain essential services when power is out, and the most economical ones ought to be part of a "resilience" plan.[78]

Noncritical customers can mitigate the damage from extended outages, in other ways than purchasing insurance from a third party. Many industrial customers who find service interruptions extremely costly have a direct connection to the bulk power system and backup generation. Other customers can purchase a backup generator, solar photovoltaic systems with smart islanding inverters, or install Powerwall batteries.[79] Residential customers can prepare for an outage by buying extra batteries, flashlights, and blankets, and mitigate losses by purchasing surge protectors. Enhancing resilience is therefore a split responsibility between utilities and their customers.[80]

VI. Policy Implications

The overall goal of resilience should be *to minimize the lost value to electric customers and society from service interruptions caused by external natural and human threats, net of costs.* In other words, actions to improve resilience should minimize the social costs from a disruptive event, which requires accounting for both the benefits and costs.

To quantify the social costs with reasonable accuracy, utilities will need to develop new data and models. These additional analytical capabilities can identify areas of greatest risks and system vulnerabilities, allocate resources more efficiently, and help prioritize investments. Research and development for promising technologies and mechanisms, like improvements to control systems and distribution automation, holds the key to improving resilience in the long term.

78. NATIONAL RESEARCH COUNCIL, TERRORISM AND THE ELECTRIC POWER DELIVERY SYSTEM Ch. 8 (2012), https://www.nap.edu/read/12050/chapter/8 [https://perma.cc/8J8R-N73C].

79. *See Battery Backup Power*, REVISION ENERGY (2019) https://www.revisionenergy.com/solar-power-for-your-home/battery-backup [https://perma.cc/4VHY-NV22].

80. *See Be Prepared for a Power Outage*, FEMA (May 2018), https://www.fema.gov/media-library-data/1527865875064-7a5a439a4714d4bb8d553294e0023d2b/PowerOutage_May2018.pdf [https://perma.cc/WGK7-YWKG].

Achieving socially optimal resilience poses more of a challenge for utilities and their regulators than reliability does. Resilience covers a wider array of diverse activities, and its benefits are more uncertain. Undertaking a cost-benefit analysis to evaluate different actions is more specious for resilience than for reliability. For example, reliability concerns are more accurately described as risks. The likelihood of inadequate capacity to meet demand is derivable from historical data. Reliability is also more precisely measurable and is less ambiguous in its definition.

To wit, a fundamental problem in developing policies that guide utility resilience investments is the lack of a consensus on the definition of resilience and deficiencies in measuring and assessing resilience on various scales. Experts and other observers disagree over the scope of resilience: should it include only actions to restore power service or does it encompass avoiding service interruptions as well? This Essay supports the latter definition.

A customer-driven approach with service-differentiated pricing is the most promising path to pursue if one wants to know how much customers are willing to pay for resilience. But because of the external benefits like macroeconomic effects, public health and safety from higher resilience, and the technical and political difficulty for a utility to differentiate services across individual customers, it would be ill-advised to rely on market forces alone to achieve a socially optimal outcome.

One important function of public utility regulators is to identify any undue barriers to enhancing resilience and those actions that can most cost-effectively eliminate or mitigate them. Such barriers exist when (1) they cause economically inefficient and socially harmful outcomes, and (2) their mitigation passes a cost-benefit test, making them amenable to public-policy intervention. One possible barrier derives from the perception that utilities could expend substantial money on enhancing resilience with the benefits only realized after a major event. Trying to quantify those benefits prior to investments is extremely difficult: what is the probability that customers will realize benefits, when will they realize them, what are the chances of a major event occurring, and how much do customers benefit when a major event occurs? It would seem hard for a utility to justify expenditures on resilience to a regulator, especially when trying to compare them with the expected benefits to its customers.

With utilities strongly motivated to enhance resilience—perhaps excessively—regulators face two tasks attuned with the public interest. The first is to make sure that utilities implement the most cost-effective actions. The second is to prevent utilities from "gold-plating" their rate base.

In closing, in an ideal world, utilities could justify proposed "resilience" actions by making demonstrated and verifiable benefits at the least cost. But since this is next to impossible, decisions affecting resilience require subjective judgment by utilities and their regulators—more so than for decisions relating to reliability. This implies that any action relies heavily on the decision-maker's judgment devoid of precise or even reasonably accurate quantification. Utilities (and regulators) need to prioritize "resilience" actions despite the absence of useful estimates of benefits or cost effectiveness.