DYNAMO
ACCELERATING ENERGY INNOVATION

Electric power sector faces a changing climate: path to resilience

Executive Summary

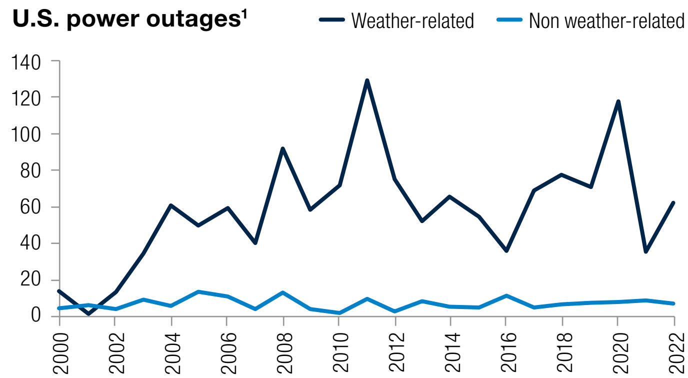
In the face of accelerating electrification, the resilience of the electric power system emerges as a pivotal concern. The contemporary landscape demands an unprecedented level of reliability, with societal expectations gravitating towards 100% availability of electricity. At the same time, the repercussions of outages are increasingly disruptive and economically impactful, particularly in the context of expanding electrification of transportation sector and industrial processes. As the dependence on the electric power system deepens, it becomes imperative for the system to seamlessly navigate both routine and exceptional operational shocks, including those stemming from weather anomalies, cybersecurity threats, pandemics, and other disruptions.

Increasing frequency and severity of weather events is a growing threat to the electric power system. The most recent U.S. government's annual National Climate Assessment shows that disasters causing at least $1 billion in damage now occur every three weeks on average in the U.S., compared to once every four months during the 1980s.[1] Utility outage data shows a similar trend, with outages due to extreme weather increasing by 68% between 2012-2022 as compared to the decade prior (2002-2012).[2]

Utilities across the country have been investing in grid hardening in efforts to improve response during major weather events, with several major utilities investing more than a billion dollars a year to manage climate risks. Utility outage performance during major weather events has improved by roughly 7% in the last 20 years,[3] but this improvement is insufficient to keep up with the changes in climate.

In addition to societal impacts of loss of power, climate risks are a financial threat to energy companies. Wildfires are widely recognized by the electric power industry as a significant challenge to the utility business model, as investors and insurance companies are concerned about potential liabilities. Wildfires, however, are not the only climate risk that can translate to a direct financial threat to energy companies. For example, Texas winter storm Uri had significant financial consequences for power producers and retailers, who faced soaring wholesale prices and market imbalances. Winter storm Uri was a primary restructuring catalyst for at least 8 companies that filed for bankruptcy protection within six months of the storm to restructure more than $3.5 billion in outstanding debt.[4] Financial health of companies in the electric power space is critical for energy transition, making climate resilience essential for achieving broader decarbonization goals.

U.S. power outages[1]



An extreme weather event can lead to multiple adverse effects within electric power value chain

Weather Event	Downstream Effects on Energy Markets	Impact Metrics
Aug. 2023 **Maui Wildfire**	• 90 miles an hour winds resulting from Hurricane Dora 500 miles ripped across the island • Ignition of parched grasses and brush outside of Lahaina soon erupted into a fast-moving wildfire, stoked by the intense winds	**100** confirmed deaths and 2000+ acres burned [2]
Dec. 2022 **Winter Storm Elliot**	• Caused extensive power outages due to unexpected plant equipment failure and fuel supply issues • Triggered potential financial liabilities for power plant owners in PJM Interconnection • Highlighted the vulnerability and reliability of gas-fired generators	**$2B** penalties faced by PJM generators for failing to run[3]
Sep. 2022 **Hurricane Ian**	• Made landfall as a Category 4 storm in southwestern Florida before continuing on to South Carolina and North Carolina • Third costliest hurricane in US history (after Katrina and Harvey) • In addition to billions in damages, it claimed more than 100 lives	**$116.3B** in adjusted costs of damages caused by Ian[4]
Feb. 2021 **Winter Storm Uri**	• Triggered widespread power outages due to freezing of natural gas infrastructure • Caused spike in electricity and natural gas prices • Bankrupted several energy companies unable to cover high wholesale electricity costs	**$195B** estimated damages from storm impact[5]
Aug. 2020 **California Heatwave**	• Caused rolling blackouts due to high demand for air conditioning • Highlighted need for additional grid flexibility and reliability • Drove temporary electricity price spikes	**>$1,000** CAISO wholesale electricityprice/MWh at peak[6]

1. *Climate Change's $150 Billion Hit to the U.S. Economy - WSJ*
2. *DOE form OE-417 data analysis*
3. *DOE form OE-417 data analysis*
4. *A&M analysis, includes Chapter 11 filings by Brazos Electric Power Cooperative, Inc.; Just Energy Group; Griddy Energy LLC; Brilliant Energy, LLC; Entrust Energy Inc; Liberty Power Holdings, LLC; Agilon Energy Holdings II LLC; Pogo Energy, LLC*

The ongoing push for reliability and resilience within the electric system is a megatrend that will continue to shape the industry going forward. The size of resilience effort for the industry is staggering both in terms of scope and costs. Resilience requires supply-side resource adequacy, significant additions and replacements to the transmission and distribution grid infrastructure, demand-side customer resources and adaptation solutions at community scale. Resilience is also complex because the target is constantly moving. Our lived history is not representative of the future when it comes to climate, making effective climate adaptation strategy and planning difficult.

The push for resilience requires significant deployment of technology. The backbone of climate adaptation is data that can then be used to drive strategy development, planning, event response and recovery. Climate adaptation has been an impetus for innovation in real-time sensing, as well as technology required to collect, aggregate and analyze the data. This trend is prevalent in such applications as climate risk modeling, weather prediction, asset management and operational situational awareness. Resilience is also a driver for increased demand for materials and equipment across the electric power value chain - poles, wires, transformers, inverters, microgrid controllers, batteries and the like.

The megatrend for reliability and resilience is occurring alongside another megatrend: the growth of the grid to enable electrification of buildings, mobility and some industrial energy needs. The Electric Power Research Institute (EPRI) has estimated that the capacity of the grid needs to increase as much as five times for United States to achieve net-zero carbon by 2025.[5] This capacity expansion is likely to include both scaling traditional types of grid infrastructure as well as integrating distributed resources into grid operations. Seen in this light, ensuring future resilience will be an exercise in both asset hardening and system design.

The growing market for resilience solutions includes several distinct customer groups with evolving needs that have a role to play in resilience: energy companies, electric power customers and governments. The key questions are *what asset and system resilience solutions will emerge, how much they will cost and who will shoulder the financial burden.* The conventional method of relying on regulated utilities to address all electric-related challenges is untenable given the mounting pressure on rates.

In the short term, some electric power consumers are likely to take matters into their own hands, investing in backup generators, solar power, and storage solutions. While such initiatives may alleviate certain outage-related impacts, greater coordination between the public and private sectors is needed to avert more substantial threats to public safety and economic activity and to protect vulnerable communities. Developing resilient communities involves innovating approaches to conceptualize and finance climate adaptation projects with broad societal co-benefits. For example, the deployment of renewable energy, in combination with microgrids and storage, can minimize impact from power outages and simultaneously reduce carbon emissions. Similarly, reducing the risk of catastrophic wildfires has co-benefits between public safety and avoiding significant carbon emissions from megafires.

The most cost-effective way to increase resilience will be to capture resilience value from new and existing infrastructure. To make business cases for resilience work, we need to pool benefit streams together. Accomplishing this will require navigating across both built environment and social systems, such as capturing load flexibility benefits of e-bus charging depots or leveraging public buildings for distributed generation. Stakeholders, including innovators and investors in this space, should adopt a comprehensive perspective, actively seeking opportunities to facilitate the design of solutions and projects with diverse emissions, resilience and flexibility benefits. This entails forging collaborative efforts among public, private and philanthropic sector entities to create resilient communities that withstand the challenges of the future. Soon, resilience planning may become effectively synonymous with community planning.

5. *Press Releases (epri.com)*

The Case for Electric Power Sector Resilience

Electric power resilience is the ability of the system to withstand and recover from operational shocks.

There is no single definition of resilience in the electric power sector. In the context of electric power system operations, resilience can encompass the ability to withstand wide range of shocks that can include supply chain disruptions, cyber security events, pandemics, physical attacks on the grid and major weather events.

Resilience to weather events in the context of changing climate is emerging as one of the top concerns in the industry. It represents a shift from a historic approach that measured electric power system performance by focusing on reliability of electric power on "blue sky" days and treated extreme weather conditions as force majeure events. The industry shift to considering resilience represents a departure from this historic paradigm, recognizing that electric power is an essential service that must be available without major disruptions, even in the context of extreme weather conditions.

Discussion in the industry is wrestling with what roles and responsibilities different entities in the electric power system (generators, utilities, electric power customers, government) have in creating the future where electric power supply is available without major disruptions and what are realistic expectations for what can be achieved at a reasonable cost.

The climate is changing and extreme weather events are causing more electric power disruptions.

The Fourth National Climate Assessment underscores a concerning trend: the nation is slated to confront increasingly frequent, intense and prolonged extreme weather events across all regions. These include extremes in temperature and precipitation, intensified hurricanes and storm surges, as well as the onset of droughts and wildfires. According to the National Oceanic and Atmospheric Administration (NOAA), the associated damage costs have already reached significant levels. Notably, 2020 marked a historic milestone, witnessing 22 separate events with damages surpassing a billion dollars and culminating in a cumulative cost exceeding $95 billion.[6] As of December 2023, the 2020 record has already been exceeded this year.[7]

The Department of Energy (DOE) corroborates the urgency of the situation by estimating that power outages are currently extracting an annual toll of over $150 billion from the U.S. economy.[8] Noteworthy grid incidents have occurred annually in recent times. In August 2020, California experienced a record-breaking heatwave that strained the state's power grid and led to rolling blackouts for the first time in nearly two decades. The following year, winter storm Uri caused widespread blackouts in Texas affecting more than four million customers, resulting in loss of life and prolonged economic disruptions. In December 2022, a series of winter storms caused Duke Energy to implement rolling blackouts affecting over 1 million customers during the Christmas holidays. These examples are not outliers - the frequency of major weather events impacting the grid has increased by more than 68% in the last two decades.[9] Simultaneously, the aging power grids are difficult to upgrade fast enough. The American Society of Civil Engineers (ASCE) underscores the need for a substantial investment of $4.8 trillion in energy infrastructure by 2039 to ensure proper maintenance and resilience in the face of climate change.[10]

The modern world is increasing dependence on electric power, while more severe weather conditions simultaneously make it even more essential that electric power is available.

Electric power demand is poised for significant growth, increasing urgency to ensure that supply is reliable. Conservative projections indicate 50% demand growth in electric power by 2050, with an anticipated doubling by the end of the century,[11] while more aggressive estimates say that US electric power demand may need to increase by as much as 3 or even 5 times to meet decarbonization goals.[12] This trend is significant because it represents a growing dependence of society on electric power. The forecasted electric power demand growth is being driven by a shift towards electrification, particularly in transportation, heating, and industrial processes. Also significant is the data center electricity consumption that can reach 8% of global electricity demand by 2030 and more than 20% by 2050, if current trends continue without major efficiency improvements.[13] Extended loss of electric power already has major impact on public safety and economic activity, and this dependence is going to increase.

More extreme climate also increases the importance of electric power supply for public safety. For example, the loss of power during periods of extreme heat amplifies the risk of heat-related illnesses and fatalities. A comprehensive analysis conducted by The Lancet projects an alarming surge of 370% in annual heat-related deaths by mid-century.[14] This projection underscores the urgent need for robust measures to address the intersectionality of power outages and climate-induced risks.

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6. *Record number of billion-dollar disasters struck U.S. in 2020 | National Oceanic and Atmospheric Administration (noaa.gov)*
7. *US hit by record number of billion-dollar disasters so far this year (phys.org)*
8. *Department of Energy Report Explores U.S. Advanced Small Modular Reactors to Boost Grid Resiliency | Department of Energy*
9. *DOE form OE-417 data analysis*
10. *Energy Infrastructure | ASCE's 2021 Infrastructure Report Card*
11. *Energy Information Administration*
12. *Press Releases (epri.com) ; Elon Musk Claims the U.S. Isn't Prepared for Future Energy Demands - The Messenger*
13. *How to stop data centres from gobbling up the world's electricity (nature.com)*
14. *The 2023 report of the Lancet Countdown on health and climate change: the imperative for a health-centred response in a world facing irreversible harms - The Lancet*

Resilience of electric power system is required for an orderly energy transition.

Severe weather events create direct costs for electric power companies. A major weather event can cost a utility tens of millions of dollars in restoration and in extreme cases can even force a utility into bankruptcy, as was the case with Entergy after hurricane Katrina and with Pacific Gas & Electric (PG&E) after Camp Fire. Other types of companies in the energy space are also financially exposed to climate risk. For example, a Sandia National Laboratories study found that hurricanes, blizzards, hailstorms and wildfires all pose risks to solar farms both directly in the form of costly damage and indirectly in the form of blocked sunlight and reduced electricity output . Texas winter storm Uri had power producers and retailers facing soaring wholesale prices and market imbalances, also demonstrating the wide impacts of climate events. Major financial losses can make the sector unattractive to investors and, therefore, resilience is essential to continue to attract investment that is needed to support ongoing operations and energy transition. Reliability and resilience are also required for public support of energy transition, as service interruptions tend to raise a question if decarbonizing the grid is also making it less reliable.

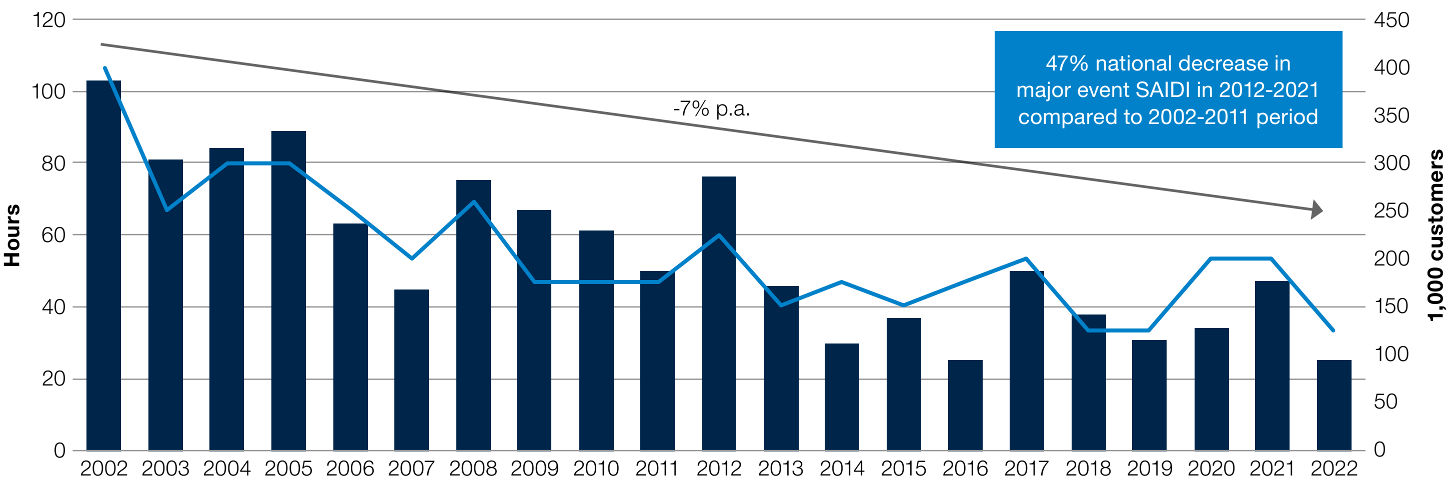
Investing in grid resilience works, but it's expensive.

Notably, utilities have emerged as driving forces behind resilience investment, exemplified by several major utilities annually allocating over a billion dollars to resilience programs. There is clear evidence that these investments work. DOE data of outages caused by major weather events shows that average outage duration and number of customers impacted have decreased by approximately 7% from 2002 to 2022.

This trend is more pronounced when looking at states that have made significant investments – duration of outages during major events have decreased by 80% in Florida, 35% in Louisiana, and 43% in Carolinas in the last decade compared to the previous one . California has seen similar impacts from major investments in wildfire risk mitigation, with risk of ignition from utility infrastructure decreasing by as much as 65-70% since the implementation of wildfire mitigation plans.[17]

Florida was one of the first states to invest in electric power system resilience after a devastating hurricane season in 2004-05, which was one of the most active and destructive in the state's history. A total of seven major hurricanes (Charley, Frances, Ivan, Jeanne, Katrina, Rita and Wilma) hit or affected Florida, causing about $218 billion in damage and leaving more than 20 million customers without power at some point. The hurricanes exposed the vulnerability of the electric grid and prompted FPL and other utilities to invest in grid resilience measures, with utilities spending more than 5 billion dollars on hardening programs that include replacing wooden poles with concrete or steel ones, installing smart grid devices and sensors, moving overhead lines underground where feasible, expanding the use of renewable and distributed energy resources. These investments have helped FPL to reduce the impact of subsequent hurricanes and restore power faster to their customers. For example, FPL was able to restore power to more than 99% of its customers within 10 days after Hurricanes Ian and Nicole in 2021, compared to more than 18 days after Hurricane Wilma in 2005.[18] FPL is continuing investing into grid resilience, with the most recent resilience program making $6.1 billion of grid hardening investments in 2020-22 period.[19]

Duration and number of affected customers during severe weather events



Source: EIA Reliability Reports
Source: DOE Electric Emergency Incident and Disturbance Report (Form OE-417)

15. *Hidden factors that affect solar farms during severe weather | ScienceDaily*
16. *DOE OE-417 report analysis, comparing outage data in 2002-2011 and 2012-2021 period*
17. *SCE Achieves Wildfire Mitigation Work Milestone to Reduce Ignition Risk While Keeping Communities Safe | Edison International | Newsroom*
18. *FPL | Blog | Watt's Happening | Hurricane Wilma*
19. *Florida approves utility storm protection plans; analysts advocate measures beyond undergrounding | Utility Dive*

While Florida was one of the first states to develop grid resilience programs, many other states and utilities have acted at scale as well. After Superstorm Sandy, utilities in the Northeast are estimated to have invested more than $285 billion in T&D, partially to harden the energy grid and make it more resilient to future storms.[20] New York Power Authority (NYPA), the largest state public power organization in the U.S., has invested in grid hardening initiatives such as upgrading substations, installing microgrids and energy storage systems, and deploying advanced analytics and digital technologies. Entergy, which lost 95 out of 125 miles of transmission lines during Hurricane Katrina, has since invested $1 billion to improve the resilience of the substations and overhead lines.[21] In California, utilities are spending more than $5 billion a year on wildfire mitigation efforts.[22] The Edison Electric Institute (EEI), an association that represents all U.S. investor-owned electric companies, reports that electric utilities have invested more than $30 billion in 2022 alone to climate adaptation and hardening efforts. In total, there has been more than 1 trillion invested in transmission and distribution infrastructure over the last decade.[23]

Resilience and Technology Nexus

Building a resilience electric power system is an opportunity to use technology to achieve level of performance not otherwise possible.

In the pursuit of climate resilience within the electric power sector, a wave of technological innovation is shaping the landscape, with both software and hardware solutions playing pivotal roles. This is an area where major established tech giants and energy industry suppliers are active alongside new innovators. A suite of solutions enables resilience capabilities along the adaptation journey from strategy through execution.

Resilience Solution Space

Software/AI   Hardware/smart devices

	Capability	Use Case Examples	Solution Examples	Company Examples
Strategy	Climate Risk Assessment & Adaptation Strategy	• Understand strategic impact of climate risk on the business • Estimate the risk exposure and impact thresholds of company assets • Understand risks and impact of climate events on company customers, communities and supply chains • Develop business cases and capital plans to mitigate climate risks • Integrate climate risk into the overall strategy of the company and identify opportunities to provide resilience as a value to customers	Climate scenario modeling and visualization tools Hazard specific and multi-peril compound models Asset failure prediction models / damage curves Risk mapping and simulation tools Integrated societal / economic impact tools	Jupiter, technosylva, Urban Footprint, ICF, sust, sphera, Descartes Labs, Climate Forecast Applications Network, ABS Group
	Forecasting and Situational Awareness	• Gather data on local conditions to predict severe climate disruption events and asset exposure to risk • Develop hyper-local and tailored weather forecast that can be used for operational response to events • Predict potential impact an upcoming weather event (e.g., major storm, extreme temperatures, high wildfire risk, etc.) • Prepare for upcoming events by right-sizing and pre-staging resources (e.g., field crews, materials etc.)	Remote sensors (e.g., weather stations) Imagery tech (e.g., satellites, LiDAR, cameras etc.) Data collection tech and services (e.g., drones) Weather modeling, forecasting and alerting Real-time event detection (e.g., fire ignition)	The Weather Company (An IBM Business), planet, Muon Space, FireScout, PANO, tomorrow.io
	Energy system hardening and operations	• Hardening overhead facilities, such is improving feeder and pole strength • Enhanced inspections and maintenance activities (e.g., risk-based vegetation management) • Change system design (e.g., undergrounding, sectionalizing etc.) • Predict when assets may fail in high impact areas and proactively replace them	Grid-side hardware (poles, wires, etc.) Protective devices and fault detection Advanced vegetation management solutions Microgrid controllers Predictive asset failure / digital twins	IND.T, PXiSE, AutoGrid, PingThings, HDR, etap, Exacter
	Customer experience	• Provide alternative and/or additional power sources to customers if back-up generation and storage • Enable customer participation in the energy system to help prevent events (e.g., demand response) • Information and visibility of impact and restoration during climate events	Back-up generation and energy storage Inverters and islanding Demand response Customer portals / communication	Tesla Powerwall, Generac, Amperon, octopus energy, CO-Z, VIOTAS, GoalZero, Avanti, accelergen
Execution	Response and Recovery	• Automatically detect an event (e.g., wildfire, tornado) and respond to it (e.g., issue alerts) • Increase real-time visibility into damages post-event • Facilitate coordination of response resources and activities across multiple organization	Automated ignition suppression technology Automated visual inspection for storm damages Coordination and visualization platforms	Intterra, One Concern, Rain, Alertus, DisasterTech, DTN

20. Energy Infrastructure | ASCE's 2021 Infrastructure Report Card
21. Ten Years After: How Entergy New Orleans survived Hurricane Katrina (power-grid.com)
22. The-Costs-of-Wildfire-in-California-One-Pager.pdf (ccst.us)
23. Improving the U.S. Electric Power Grid: Mitigating Vulnerabilities and Enhancing Operation (powermag.com)

Climate risk models have broad applications across industries and have gained traction in the market as organizations and communities grapple with climate risks.

Climate risk modeling is an example of a highly valuable application of advanced analytics and machine learning. For example, leading utilities have developed capabilities to combine climate risk models with asset management to assess the likelihood and magnitude of potential impact of events. This analysis can drive grid hardening plans, such as elevating substations to mitigate flooding risks and burying overhead lines to prevent wildfire ignitions. Similarly, governments use climate risk models to drive development of adaptation plans. The is a growing number of solutions and offerings in this space, including from major tech companies and from VC-funded innovators. For example, Google has developed Climate Insights, a suite of cloud-based AI tools and data sets designed to help organizations understand and manage climate risks. Jupiter Intelligence has emerged as a VC-funded company exclusively focused on climate risk analytics. Founded in 2016, it has raised approximately $100 million in funding from investors such as Clearvision Ventures, MPower Partners, CDPQ, Energize, DCVC, MS&AD Ventures QBE Ventures, SYSTEMIQ and others. Jupiter Intelligence has partnered with several leading organizations, including the World Bank, the United Nations Development Programme and the Global Resilience Partnership, and has been recognized as one of the World Economic Forum's Technology Pioneers. There are many other examples of innovative companies emerging in this evolving space as demand for more specialized solutions grows.

Hyper-local and tailored weather forecasting tools are essential for managing climate risks, while also providing some of the best opportunities for ongoing innovation.

Weather and short-term climate condition forecasting is a growing innovation space because these solutions serve two vital purposes: enabling granular adaptation planning and effective event response. Broad climate risk models can provide directional information about the overall trends, but they are not helpful to companies like utilities that need to make decisions about which specific assets to upgrade or which communities need specific adaptation solutions. Similarly, precise weather forecasts facilitate response during events by enabling governments to issue effective alerts and warnings, plan evacuations and mobilize resources. Precise forecasting also has high value for energy companies, from generators bidding into the market to utilities responding to storms.

One of the best examples of the application of hyper-local and specialized weather forecasting capabilities is wildfire management in California. The backbone of the California wildfire program is comprehensive, state-of-the-art predictive models that analyze fuel conditions, moisture, temperature, wind conditions and historic wildfire behavior to generate a week-ahead fire potential forecasts at 3-kilometer resolution. This accurate wildfire risk forecasting capability enables risk-reduction activities, such as prescribed burns and utility proactive line de-energization to prevent ignitions. This system is the result of initial innovation through public-private-academic partnerships that were set-up in San Deigo and included San Diego Supercomputer Center, San Diego Gas & Electric, California Department of Forestry and Fire Protection, the U.S. Forest Service, San Diego County Emergency Operations Center and Fire Department, and others. Private sector innovators have also emerged in this space. For example, Technosylva developed a suite of wildfire risk analysis SaaS products to simulate and accurately predict wildfires, with capabilities to take in real-time data to predict behavior of fires in real time. Technosylva is widely used by utilities and firefighting agencies and has obtained investment from TA Associates to support its growth.

Achieving resilience will drive proliferation of data gathering and analytics (AI and machine learning) solutions to make data actionable.

The interaction between the environment and the built environment is dynamic and complex, creating opportunities for technology to unlock capabilities that are not otherwise possible with traditional approaches. Achieving a step-change in electric power resilience will require innovation and the application of new breakthroughs in AI and machine learning to resilience use cases. Asset owners and operators are increasingly using analytics and "digital twins" to better manage their assets, including to increase resilience. Digital twins can be used to prioritize asset replacement, identify performance issues before they arise, model potential failure modes under various environmental conditions, and estimate the impact to customers and the economy. AI also plays an essential role in operations, enabling functions such as fault detection and automatic line disconnection. Other types of solutions can aggregate distributed resources, helping lower demand when there are supply side constraints or pool distributed generation into virtual power plants (VPP). A big opportunity for technology is in assisting response and recovery from events, particularly in automation of damage inspections and optimizing restoration activities. Push for resilience will accelerate deployment of technology across many use cases.

Resilience is a tailwind for the energy value chain, particularly for transmission and distribution hardware and energy storage.

Adapting to the changing climate will require significant upgrades to the existing transmission and distribution system and will therefore be a headwind for a wide range of grid hardware. One relevant example of the magnitude of this investment is Florida Power and Light (FPL), which has a long track record of investing in resilience. FPL has been investing in grid hardening for storms at a rate of $0.7-1.4 billion a year and expects to continue investing at a similar rate through 2032.[24] Other utilities have similar programs, with some variation of hardening techniques (e.g., using covered conductor vs. undergrounding).

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24. Microsoft Word - 20200067-71 Prehearing Order.CLK.docx (state.fl.us)

Required investment in grid hardening is compounded, in terms of costs, by requirements to increase transmission and distribution capacity to facilitate the energy transition. At the national level, transmission investment is likely to exceed 15% a year over the next decade, while distribution will likely be 5-8% a year.[25] The actual need for investment is higher than the current and projected rate of investment due to affordability concerns and various operations constraints (permitting, supply chain, trained workforce, etc.).

As utilities work to harden the grid, resilience concerns have propelled adoption of distributed energy resources. Households, communities, and businesses seeking to minimize the impact of disruptions are increasingly buying solar and storage solutions. Tesla Powerwall, for instance, has witnessed substantial growth in recent years. As of July 2023, Tesla reported a 222% increase in energy storage deployments[26] in the second quarter of 2023 compared to the same period in the previous year. Similarly, Generac, a leading provider of fossil-fuel generation sets, reported a revenue increase of 30% in the first quarter of 2023 that was driven largely by the heightened demand for home standby generators. The increased demand for backup gas and diesel generators highlights the importance of solving for resilience as part of energy transition.

The Path to a Resilient Future

Affordability constraints make it essential that resilience is designed into energy transition at large.

The needed grid investments are running into affordability challenges. The average electricity prices in the United States have increased by roughly 18% in the last 10 years, from 10.54 cents per kilowatt-hour on average in 2011 to 12.47 cents per kilowatt-hour in 2021.[27] States that have invested heavily in resilience have also seen some of the biggest rate increases. For example, in Florida, average electricity rates in the last ten years have gone up by 24% for FPL and 20% for Duke Energy.[28] While there are many factors behind rate increases, the need for hardening has been a significant contributor.

The affordability pressure makes it essential that resilience is built into all aspects of energy transition to lower the total cost to society. Every project can have a resilience lens – a parking lot with solar and EV charging can also serve as a resiliency zone in an emergency, a utility circuit upgrade to harden conductors can also create additional capacity to support distributed generation interconnection. The approach to distribution system planning and engineering needs to evolve from thinking of the grid in terms of asset classes to community level design. Distribution system planners need to be equipped with new processes and tools to dynamically evaluate the condition of existing assets, changing load patterns, distributed energy resources, and climate risks.

A winning strategy for suppliers in the energy value chain is to deliver infrastructure projects, specifically transmission and distribution grid upgrades, at declining cost. PG&E's undergrounding program is a great example of what is possible when utilities work together with their engineering and construction contractors and equipment suppliers. Through a joint, focused effort, PG&E was able to reduce the cost of burying power lines by more than 10% in one year and plans to reduce costs by additional 33% by 2026.[29] Utilities and other energy companies will increasingly look for cost effectiveness and the suppliers in the industry can benefit from leaning into this trend.

Electric power consumers will take matters into their own hands to increase resilience of their electric power supply and these resources need to be leveraged for overall system resilience.

As critical aspects of daily life increasingly require electricity, individuals and families face a compounded burden during disruption events. This drives demand for backup generation by those who can afford it. A comprehensive study looking at data from generator companies, augmented with trade data on U.S. imports of generators, concluded that consumer intolerance to disruption is the strongest driver of sales for backup power.[30] Households in the US are investing in generation and storage to mitigate the impact of grid outages, especially in regions where outages are more frequent or severe due to extreme weather events or other factors. According to a study by Wood Mackenzie, a global research and consultancy firm, the US residential battery market grew by 44% in 2020, reaching a record high of 540 megawatts.[31] The study attributed this growth to several factors, including the increasing frequency and duration of grid outages. However, due to the high initial cost of backup power, this resilience solution is cost-prohibitive and without public investment, could exacerbate a socioeconomic gap by segmenting people with power and people without power.

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25. *A&M analysis*
26. *Tesla Q2 storage deployments increase 222% as company navigates 'fractured regulatory environment' | Utility Dive*
27. *Statista, average retail electricity prices*
28. *A&M analysis of US Energy Information Administration historic electric rates data*
29. *PG&E Corporation 2022 Investor Day (q4cdn.com)*
30. *Thompson D, Pescaroli G. Buying electricity resilience: using backup generator sales in the United States to understand the role of the private market in resilience*
31. *Residential Energy Storage: U.S. Manufacturing and Imports Grow Amid Rising Demand (usitc.gov)*

Similarly, the corporate sector is increasingly focused on electric power consumption in the context of corporate decarbonization targets, while also needing to ensure access to reliable and cheap power. Companies across various sectors are taking steps to understand their exposure to climate risks and take mitigation actions. Technology companies have been some of the most active in taking action because of their commitment to decarbonization and because climate events impacting data centers have the potential to interrupt their core service offering. For this reason, tech companies tend to combine their climate adaptation and decarbonization strategies. For example, Microsoft has signed power purchase agreements with renewable energy providers, as well as invested in hydrogen fuel cells and diesel generators, to back up its cloud services and data centers. Microsoft aims to be carbon negative by 2030 and remove all its historical emissions by 2050.[32] Amazon has invested in renewable energy projects such as wind and solar farms, as well as battery storage systems, to power its data centers and fulfillment centers.

Proliferation of energy resources adopted by households and companies provides an opportunity to use this resource to increase overall system resilience, in addition to benefiting the individual customers. Nevertheless, establishing the infrastructure and systems to leverage behind-the-meter resources through demand resource and virtual power plant programs will require continuous support from policymakers.

There is an opportunity for investors in the resilience space.

> *"If wildfires were a country, they would rank fourth in terms of climate emissions, not to mention their devastating impact on human life, property, and biodiversity. New technologies to prevent the ravages and carbon release of wildfires are being developed that promise more resilience to communities, utilities, real estate and insurance companies, governments and indigenous populations."*
> **- Nancy Pfund, DBL Partners**

Climate tech is a top focus for investors, including climate adaptation and resilience. Nevertheless, developing and executing an effective business model in resilience is difficult. Responsibility for resiliency typically resides with governments and utilities, which have lengthy sales cycles. Accessing this market requires investors to have a longer than usual investment horizon, as governments and utilities expect rigorous technology evaluation processes inherent in industries with public safety implications, which can take a decade or more.

Adapting products and business models to a wider customer base, including electric power users (homeowners and corporate), landowners, insurance companies and financial institutions can potentially provide a quicker pathway to profitability and access a broader base of finance. Predictive weather modeling is an example of technology that can effectively cut across multiple market segments.

> *"Standards for today's multi-directional grid and home electricity [..] will help prevent fires, ensuring safety, and allow for current innovations to commercialize"*
> **- Roy Moorefield, CO-Z/Hygge Power**

Updating standards and providing technology testing and approval processes can be helpful in supporting innovation and attracting additional investment by creating more certainty in the market. Government policy can support innovation by creating stable funding sources and pathways for getting new technology approved for broader industry adoption.

Public-private collaboration will be key to achieving electric power system resilience, keeping electric power affordable, and making sure vulnerable communities are not left behind.

The public sector is at the center of effective climate adaptation, particularly in the context of electric power system resilience. Government action is required to foster a more equitable and resilient response to the complex interplay between climate change and power infrastructure. Supporting underserved communities through this transition should be a top priority for policymakers at the Department of Energy and state utility Commissions.

32. Microsoft is committed to achieving zero carbon emissions and waste by 2030 - CEE Multi-Country News Center

One of Government's key strategies is to make funding available to incentivize resilience projects, especially to the benefit of underserved communities. A current focus area is the administration of more than $13 billion Federal grants and programs that were funded by the Bipartisan Infrastructure Law (BIL) through two programs dedicated specifically for resilience:

- The Grid Resilience Innovation Partnerships Program (GRIP) provides $10.5 billion to enhance grid flexibility and improve grid resilience. The program consists of three components: Grid Resilience Utility and Industry Grants ($2.5 Billion); Smart Grid Grants ($3 Billion); and the Grid Innovation Program ($5 Billion). The GRIP program has issued $3.46 billion for 58 projects across 48 states through their first funding opportunity. A second funding opportunity of $3.9 billion was announced in early November and will be awarded in early 2024.[33]

- The Grid Resilience State and Tribal Formula Grants is a $2.3 billion program designed to strengthen and modernize the power grid against wildfires, extreme weather, and other natural disasters exacerbated by climate change. To date, GDO has awarded 48 states, 49 tribal entities, three territories and the District of Columbia a combined total of more than $748 million.[34]

These programs are useful, but in the first phase primarily support incremental progress to fill current gaps in the most vulnerable parts of the system and help utilities catch up on some essential backbone technologies, such as smart meters. There is an opportunity for communities to use BIL and other sources of funds to move forward in future phases of these programs to build community resilience through more holistic and innovative approaches.

There are many other potential sources of funds for states and local governments for resilience programs, including through many federal agencies including Federal Emergency Management Agency (FEMA) Hazard Mitigation Assistance grant programs, U.S. Department of Housing and Urban Development (HUD) Community Development Block Grants, National Oceanic and Atmospheric Administration (NOAA) grants for projects related to coastal and marine resilience and others. The challenge for communities is that those grants are typically not enough to fund complete adaptation strategies and local governments are forced to cobble together multiple funding sources and/or scale back project scope to fit the funding they are awarded. This is not only impractical for local governments, but it also poses a major barrier to innovation and private sector solutions, as the inconsistency of funding year to year impacts revenue and business planning. To establish sustainable, long-term initiatives that transcend incremental improvements, local governments need reliable and predictable funding.

Public-private coordination should be a bigger part of the solution. Collaborating with private entities can be a source of funding for communities. Public-private partnerships enable governments to leverage private sector resources for climate adaptation projects and grid modernization – not just financial, but also creative. The right private partner – an industrial player, for example – can help local governments ideate projects and fine tune planning. Utilities and other energy companies are well-positioned to help communities develop solutions that protect essential infrastructure at scale.

33. Grid Resilience and Innovation Partnerships (GRIP) Program | Department of Energy
34. Grid Resilience State/Tribal Formula Grant Program | Department of Energy

Playbooks for resilience need to put communities at the center.

While there are best practices and success stories, the industry has not fully coalesced around a clear definition of resilience, let alone an agreed approach to managing costs of resilience improvements. This often leads to solutions being debated without a clear cost-benefit fact base to enable decision making across a broad set of potential solutions. Most importantly, the *interplay between community-level adaptation and electric infrastructure specific initiatives is not well understood.* For example, the effectiveness of utility wildfire prevention programs is dependent on forest management practices. Similarly, flood management at a community level impacts the type of investment a utility needs to make into raising substations above flood lines. This is a critical area that needs to be explored to ensure that society doesn't just end up with hardened infrastructure when we actually need to achieve the larger goal of communities that are well adapted to climate conditions.

The industry is active in organizing itself around resilience, including action on resilience from major associations:

- **Edison Electric Institute (EEI)** supports utility coordination and sharing of best practices within the industry and serves as a forum for coordination between utilities and federal government for preparedness and response via Electricity Subsector Coordinating Council (ESCC). Some of the main topic that EEI is focused on are mutual assistance between utilities, spare equipment, undergrounding and use of drones.[35]
- **Electric Power Research Institute (EPRI)** has been working on developing a comprehensive, consistent, and consensus-based framework to inform infrastructure investment and deployment through Climate READiTM (REsilience and ADaptation initiative).[36] Industry stakeholders can engage with Climate READi efforts through the Initiative's "Affinity Group" Over 80 organizations that have formally signed on from around the world and a wide variety of backgrounds, bringing their expertise to provide input to the development of the Framework and other related deliverables.
- **National Association of Regulatory Utility Commissioners (NARUC)** has established a sub-committee dedicated to resilience and published a reference guide for state Commissions on how to approach mitigation of risks posed by changing climate. NARUC has developed guidance on three topics: (1) definition of resilience, (2) putting value on resilience investment and (3) resilience strategies for regulators to consider.[37]
- **Environmental Defense Fund (EDF)** has developed a Climate Resilience Maturity Model[38] that provides an opportunity to assess resilience capabilities of an organization by looking at several key domains that include governance, climate-aware planning, stakeholder and community collaboration, resilience and adaptation actions, customer engagement and attention to equity.
- **The Initiative on Climate Risk & Resilience Law (ICRRL)** has been focused on developing legal frameworks to help address the consequences of climate change. It has developed an electric resilience toolkit that provides information on ways to enhance climate resilience planning by electric utilities.[39]

The resilience frameworks and approaches need more visibility and engagement from a broader set of stakeholders, particularly state and local governments. One notable step in the direction is a focus on increased community engagement is the NARUC "Resilient Community Design Framework." It articulates a proposed process for assessing threat environments of communities, followed by robust analysis of policy-based interventions and associated costs. This type of discussion is essential to make sure that climate adaptation solutions achieve the overall societal goals.

In the face of increasingly severe climate conditions, the electric power industry continues its efforts to ensure customers have uninterrupted service. The broader goal, however, is adaptable communities across socio-economic spectrum. Achieving this goal necessitates a comprehensive, community-centric approach, facilitated by dynamic public-private partnerships. This collaborative strategy is essential for proactively adapting to the changing climate landscape. The synergy between industry innovation and community resilience is pivotal in creating an enduring electric power infrastructure that actively contributes to the resilience of the served communities.

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35. Reliability & Emergency Response | (eei.org)
36. https://www.epri.com/research/sectors/readi
37. Resilience - NARUC
38. Climate Resilience Maturity Model | Environmental Defense Fund (edf.org)
39. https://www.icrrl.org/electric-resilience-toolkit/

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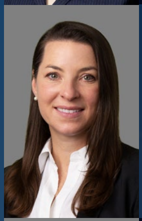

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Dynamo Energy Hub was founded in 2019 by industry veterans Meade Harris and Kristin Barbato in response to the increasing need for companies to connect in the clean energy transition. Because of their experiences, they wanted to build a better way for innovators to collaborate and develop trusted relationships across startups, investors, corporates, and governments in a fragmented industry. And thus, Dynamo Energy Hub was born.

What started out as one hub in New York City and a few initial events has now grown to over a dozen hubs across two continents, 100 events both in-person and virtual, as well as a robust membership list including some of the world's most impactful corporates, cleantechs, and investors. With the clean energy transition showing no signs of slowing, Dynamo enables companies' growth with flexible places to work and powerful networking connections for regional and global impact.

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