NARUC
National Association of Regulatory Utility Commissioners

Energy Resilience Reference Guide

Chapter One: Developing A Shared Definition of Energy Resilience

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Disclaimer

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Introduction to NARUC Resilience Reference Guide

The NARUC Resilience Reference Guide is envisioned as a one-stop primer for state public utility commissions (PUCs) to assist in the development of a shared language, valuation framework, and educational tool on the topic of energy resilience. The resilience of the energy system has increasingly become part of commissions' regulatory scope so informed decisions are made regarding how to best enhance system resiliency. Several states have already established evaluative resilience criteria (via legislative statute or regulatory directive). This guide is intended to summarize many of the critical topic areas within energy resilience and to facilitate adoption of resilience valuation frameworks by which PUCs can weigh investment decisions regarding energy system resiliency. This guide is intended to encourage state public utility commissions to develop their own frameworks that align with existing resources and to provide topical information related to enhancing system resilience to extreme weather, cyber-attacks, a changing energy landscape, and other threats to critical infrastructure. This guide will also assist in continual assessment of new policies and regulations that seek to enhance energy system resilience.

This primer attempts to synthesize key takeaways on energy resilience topics. Individual chapters will highlight emerging best practices on a variety of topics, profile individual state efforts at enhancing system resilience, solicit contributions from subject matter experts, and summarize key regulatory considerations for energy system resilience.

The objective of the first chapter of the NARUC Resilience Reference Guide is to highlight challenges pertaining to differences in definitions of resilience and encourage state public utility commissions to develop a shared language around the concept of energy resilience.

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Chapter 1: Developing a Shared Definition of Energy Resilience

Modern society is increasingly reliant on infrastructure systems that supply and deliver natural gas, water, electric, and telecommunication services to function properly. This infrastructure was initially planned, designed, built, and operated around the concept of reliability, ensuring constant service with an acceptable level of interruption. The appropriate level of reliability is heavily determined by regulatory and policy decisions at the federal and state levels. Regulatory approaches and corresponding metrics for maintaining reliability have generally been well-established, focused on system preparedness to operate through routine, recurring challenges.[i] There is ample literature and data on the economic and societal effects of recent infrastructure interruptions. Regulators could benefit from additional frameworks, strategies, and metrics by which to evaluate investments aimed at bolstering resilience in the energy system.

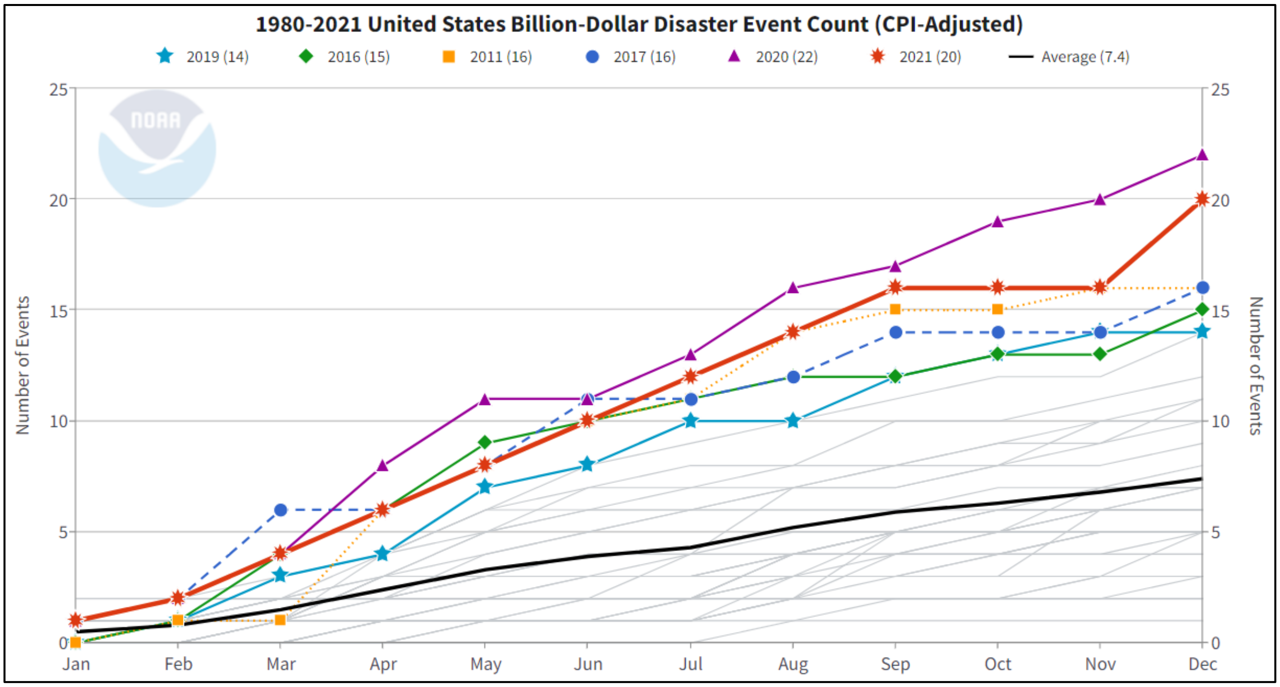
Resilience, a term that closely relates to reliability, has gained attention from regulators, policymakers, and stakeholders over the past decade, largely due to the increasingly frequent, human-induced and extreme weather events that impact society and the economy (Table 1).

Table 1: Event Categories and Examples

Type of Event	Subcategory	Examples
Human Induced	Physical Attack	Metcalf Substation Sniper Attack; California (2013)
	Cyber Attack	Colonial Pipeline Disruption; Eastern United States (2021)
	Operator Error / Human Performance	Switching error; Arizona, Southern California (2011)
	Supply Chain Issues	New England LNG shortage; Massachusetts (2012)
Extreme Weather / Natural Disaster	Drought/ Heat Wave	Reduced electricity generation due to high cooling water temperatures; Texas (2012)[ii]
	Earthquake	1994 Northridge earthquake; California (1994)
	Flood	Watson Flooding; Louisiana (2016)
	Hurricane	Hurricane Ida; FEMA regions 1-6 (2021)
	Ice Storm	Winter Storm Uri; Texas (2021)
	Pandemic	COVID-19 (2020)
	Tornadoes / Regional Storm	Tornado outbreak; Kentucky, Illinois, Arkansas, Missouri (December 2021)
	Tsunami	N/A
	Wildfire	Paradise California wildfires; California (2018)

According to the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information, "…in 2021, there were 20 weather/climate disaster events with losses exceeding $1 billion each…the 1980–2021 annual average is 7.7 billion dollar events (CPI-adjusted); the annual average for the most recent 5 years (2017–2021) is 17.8 events (CPI-adjusted)."[iii] Figure 1 further demonstrates the month-by-month accumulation of billion-dollar disasters for each year on record, with the colored lines representing the top 6 years.[iv]

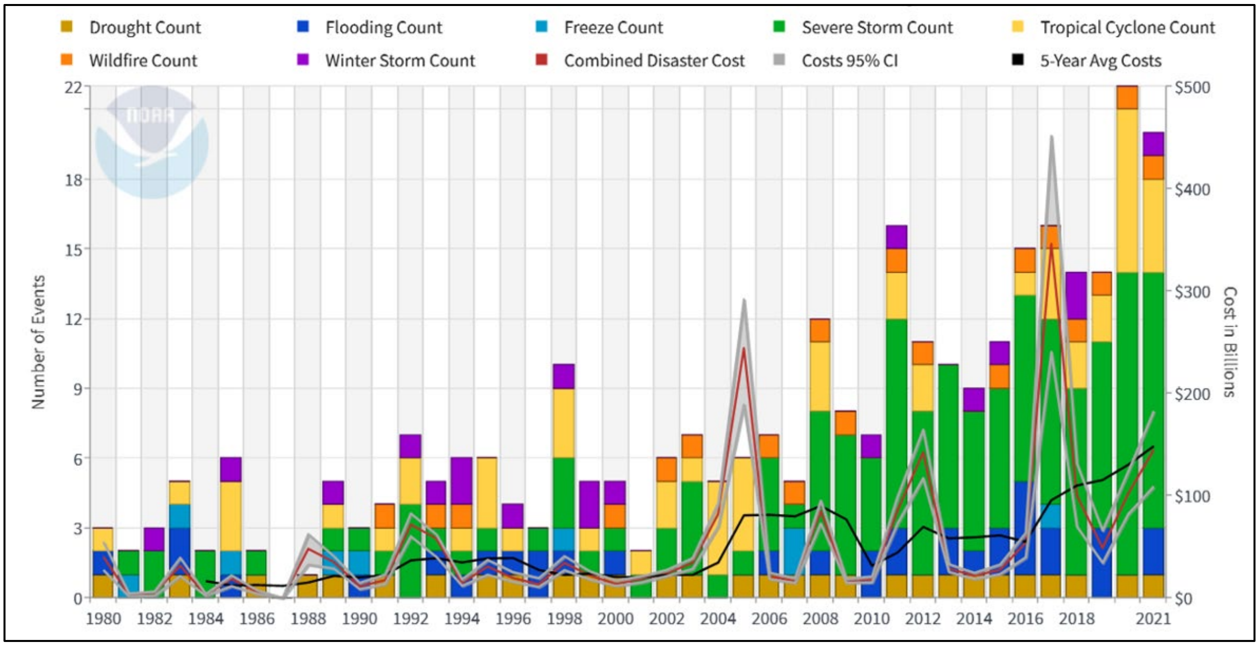
Figure 1: 1980-2021 United States Billion-Dollar Disaster Event Count (CPI-Adjusted)



The data indicates that extreme weather events are increasing in frequency, severity, and economic impact. The monetary costs are especially concerning, since nearly all economic activities are essentially halted when electricity service is interrupted—particularly after longer-term (4+ hour) outages.[v] Electrical outages have additional impacts on the availability of other utility sectors and services, including water and natural gas delivery systems. The telecommunication sector—particularly internet and cell phone service—are also dependent on reliable the delivery of electricity.

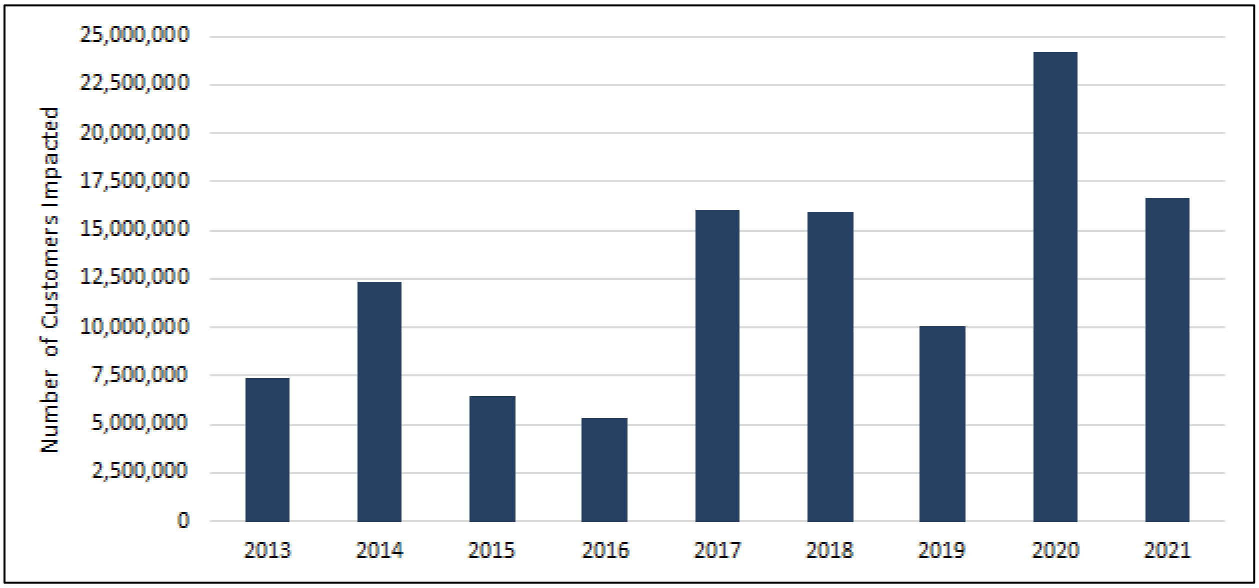
Extreme weather events are trending upward at a time when ongoing technological advancements are increasing consumer dependence on consistent and reliable service.[vi] According to the International Energy Agency, "…the Covid-19 pandemic reminds us of the critical importance of electricity in all aspects of our lives, such as keeping medical equipment working in hospitals and IT systems available for teleworking and video conferencing. The impacts of an extended outage go far beyond the power system or the value of the lost energy…"[vii] In 2020 alone, hurricanes, heatwaves, windstorms, wildfires, and other events resulted in electric utility customers experiencing 1.33 billion outage hours, up 73 percent from 2019.[viii] Concurrently, residential electricity consumption in the United States "…increased slightly in 2020 as states began to announce stay-at-home guidance in response to the COVID-19 pandemic."[ix] Analysis by the National Bureau of Economic Research reinforced this trend, finding that "Americans spent $6 billion more on at-home power consumption from April to July 2020 than during normal times, nearly offsetting a decline in business and industrial demand."[x] This demonstrates the importance of a resilience grid to serve America's growing reliance on electricity – particularly for the residential customer class.

Figure 2: U.S. Billion-Dollar Disaster Events, 1980-2021 (CPI-Adjusted)



The data shown in Figure 2 is somewhat correlated with the actual impacts on electricity service. According to U.S. Department of Energy's Electric Emergency Incident and Disturbance Reports (Form OE-417), four of the past five years have shown the highest numbers of customer outages due to either extreme weather or natural disasters (Figure 1).

Figure 3: Number of Customer Outages Due to Severe Weather or Natural Disasters[xi]

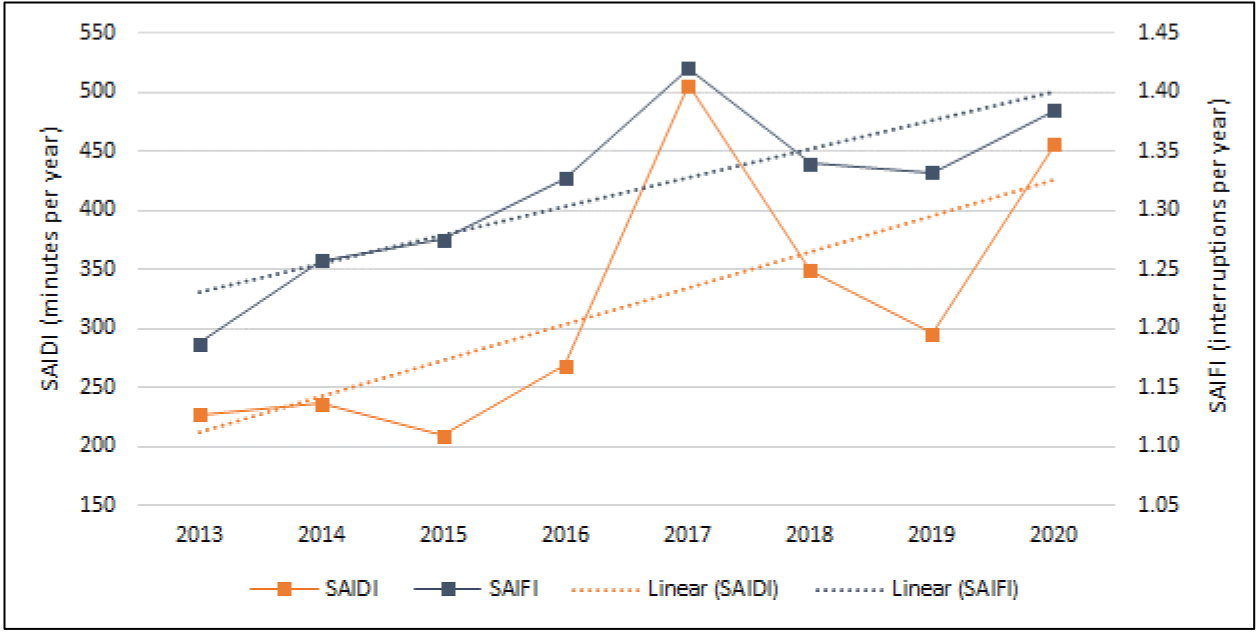


Similarly, the two primary metrics to assess the frequency (SAIFI) and duration (SAIDI) of outages has also been trending upward (Figure 2). These two metrics are defined below:

- **SAIFI**: SAIFI: System Average Interruption Frequency Index. It is the number of non-momentary electric interruptions, per year, the average customer experienced.

- **SAIDI**: System Average Interruption Duration Index. It is the minutes of non-momentary electric interruptions, per year, the average customer experienced.

Figure 4: SAIDI and SAIFI Values for the U.S. Distribution System, 2013 – 2020



These trends further underscore the importance of establishing a common understanding and framework of resilience in the regulatory community to inform future investment decisions across all sectors. This will allow for the subsequent development of common tools, metrics, and other methods for valuing resilience. During the past decade, several definitions have been proposed for the electricity sector with a common theme that can also be applied to the gas, water, and telecommunication sectors (Table 2).

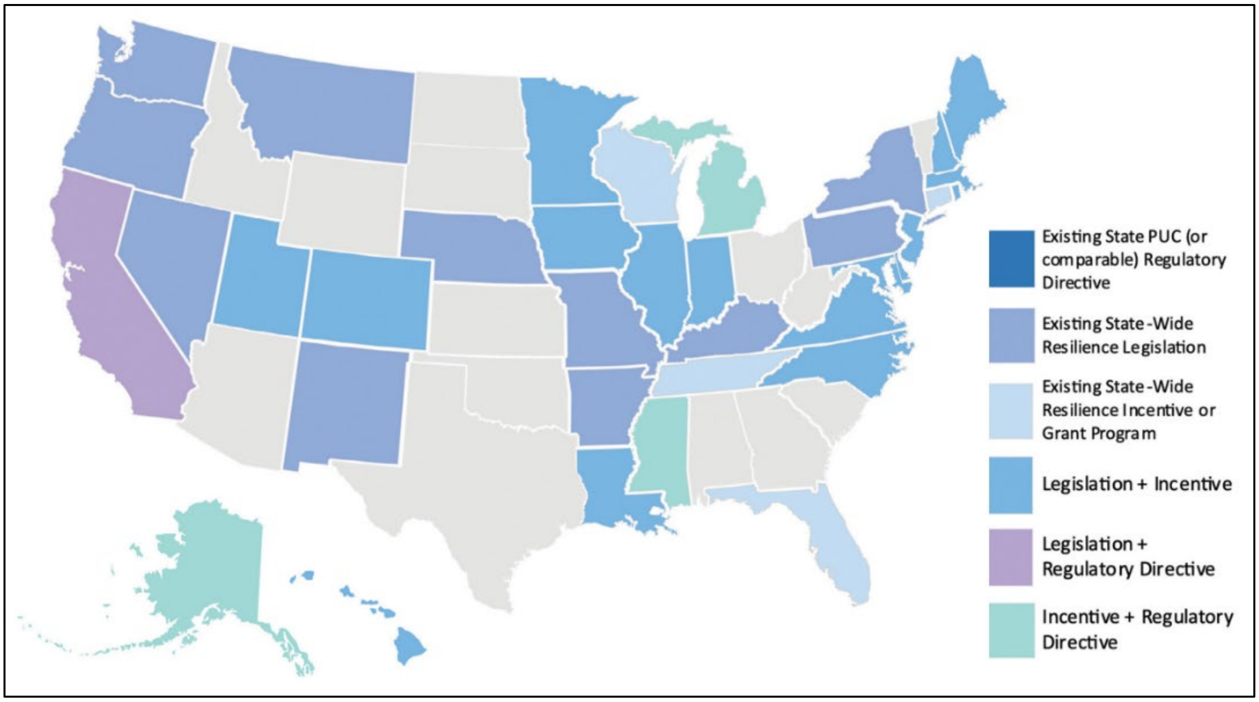
Table 2: List of Resilience Definitions

Authority / Publishing Entity	Definition	Source / Year
NARUC	"Robustness and recovery characteristics of utility infrastructure and operations, which avoid or minimize interruptions of service during an extraordinary and hazardous event."	Resilience in Regulated Utilities – Keogh & Cody, 2013
Federal Energy Regulatory Commission (FERC)[xii]	"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 recover from such an event."	Order 162 ¶ 61,012 – FERC, 2018
Presidential Policy Directive Critical Infrastructure Security and Resilience (PPD) 21	"The ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents."	PPD-21: Critical Infrastructure Security and Resilience – Obama White House, 2013

National Renewable Energy Laboratory (NREL)	"The ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions through adaptable and holistic planning and technical solutions."	Resilience Roadmap: A Collaborative Approach to Multi-Jurisdictional Resilience Planning – Hotchkiss & Dane, 2019
Electric Power Research Institute (EPRI)	"In the context of the power system, resiliency includes the ability to harden the system against—and quickly recover from—high-impact, low-frequency events."	Electric Power System Resiliency: Challenges and Opportunities, 2016
PJM Interconnection	"Resilience, in the context of the bulk electric system, relates to preparing for, operating through and recovering from a high-impact, low-frequency event. Resilience is remaining reliable even during these events."	Evolving Resource Mix and System Reliability, 2017
National Academies of Sciences, Engineering, and Medicine (NASEM)	"Resilience is not just about lessening the likelihood that that these outages will occur. It is also about limiting the scope and impact of outages when they do occur, restoring power rapidly afterwards, and learning from these experiences to better deal with the events in the future."	Enhancing the Resilience of the Nation's Electricity System, 2017
National Governors Association (NGA) / National Association of State Energy Officials (NASEO)	"The ability to withstand disasters better, respond effectively, and recover more quickly and to a more improved state."	State Governance, Planning, and Financing to Enhance Energy Resilience, 2021

The definitions above have a shared common element: focusing on enhancing infrastructure systems to not only operate reliably under normal conditions, but also adapt, withstand, and more rapidly recover from a growing number of high-impact, low frequency (HILF) events. Even with varying resilience definitions, many public utility commissions (PUCs) and state energy authorities are utilizing a range of resilience investments and initiatives to harden infrastructure. EPRI has tracked these developments (Figure 5).

Figure 5: U.S. State-Level Resilience Activities (EPRI, 2021)[xiii]



State resilience initiatives often involve examining risks and potential impacts of man-made and natural hazards to identify which investments will have the largest impact on either protecting or more aptly responding to vulnerabilities, usually based on a wide range of scenarios. This may be informed by an examination of data on the economic and societal impacts that resulted in interruptions to various utility services. The Department of Energy has also developed Energy Risk Profiles for each U.S. state and FEMA Region that offers additional insights into the energy infrastructure landscape, potential energy system disruptions, and the impact and frequency of those disruptions.[xiv]

In the absence of a consistent definition and framework for resilience, state legislators and commissions have more recently developed a range of programs focused on maintaining or improving electric grid reliability, by investing in "…hardware and software, vegetation management, human capital, and customer-side measures."[xv]

Therefore, it's important to review the existing reliability concepts and approaches, recognizing that reliability metrics vary significantly by sector, geography, and specific system attributes. In the electricity sector, the North American Electric Reliability Corporation (NERC) defines reliability by separating it into two categories.[xvi]

- **Adequacy**. The ability of the electricity system to supply the aggregate electrical demand and energy requirements of the end-use customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements.
- **Operating reliability**. The ability of the bulk power system to withstand sudden disturbances, such as electric short circuits or the unanticipated loss of system elements from credible contingencies, while avoiding uncontrolled cascading blackouts or damage to equipment.

State and federal regulatory and policy decisions have generally been centered around maintaining reliable service across all sectors. Currently, infrastructure resilience is essentially a “built-in” externality of adhering to established planning and operating practices designed to achieve a reliable system. The electricity grid is particularly demonstrative of this, as it is operated around reliability standards that require enough reserve capacity to maintain service to customers, even if the single largest component (transmission line or power plant) fails.[xvii] Similarly, from long-term planning perspective, the industry builds or procures enough capacity to serve at least 10 percent more demand than is forecasted, as measured by NERC’s primary reliability metric, the Reserve Margin. [xviii]

The three interconnected grids in the U.S. were also built with redundant paths and operate with high levels of fuel diversity in most regions. Therefore, fuel supply interruptions will only impact a portion of a region’s generation fleet. According to NERC, “Maintaining fuel diversity provides inherent resiliency to common-mode risk.”[xix] Conceptually, existing industry practices promote system reliability by addressing high-frequency, low-impact events stemming from outages and disruptions under routine operating conditions.[xx] Adhering to these practices, as well as regional reliability criteria achieves some level of resilience. However, a recent upswing in extreme weather events (discussed above) has heightened awareness among regulators and policymakers for a need to go beyond maintaining reliability and invest in infrastructure system resilience.

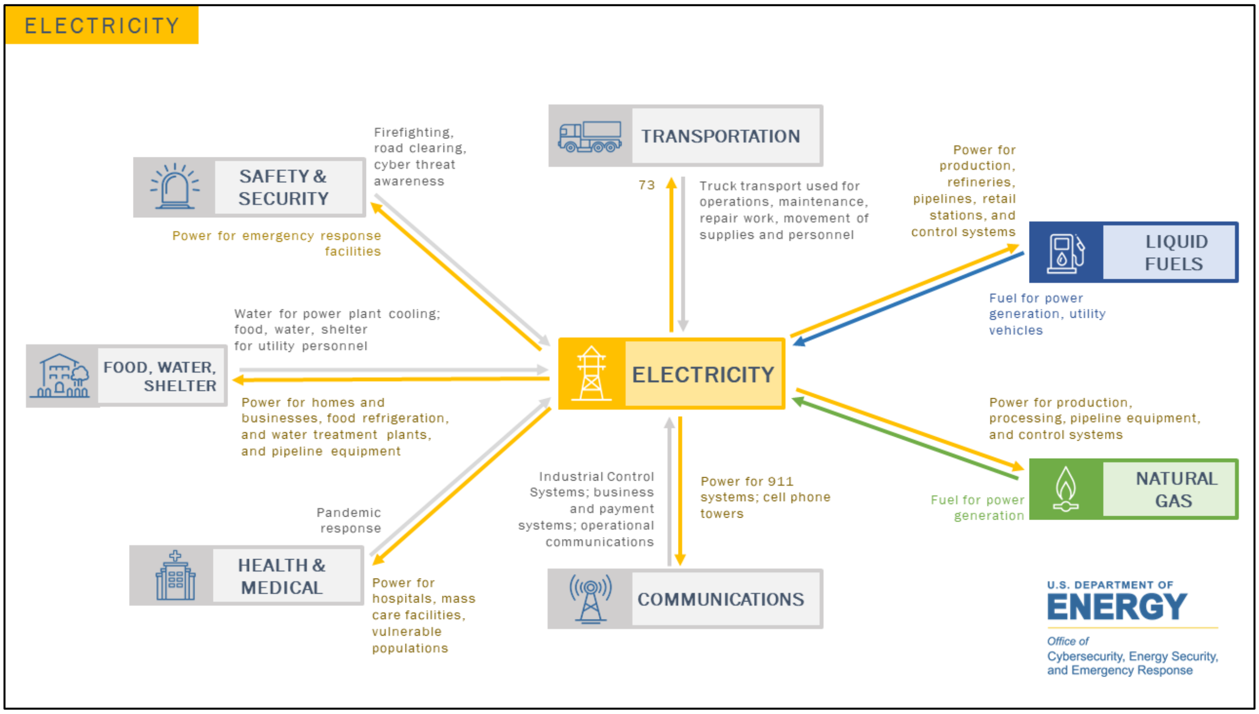
State policymakers and public utility commissions (PUCs) are largely responsible for determining public and private investments across the gas, water, electric, and telecommunication sectors. This includes ratemaking authority with consideration for potential investments—including potential costs towards improving system resilience. Resilience investment decisions require a thorough understanding of the two complex inputs: 1.) the costs of a long-duration outage in the absence of the investment; and 2.) the potential impacts (benefits) of the infrastructure investment under consideration. The costs of a long-term electrical outage may include societal impacts (number of lives lost, economic costs, and value of lost load for residential, industrial, and commercial customer classes). Policymakers must also consider the direct and indirect impacts on other sectors (gas, water, telecommunications) that are increasingly interdependent. Some examples of these interdependencies are included in Table 3.

Table 3: Infrastructure Sector Resilience Interdependencies

		Impact to Other Sector			
		Gas	**Electricity**	**Water**	**Telecommunications**
Outage Type	**Gas**	N/A	Loss of fuel supply to gas-fired power plants	Loss of supply to residential gas for water heaters	Loss of supply for electricity & potential cascading outages
	Electric	Loss of electric supply to pipeline compressor stations	N/A	Loss of power to pumping stations, water treatment facility, or wastewater plant	Loss of electricity for cell-phone towers & data centers
	Water	N/A	Potential loss of cooling water	N/A	Potential loss of cooling water for data centers

	Telecommunications	Inability to communicate with gas pipeline operator	Inability to communicate with system operator, loss of situational awareness, loss of control systems	Inability to communicate with water network	Emergency situations are particularly reliant on communication for coordination efforts

Figure 6: Electricity Sector Resilience Interdependencies (DOE CESER, 2022)



Additional factors impacting prudent infrastructure investment decisions are shown in Table 4.

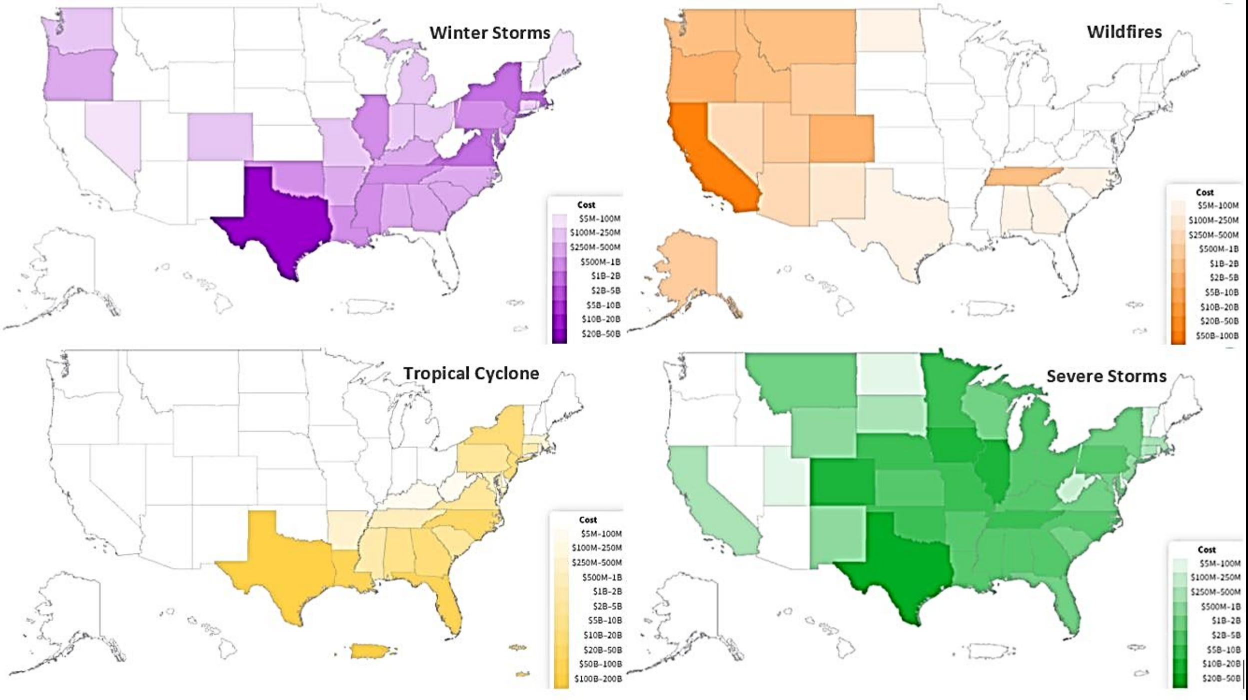
Table 4: Factors in Making Resilience Investment Decisions

Factor	Assessment
Regionality Geographic Region	Risk vary by geographic region (e.g., hurricanes occur in the Southeast U.S. and not in the Northwest U.S.); examine frequency / impact of recent extreme weather events and natural disasters- and projected / future
Reliability/Integrity of Existing System or System Components	Determine how reliable the existing system is by examining performance during recent events; review existing plans to upgrade system components
Mitigation vs. Responsive	Quantify potential benefits of investments to protect a system from future events vs. investments to more quickly respond after an event
Interdependencies	Evaluate the potential impacts of the loss of one sector on another (e.g., the loss of electricity on the natural gas pipeline delivery system)
Project Costs	Examine how much a resilience project will costs to complete, operate, and maintain throughout its operational life.
Impact	Determine the overall impact of a resilience project through cost-benefit analysis with various scenarios that examine a range of severity and frequency of potential events.
Timeline	Anticipated timeline for impacts from physical, climate, or cyber threats.

Consequence Prioritization	Investments in enhancing system resilience will be prioritized based on greatest threats and needs. Most important functions and assets that support core mission will be addressed first.

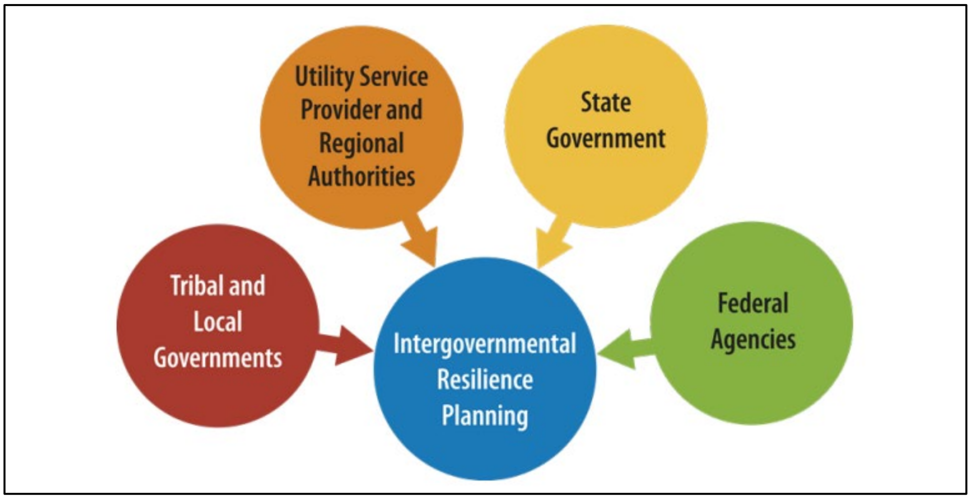
The economic and societal impacts of natural disasters affecting infrastructure vary across the country, as will the associated costs and benefits of potential resilience investments. Although Federal initiatives can help create uniform approaches, there is no one-size-fits-all solution for improving resilience across the country. However, there are common approaches that can be used for disaster types and common-mode failures. Specifically, cyber threats can be ubiquitous and similar natural disasters (e.g., floods) can be addressed with similar resilience-related approaches throughout across the country. Infrastructure systems do not adhere to political boundaries and the impacts of extreme weather events, cyber and physical threats, and other vulnerabilities require coordination between various jurisdictions. However, utility regulators and policymakers are well-positioned to identify and address vulnerabilities unique to their state. The maps below demonstrate the susceptibility of each state to various types of natural disasters, and why potential resilience investments vary geographically (Figure 6).

Figure 7: State Cost and Frequency, 2013-2021[xxi]



As more state-specific proceedings and legislation are aimed at addressing resilience on a state-by-state basis, it is also important that there is ample coordination across regions that share similar goals. For example, the NARUC regional associations[xxii] and NERC's Reliability Issues Steering Committee (RISC) are forums where the regulatory community can discuss state and regional initiatives to address associated geographic risks. The Infrastructure Investment and Jobs Acts (IIJA) includes new language for coordination around regional security. State energy plans can also be modified and updated by State Energy Offices to reflect the changing risks to infrastructure reliability and resilience. The National Renewable Energy Laboratory (NREL) has examined this issue, highlighting the need to identify shared regional infrastructure interdependencies and vulnerabilities to yield "a more robust set of resilience strategies."[xxiii] To achieve this, NREL has developed a strategic framework for collaboration with the involvement of federal agencies, state governments, and local communities to assess and plan for regionally specific vulnerabilities and interdependencies (Figure 8).

Figure 8: Intergovernmental & Multi-jurisdictional Planning Roadmap for Resilient Infrastructure Systems[1]



The regulatory community (and the sectors they regulate) will benefit from more robust sharing of approaches and frameworks for evaluating potential resilience investments, leading to more informed decisions. This includes the development of metrics to analyze the capital expenditures compared to the potential benefits of an investment to harden infrastructure. Comparative measurements and metrics will also inform regulators' understanding of the different investment impacts throughout the country and allow for benchmarking of progress towards more resilient infrastructure systems. This manual will explore various options.

Resilience Questions Facing the Regulatory Community

- Can existing reliability metrics be adjusted or enhanced to improve system resilience?
- How will the continued onset of DERs and microgrids impact both reliability and resilience?
- Could the approach for reserve planning and contingency reserves be reexamined and potentially modified to improve overall system resilience?
- How can the impacts to interdependent sectors (gas, water, electric) be factored into decisions on electricity resilience investments?
- Can the strategic advancement of microgrids improve resilience?
- How can regulators assess potential costs of system damage caused by extreme weather?
- How can regulators measure the preventative investments under consideration, compared to the potential recovery costs from another event (cost-benefit analysis)?
- How are customer costs of past power interruptions measured?
- How are you factoring in climate change forecasts for your service area and consumer base into planning approaches for siting new assets?

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[1] https://www.nrel.gov/docs/fy19osti/73509.pdf. P. 5.

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[i] https://pubs.naruc.org/pub/1B571AB6-1866-DAAC-99FB-2509F05E4A67. P. 4. Reliability metrics are continuing to evolve. For examples, the ongoing transformation towards a carbon-free electricity sector will warrant updated reliability metrics that can measure and maintain a level of reliability that is commensurate to the operational characteristics of renewable resources. Similarly, the addition of over 35 GW of natural gas power plants between 2015 and 2019 have led to FERC's Orders (Nos. 787 and 809) that modified information sharing and operational dispatch timelines to promote reliability.

[ii] https://www.sciencedirect.com/science/article/pii/S2352484715000323.

[iii] https://www.ncei.noaa.gov/access/monitoring/billions/.

[iv] https://www.climate.gov/news-features/blogs/beyond-data/2021-us-billion-dollar-weather-and-climate-disasters-historical.

[v] Holmgren, AJ. (2007). "A framework for vulnerability assessment of electric power systems," in Critical Infrastructure Reliability and Vulnerability, eds Murray A. and Grubesic T. (Berlin: Springer-Verlag), 31–55.

[vi] National Academy of Sciences. "Enhancing the Resilience of the Nation's Electricity System." P. 8. (https://www.nap.edu/24836).

[vii] https://www.iea.org/reports/power-systems-in-transition/electricity-security-matters-more-than-ever.

[viii] https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/us-power-outages-jumped-73-in-2020-amid-extreme-weather-events-62181994.

[ix] Energy Information Administration. Today in Energy: "Despite more people staying at home, U.S. residential energy use fell 4% in 2020." May 17, 2021. (https://www.eia.gov/todayinenergy/detail.php?id=47976).

[x] The National Bureau of Economic Research. "Working from Home's Impact on Electricity Use in the Pandemic." The Digest: NO. 12. December 2020. (https://www.nber.org/digest-202012/working-homes-impact-electricity-use-pandemic).

[xi] Form OE-417. Event categories have been inconsistent between 2013 and 2021. Analysis performed by NARUC staff was intended to promote consistency in event type to include only outages caused by weather and natural disasters. OE-417 has specific requirements regarding duration. According to the EIA: "Electric utilities that operate as Control Area Operators and/or Reliability Authorities as well as other electric utilities, as appropriate, are required to file the form. The form is a mandatory filing whenever an electrical incident or disturbance is sufficiently large enough to cross the reporting thresholds. Reporting coverage for the Form DOE-417 includes all 50 States, the District of Columbia, Puerto Rico, the U.S. Virgin Islands, and the U.S. Trust Territories." (https://www.oe.netl.doe.gov/OE417_annual_summary.aspx).

[xii] The North American Electric Reliability Corporation (NERC) and the National Infrastructure Advisory Council (NIAC) adopted FERC's definition.

[xiii] Electric Power Research Institute (EPRI). (2021). "Value of Resilience White Paper." Washington, DC. (www.epri.com/research/sectors/technology/results/3002020795).

[xiv] https://www.energy.gov/ceser/state-and-regional-energy-risk-profiles.

[xv] https://pubs.naruc.org/pub/1B571AB6-1866-DAAC-99FB-2509F05E4A67.

[xvi] https://www.nerc.com/AboutNERC/Documents/NERC%20FAQs%20AUG13.pdf.

[xvii] Power system reliability is well-defined and enforced by mandatory reliability standards. The North American Electric Reliability Corporation (NERC) defines bulk-power system reliability as the ability to "meet the electricity needs of end-use customers even when unexpected equipment failures or other factors reduce the amount of available electricity." NERC's reliability standards establish requirements for designing, planning, and operating the bulk power system. NERC reliability standards also address cyber and physical risks, and well as cold weather preparation (not enforceable yet). www.nerc.com/pa/Stand/Project%202010141%20%20Phase%201%20of%20Balancing%20Authority%20Re/Project2010-14-1BAL-002-2Standard-Clean-20131015.pdf.

[xviii] "[The] Planning reserve margin is designed to measure the amount of generation capacity available to meet expected demand in planning horizon. Coupled with probabilistic analysis, calculated planning reserve margins

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have been an industry standard used by planners for decades as a relative indication of adequacy." (https://www.nerc.com/pa/RAPA/ri/Pages/PlanningReserveMargin.aspx).

[xix] North American Electric Reliability Council (NERC). 2016 Long-Term Reliability Assessment. P. 16. December 2016 (https://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/2016%20Long-Term%20Reliability%20Assessment.pdf).

[xx] https://bipartisanpolicy.org/download/?file=/wp-content/uploads/2019/03/BPC-Energy-Power-System-Resilience-Primer.pdf.

[xxi] https://www.ncei.noaa.gov/access/monitoring/billions/mapping.

[xxii] https://www.naruc.org/meetings-and-events/regionals/.

[xxiii] https://www.nrel.gov/docs/fy19osti/73509.pdf. P. 5.