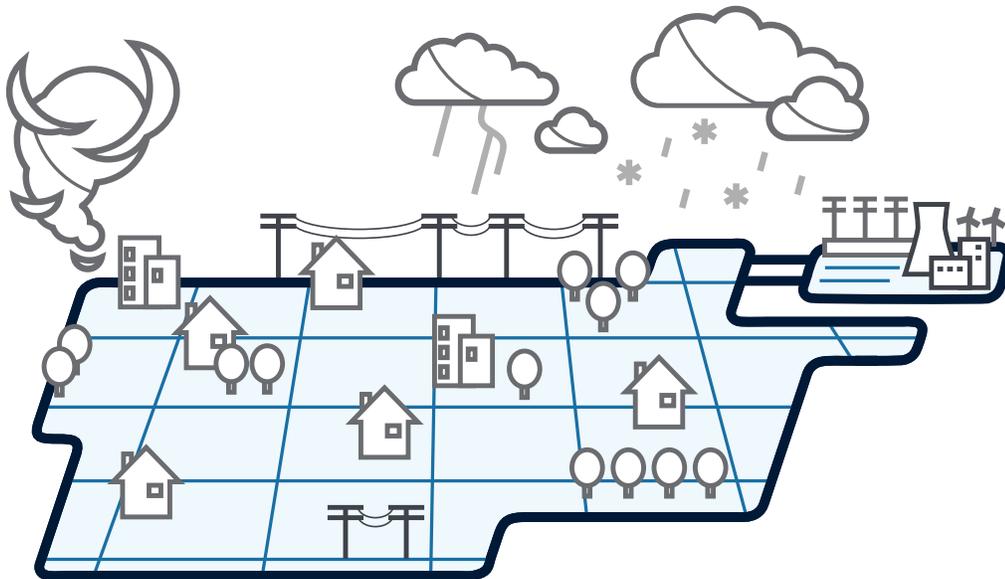


## Grid Resilience

Natural disasters and extreme weather events can devastate the electric grid. The annual number of billion-dollar weather and climate disasters in the U.S. has been steadily increasing since 1980,<sup>1</sup> and climate change is expected to increase the frequency and severity of extreme weather events.<sup>2</sup> Consideration of both current weather patterns and the changing climate is essential to increase the resilience of the electric grid, including both robustness during storms and quick recovery after outages. A suite of strategies and tools, including grid hardening to physically strengthen the grid, smart grid management and control technologies, and resource diversification can contribute substantially to increased grid resilience.



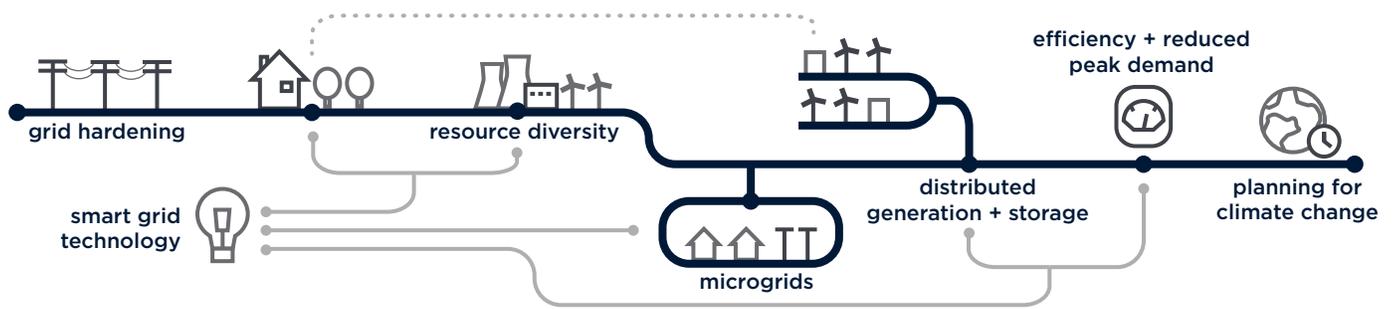
### **Threats to the electric grid from weather and climate**

Severe weather events across the US, including hurricanes, sleet, and intense local storms, resulted in more than 679 outages from 2003-2012.<sup>3</sup> For example, in 2012, Superstorm Sandy left more than 8.5 million customers without electricity.<sup>4</sup> High winds, flooding, lightning and ice can all damage grid infrastructure. Climate change can exacerbate many of these impacts through shifts in weather patterns, increases in storm intensity and frequency, and rises in sea levels and coastal storm surges.<sup>5</sup> Warmer weather can also strain existing electric grids by increasing demand for air conditioning on hot days when electricity demand is already at a peak.<sup>6,7</sup> Moreover, fossil and nuclear generators are less efficient at higher ambient temperatures and are at risk of having less available cooling water, which reduces their ability to meet demand on hot summer days.<sup>6</sup> Hydropower is already at risk in some regions due to changing rainfall patterns and drought.<sup>5</sup>

### **Tackling resilience, energy security and carbon mitigation together**

Many of the technologies that provide grid resilience can also play an important role in reducing carbon emissions from the grid. These include smart grid technologies, microgrids, distributed generation, and energy storage. The technologies and strategies outlined below can increase overall grid efficiency and help to integrate renewable electricity generation by increasing flexibility and the diversity of energy supplies.

Distributed and diverse energy resources can also contribute to increased energy security by protecting against uncertainty in the supply or the price of any one resource.<sup>14,15</sup> With careful planning, investments in grid resilience can strengthen the grid in the face of extreme weather events and climate change while simultaneously providing environmental and security co-benefits.



## Strategies for resilience

Grid resilience requires both strengthening infrastructure to withstand damage and the incorporation of smart, flexible technologies that allow the grid to respond quickly and adapt to changing weather or outages. Some of these strategies and technologies are:

- **Grid hardening:** physical strengthening and reinforcement of grid components such as utility transmission and distribution poles and moving at-risk facilities out of flood zones can make electricity infrastructure more robust.<sup>3</sup>
- **Smart grid technology:** advanced monitoring, communication and control technologies, often employed to increase grid efficiency, can also help to identify outages and re-route power flow around damaged areas to reduce outage extent. Key technologies include smart meters<sup>8</sup> on houses and transmission monitoring technologies such as synchrophasors,<sup>9</sup> which can help quickly detect outages. Advanced control methods are capable of assessing this data, which allows grid operators to rapidly locate and repair damages. Furthermore, on an ongoing basis, these technologies can help integrate and manage distributed energy resources.
- **Microgrids:** microgrids are smaller power systems with their own electricity generation and control technology within the larger grid. They have the ability to “island” or operate independently from the grid in the case of an outage. Microgrids may incorporate combined heat and power systems, renewables, energy storage, and other technologies. They are often located where maintaining electric supply is considered critical, such as hospitals and industrial facilities.<sup>10</sup>
- **Distributed generation and storage:** rooftop solar systems and other distributed electricity generation can continue to provide local electricity during a grid outage, as long as this generation is equipped with technology enabling it to “island” from the grid and provide power on site. Energy storage, combined with solar or on its own, can also provide backup electricity during outages. Poorly planned integration and coordination of distributed resources can negatively affect grid reliability. However, careful planning, siting and management of these distributed resources can have the opposite effect and enhance reliability.<sup>11,12</sup>
- **Resource diversity:** the utilization of a wide range of grid resources, from the distribution technologies described above to diverse centralized generation including large-scale renewables, can create flexibility and provide resilience by reducing the reliance on any one resource.<sup>11,13,14</sup>
- **Planning for climate change:** including climate change models in grid planning can help protect the grid by accommodating potential changes in weather, rainfall, sea level, temperature, and changing electricity demand.<sup>13</sup>
- **Efficiency and reduced peak demand:** end-use efficiency, distributed local energy resources as discussed above, demand management, and other measures that reduce peak and total electricity load help reduce the strain on the electric grid during maximum demand. These measures reduce the risk from a generator going offline unexpectedly and will be increasingly important in regions where peak demand is projected to increase with climate change.<sup>13</sup>

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