RESILIENCE STRATEGIES FOR POWER OUTAGES

C2ES CENTER FOR CLIMATE AND ENERGY SOLUTIONS

A warming atmosphere is giving extra energy to storms, making the hurricanes, tornadoes, and thunderstorms of today more intense than those of the past. This trend is projected to accelerate in the years to come. These stronger storms are more likely to cause power outages, and the loss of power can be costly in terms of lives lost, economic impact, and public health. This fact sheet outlines strategies that local governments could implement to reduce the frequency and duration of power outages and help communities better withstand them when they do occur. For each resilience strategy, the paper discusses costs and co-benefits, both of which are important considerations for implementing strategies. A case study of New Orleans looks at the different strategies put in place since Hurricane Katrina caused widespread destruction in 2005 and the performance of those strategies to the hurricanes that have made landfall since. The paper also includes a list of tools for quantifying the co-benefits of the resilience strategies discussed.

INTRODUCTION: THE GROWING THREAT OF STORM-RELATED POWER OUTAGES

Severe storms are by far the most common type of billion-dollar weather and climate disaster in the United States. According to data collected by the National Oceanic and Atmospheric Administration (NOAA), storms account for 95 of the 227 such events from 1980–2017.[1] Tropical cyclones (including both tropical storms and hurricanes) are less prevalent in that database (40 events) but are the most deadly and costly. These events cause direct damage to property, infrastructure, and crops, but the indirect damage they cause is also consequential. Key among these indirect impacts are power outages which cost the U.S. an estimated $20–$55 billion annually.[2]

Evidence is accumulating that climate change is increasing the intensity of all types of storms, though the limitations in historic observations of hurricanes, tornadoes, and other events make it difficult to attribute the extent to which human activity is involved.[3] There is, however, broad consensus in model projections that hurricane strength, precipitation intensity, thunderstorm frequency, and winter storm activity will all increase in the future.[4] A 2013 Department of Energy report found that electricity transmission and distribution systems face increasing risks from stronger storms (e.g. utility poles knocked down by high wind events).[5] Flooding and increased heat can also result in power outages when they damage electricity system infrastructure such as power lines, substations, or transformers. These various weather-related events all result in power outages that can take days or even weeks to restore.

There are many strategies that local governments can use to increase resilience to power outages. While power outages may be impossible to completely avoid, resilience strategies can reduce the duration and severity of these events and their impact on people. This fact sheet highlights resilience benefits and co-benefits (societal, environmental, and the economic) that can create more opportunities for financing, collaboration, and community buy-in for these resilience actions. The estimated costs and values of individual benefits vary across communities based on a number of factors, including the local environment and climate projections. A separate

C2ES publication, *Resilience Strategies for Flash Flooding*, covers resilience strategies to heavy precipitation and the subsequent flooding that often follow storms.[6] Local governments seeking resilience for all aspects of storms should consider recommendations from both publications.

ELECTRICITY SYSTEM HARDENING

When electricity distribution systems, such as long-distance transmission lines or feeder lines that serve individual houses, are damaged by storms, communities suffer from the disruption in services that follow. There are strategies to make energy systems more resilient (typically referred to as "system hardening"). For example, wooden poles to support transmission lines might be replaced with steel poles that can withstand higher wind speeds. Lines can be buried underground to avoid wind damage, although flooding still poses risks. Tree trimming, also known as "vegetation management," can create an open space around wires that prevents wind and other storm-related damage (i.e., trees bringing down power lines).

Other hardening options aim to promote faster recovery, such as participating in mutual aid agreements with other jurisdictions or stockpiling replacement parts. Emerging technology solutions, like wires designed to disconnect from poles when debris falls on them, can also promote faster recovery. This prevents the falling debris from dragging down multiple poles, which can cause more widespread outages and take longer to repair.

For electricity system hardening, the measure of success is not necessarily avoided outages but rather a reduced amount of time an outage lasts. For example, Florida Power & Light, a utility serving many parts of South Florida, has been hardening its system after widespread damage from Hurricane Wilma in 2005. When Hurricane Irma struck the same area in 2018, power was restored in several days compared to several weeks following Wilma.[7] Reducing outage time improves resilience by hastening the community's return to normal conditions.

Many resilience solutions exist for energy systems, and the industry is beginning to implement them across the country.[8] Not all local governments will have control over their utilities to implement these strategies, and many hardening efforts require regulatory approval from state utility commissions. Regardless of whether it operates its own utility, local governments can be helpful partners in promoting more resilient electricity distribution systems.[9] The following discussion describes electricity hardening costs and benefits from a community perspective.

COSTS

Some system hardening options can be quite costly. Converting overhead distribution lines to underground ones is estimated to cost $536,760–$12,000,000 per mile in urban areas, $1,100,000–$11,000,000 per mile in suburban areas, and $1,100,000–$6,000,000 per mile in rural areas.[10] Undergrounding new distribution lines (for example, as part of a new development) is somewhat less costly at $1,141,300–$4,500,000 per mile in urban areas, compared to $126,900–$1,000,000 per mile for overhead lines in suburban areas.[11] Upgrading existing wooden poles to stronger, more resilient materials such as steel and concrete costs $16,000–$40,000 per mile, according to recent utility experience in both Texas and Florida.[12] However, steel poles are more durable than wood, so lifetime maintenance costs may be more comparable depending on local circumstances. The electric utility in Tucson found that the cost of steel poles to replace wooden ones in its system were nearly double, but they had a 60-year lifetime compared to 30-years for wood poles, so the lifecycle costs were approximately the same (but the steel poles have the added benefit of better withstanding high winds, making the system more resilient).[13]

BENEFITS

Shortening the duration of power outages has both economic and social benefits, as described below.

Reduced Economic Losses

System hardening actions can shorten outage duration times after major events by several days, which significantly reduces economic losses. Quantification methodologies for the economic losses from power outages are complicated, and very little work has been done to study long-duration outages (in part because these are rare events). But for outages lasting more than a day there can be spillover effects to the broader economy, making every day of outage more costly than the last.[14]

Public Health Benefits

Power outages are known to negatively impact health, often in indirect ways. For example, following a power outage related to a 2009 ice storm in Kentucky, 10 people died from carbon monoxide poisoning because they had been using generators, kerosene heaters, and propane heaters inappropriately.[15] Additional negative health impacts of power outages include illness from consuming food that spoiled after lack of refrigeration and accidental deaths that occur in darkness.[16] Electricity system hardening can prevent some outages and shorten others, thus limiting the exposure to these risks.

IMPLEMENTATION EXAMPLES

- In June 2012 a meteorological phenomenon with very high wind speeds known as a "derecho" affected many parts of the Midwest and Mid-Atlantic regions with hurricane-force winds that downed trees. West Virginia suffered some of the worst damage, exacerbated by a heat wave that immediately followed the derecho. 63 percent of West Virginians were without power for two weeks or more in the extreme heat. To shorten power restoration times in future events, the state public service commission ordered utilities to switch from an as-needed management program to a four-year cycle of continual maintenance, whereby trees near power lines would be trimmed regularly. For one utility, Appalachian Power, the costs to do so are estimated to be $44.472 million. Customer electricity rates increased 3.24 percent to pay for the increased tree trimming.[17]
- Entergy is a utility that serves several states along the Gulf Coast and has long experience with hurricanes. The utility began replacing wooden poles with stronger materials after Hurricane Betsy made landfall in 1965. A 2007 internal study by the utility found that 99 percent of its structures near the coast survived the winds of Hurricanes Katrina and Rita in 2005 because of this hardening effort, although the financial value of this resilience was not estimated.[18] While methodologies for monetizing the value of these avoided losses are limited, it no doubt made recovery efforts faster.
- New York City suffered major power outages after Hurricane Sandy in 2012. To prevent similar impacts from happening again, a four-year system hardening program was undertaken by the utility ConEd. The utility installed smart switches and undergrounded some electricity lines. Hardening actions to protect from flooding were implemented as well. As of October 2017, the utility reported that the upgrades avoided 250,000 customer outages.[19]

SMART GRID

The term "smart grid" refers to a group of technologies including smart meters and communications networks that allow parts of the electricity system to remotely communicate with each other and with grid operators. These technologies can promote resilience by quickly identifying sections of the grid that are impacted by storms and isolating them so that power outages are not widespread.[20] Smart grid technologies can also preemptively turn off power to a small area before a storm to prevent system-wide damage. Each of these uses reduce the extent of power outage, and can lead to shorter recovery times as well since there will be less system damage following a storm.

Smart grid technologies are already widely installed across the country. A 2017 survey of electric utility smart meter plans found that 76 million households had smart meters installed as of December 2017 and 90 million households, or about 60 percent, will have the technology by 2020.[21] Where they are deployed, they have already been shown to reduce the occurrence and duration of power outages. CenterPoint Energy, the investor-owned utility in Houston, avoided nearly 41 million minutes of outage time after Hurricane Harvey because of the smart grid infrastructure it had previously deployed.[22]

Smart grid technologies, like electricity system hardening, are implemented by utilities subject to approval by state regulatory commissions (except in the case of municipal utilities). Local governments without a municipal utility will need to partner with utilities and state regulators to champion the resilience benefits that system upgrades can provide.

COSTS

Deploying a smart grid requires investment in both physical hardware and operation and maintenance (O&M).

Hardware components include meters and switches while O&M investments include network communications, educating consumers on usage, and servicing equipment in the field. The cost of an individual smart grid component is not a good measure of the cost of this strategy since the resilience benefits of a smart grid result only once the infrastructure is widely deployed. In other words, a single smart meter does not provide resilience benefits until a threshold of deployment is reached. However, project costs are often described as a per meter value, to allow for better comparison between projects. These per-meter values typically include network installation and O&M costs.

A report by the Northeast Energy Efficiency Partnerships (NEEP) reviews smart grid deployment projects in the Northeast from 2007 to 2015.[23] The eight projects reviewed varied in size, year of implementation, and location, all of which can affect the cost of installation. Total project costs, including capital and O&M, ranged from $124 million to $1.66 billion, depending on the size and year. On a per-meter basis, the total costs of the smart grid projects ranged from $205 to $531 per meter.

BENEFITS

Reduced Energy Costs

Many of the energy cost savings that customers realize in a smart grid come from reduced operations costs for the utility which are then passed along as rate reductions to customers. Utilities save costs when using smart grids because crews are no longer needed to manually read meters for billing, energy theft can be prevented, and service can be remotely connected or disconnected when customers move in or out of buildings. The NEEP study that reviewed several smart grid deployment projects in the Northeast saw expected utility O&M savings of $19 million to $1.383 billion, or $74 to $354 per meter.[24]

Smart grids can provide additional energy cost savings by enabling various types of consumer efficiency programs. In Chicago, one program lets customers opt into hourly pricing and provides tips on reducing energy use during the times of the day when it's most expensive. Program participants reduced their energy costs 15 percent, on average, between December 2012 and December 2015.[25] Another smart meter-enabled program lets customers with central air conditioners opt to have the compressor cycle during summer months, as a way to reduce total systemwide energy use. Participating customers receive up to a $10 per month credit on their electricity bill.[26]

Reduced Greenhouse Gas Emissions

Smart meters can be read remotely for billing instead of sending a meter reader in a truck to the site. This leads to reductions in greenhouse gas emissions from vehicles, with the greatest reduction benefit coming in areas with the lowest population density. A 2012 evaluation of smart meter deployment across the country found greenhouse gas reductions of 12–59 percent due to the smart meters.[27] Estimates for utility ComEd, serving Chicago, are that in 2017 its deployment of smart meters and the smart meter-enabled customer energy savings programs noted above led to 2,671 fewer metric tons of carbon dioxide emitted.[28]

IMPLEMENTATION EXAMPLES

- CenterPoint Energy, an investor-owned utility serving the Houston metropolitan area, upgraded its entire distribution system, including more than 2 million meters, to a smart grid between 2010 and 2014. It installed smart meters, communications systems, and data management software. The total project cost $514,519,057, or $241 per meter on average. Between 2012 and 2014, the utility saw annual cost savings of around $20 million. Between 2011 and 2014, customer outages were reduced by 15.5 million minutes. By avoiding the use of trucks to deploy meter reading crews, the utility avoided use of 950,000 gallons of fuel between 2011 and 2014, with resulting avoided greenhouse gas emissions.[29] When outages in that period did occur, power was restored to customers up to 35 percent faster. The biggest test of CenterPoint's smart grid resilience came when Hurricane Harvey impacted Houston in 2017. During the storm and its impacts, the capabilities of the smart grid avoided 41 million minutes of outage time for Houston residents, in part because electricity could be directed away from flooded substations, thus preventing equipment damage that takes a long time to repair. The utility could also remotely turn off power within the mandatory evacuation zone that the city established due to flooding after the storm. During the recovery effort, the data management and communications capabilities of the smart grid helped the utility restore power faster than would have been done without the technology.[30]

- The city of Chattanooga built a high-speed internet network in 2009 which then enabled development of a smart grid to serve the community. The city-owned utility deployed smart meters, switches, and sensors for the roughly 180,000 customers in the community. The project, which cost $369 million to deploy, delivers $23.6 million in annual cost savings to the utility and $43.5 million in indirect annual economic benefits to the community, mostly from reduced electricity outages. During a severe storm in 2012, the city was able to restore power 55 percent faster than would have been possible without the smart grid.[31]

DISTRIBUTED ENERGY RESOURCES

Loss of power can be fatal, especially when critical services are disrupted. In the widespread power outages following the June 2012 derecho, and its accompanying high-speed winds, 9-1-1 communications services for more than 3.6 million people in the Midwest and Mid-Atlantic were interrupted, in some cases for several days, in large part because service providers did not have backup power in place at central offices.[32]

One way to provide backup power is through distributed energy resources. Distributed energy resources (DER) are located onsite, so they may be less at risk of being disrupted when storms prevent electricity transmission and down distribution wires. They include microgrids, combined heat and power (CHP) systems, rooftop solar installations, backup power generators, and battery storage systems. Local governments can consider adding DER to municipal buildings as a way of ensuring continuity of government function during power outage. Incentives to encourage DER in other locations can also promote wider community resilience, especially for buildings providing critical services, like hospitals.

Importantly, not every distributed energy resource provides resilience to power outages, and sometimes their deployment actually increases vulnerability. For example, most rooftop solar installations “trip off” by default when the electricity grid loses power, as a safety precaution for utility workers.[33] Many solar installations owners don’t understand this possibility and can be left unprepared for power outages because they incorrectly anticipate their solar panels will provide them with power.

MICROGRIDS

Microgrids are electrical systems that pair electricity generation (from renewables, diesel, or other fuel) with electricity demand. They vary significantly in size, fuel source, and design, and these factors all determine system costs. Microgrids may or may not be able to operate during an outage on the broader grid, depending on how they are designed. Islandable microgrids, those that can operate offline from the grid, have greater resilience benefits. Some CHP systems can also be operated as islandable microgrids. A separate C2ES report *Microgrid Momentum: Building Efficient, Resilient Power* examines the financing and legal considerations for microgrids, which differ by state and can affect microgrid costs.[34]

COMBINED HEAT AND POWER

Combined heat and power systems combine electricity generation and thermal energy (e.g. steam) production in a single system. Typically, the facility with the CHP system would use all the steam generated for its heating needs and have excess electricity to sell. Municipal office buildings could install CHP systems, or municipal services like wastewater treatment could use them. District energy systems, which can be centrally built and serve multiple buildings, are an example of a CHP application. Cities can build and operate district energy systems to serve downtown buildings with heat and electricity, as has been done in Nashville, St. Paul, and other cities. Large energy users like hospitals and universities may also build them. CHP systems of any type tend to result in cost savings for system owners because they are more efficient than separate systems and use less fuel overall.[35]

SOLAR + STORAGE

Solar PV systems generate electricity directly from solar energy. The number of installations is still relatively low, but growing rapidly because of declining costs and policy incentives. As mentioned above, PV systems are not typically designed to operate during power outages. The solar PV cells generate direct current (DC) electricity, which is then typically connected to an inverter to convert the DC electricity into alternating current (AC) electricity. The power grid and many appliances use AC electricity. A PV system's inverter will send power to the grid, and most of them will automatically disconnect the system when an outage affects the grid. However, specially designed inverters can be included in solar PV installations along with onsite batteries to allow the system to be islandable. Such systems are called solar + storage, and they provide resilience benefits by being able to provide some power during system outages, at least for as long as the battery can last.

BACKUP POWER AND/OR BATTERY STORAGE

Backup power is typically provided by gasoline- or diesel-fueled generators, but batteries are becoming another backup power option, especially when solar panels are installed on critical facilities or nearby. Cities can also consider how battery electric vehicles and fuel cell vehicles (EVs) are emerging as new potential devices to promote resilience to power outages. New technology is just beginning to be tested to allow vehicle-to-building (V2B) and vehicle-to-grid (V2G) interactions that can use vehicle batteries to power buildings or the grid at large. Even without V2B or V2G technology, EVs provide a redundant fuel source when motor fuel distribution is disrupted, as can happen following very large storms like hurricanes. Early EV adopters were pleased to find they could charge their vehicles and avoid long lines at gas stations that affected most drivers in the New York City region after Hurricane Sandy struck.[36]

Backup power for critical municipal services is a key resilience strategy, but cities can also provide incentives to homeowners and business owners to install backup power systems, including battery storage systems. Making sure the population can withstand a day or two without power makes them more resilient. This is especially important for individuals with medical devices at home. These critical customers may require special consideration from government and utilities in emergency planning.

COSTS

The costs of DER projects depend on the fuel used, power generating capacity (size), and other local factors. Costs are typically declining for all forms of distributed energy. State policies and electricity rate designs also influence the total net costs of DER projects.[37]

Microgrids

The upfront costs of microgrids can often be more expensive than buying grid power and installing traditional backup power such as gasoline- or diesel-fired generators. A benefit-cost analysis of five potential microgrids serving critical facilities in New York state found that all five had costs in excess of benefits, at least when the analysis included the value of electricity alone and excluded benefits of continuous power during long-duration outages. In the analysis, the case with the largest financial benefits was one where backup generators were already installed at a wastewater treatment plant and a fire station. The cost of installing a microgrid (distribution lines and control equipment) to connect these facilities with a nearby elementary school ranged from $439,000 to $919,000, depending on whether two or three facilities were part of the microgrid. Ongoing monthly variable costs were estimated at $5,000–$8,000.[38] The study authors concluded that installing traditional backup generators at the school was likely a lower cost option.

Identifying revenue streams from grid services and other electricity system benefits can change the benefit-cost analysis, though. Another site from the same study, in Suffolk County, developed a financially viable community-wide microgrid by combining benefits of solar power and avoided costs of new transmission to serve about 40,000 residents of East Hampton, New York. The microgrid also provides backup power to water pumping stations and a fire station. The solar generation of the microgrid ensures these critical facilities will continue operating, even if diesel supplies to operate their existing backup power units are interrupted. The project had 20-year costs (installation, operation, and maintenance) of $40.4 million, and 20-year benefits of $40.5 million when accounting for avoided transmission and $40.7 million when accounting for avoided power outages of up to one week per year.[39]

Combined Heat and Power

For services with high heating and power needs, such as hospitals or wastewater treatment plants, CHP systems typically provide cost savings, relative to buying power from the grid and generating thermal energy onsite, because a single system provides both functions. In addition, many CHP systems can operate when the power grid is offline, avoiding the need to purchase and maintain other backup systems.

System costs depend on the size, fuel used, and configuration. The city of Hampton Falls, NH, for example, replaced a fuel oil-fired furnace in its Public Safety Building with a CHP system fueled with propane and solar panels that provides electricity (offsetting grid purchases) and thermal energy. That small-scale project cost $78,000 to install and will offset $8,127 in annual energy costs, achieving a payback period of 7–10 years.[40] Similarly, the Winnebago County Sherriff's Office in Wisconsin installed a CHP system in 2007, then expanded it in 2009 to provide 2.5 MW power, building heat, and hot water. That system cost $3 million to install and has saved over $900,000 each year in energy costs, relative to buying power and generating heat onsite.[41]

Solar + Storage

The typical installation costs of solar PV systems in 2016 are estimated to be $15,581 for a small-sized system suitable for residential application. Simultaneously installing a battery increased the upfront cost by $13,987 to $29,568 for an AC-coupled system. Retrofitting an existing PV installation with an AC-coupled battery added $17,205 to the PV system costs.[42] The full cost of ownership of these systems would also consider operation and maintenance costs plus the reduced energy costs due to lower utility bills. Local policies will affect the utility bill reduction of DER, for example the kind of net metering policy that a state has in place.[43]

Backup Power

Diesel generators, which are widely used for backup power, cost less to install than many other DER, typically a few thousand dollars for a unit serving a single building. Operations and maintenance costs over the lifetime of the generator will vary with usage and diesel prices. Installing sufficient backup capacity to power critical services can be much more costly, though, because of the large size of the systems required. A study of supplying backup power to critical services in two Connecticut towns found that lifetime costs for backup diesel generation could be $15–$54 million dollars, depending on the size of the load being served. The study authors point out that while diesel generators had the lowest lifetime costs of any technology studied, they become much more expensive during long duration outages, and, since diesel supplies may run out during prolonged outages, they may not be the most attractive option available to communities.[44]

BENEFITS

Benefits of DER projects depend upon the type of fuel and the design of the project. Projects that use renewable electricity sources will have more environmental benefits than others. Projects designed to guarantee backup power supply will have greater continuous power benefits.

Reduced Energy Costs

As noted above, DER systems can lower energy costs, in some cases completely offsetting the capital costs of the energy generator and any electrical equipment needed for connecting and integrating the system with the grid. Today, CHP and solar + storage projects are more likely to have cost savings, relative to non-DER alternatives. Microgrids and backup power systems tend to be more expensive than relying on grid power alone, so they may be more attractive for critical systems where the resilience benefits are large. Each project will need to be evaluated for its own cost savings, but some illustrative examples demonstrate the potential savings that can be achieved. The town of Fairfield, Conn. implemented a community microgrid in 2015 that used multiple DER components to provide year-round heat and power to the town's police and fire headquarters, emergency communications center, a cell tower, and a homeless shelter.[45] The town is saving $70,000 in heating and power costs annually, and can provide services even during power outages. A completely solar-powered microgrid being constructed at a Seattle community center is expected to save $4,000 in electricity costs annually.[46] The center will also be used as a shelter during emergencies, providing community resilience benefits.

Continuous Power

Onsite sources of continuous power help avoid economic losses that power outages can cause through loss of productivity, loss of inventory, or other damages. The loss that any individual community experiences after a severe storm will depend upon the specifics of the storm. Major hurricanes that cause widespread outages lasting days are extremely costly. Just the outage-related costs of Hurricane Ike and Sandy are estimated to be $24 to $45 billion and $14 to $26 billion, respectively.[47] In comparison, a 13-hour outage affecting just the San Diego region in 2011 caused an estimated $93–$118 million in damages across the local economy.[48] U.S. Department of Energy has developed the Interruption Cost Estimate Calculator (ICE Calculator) to estimate losses due to power outages, though the tool only applies to outages of up to 24 hours in duration (see Tools). Very large storms can cause outages lasting several days or weeks.

For certain facilities, a continuous supply of electricity is of extremely high value. This is the case for critical services like hospitals, emergency shelters, and emergency responder stations. Uninterrupted power is increasingly becoming critical in homes where residents rely upon medical equipment for survival, and a power outage is a matter of life and death. To help protect this segment of the population, the U.S. Department of Health and Human Services created the emPOWER Map tool that shows the location of 2.5 million Medicare beneficiaries who use electricity-dependent equipment (EmPOWER Map described in "Tools" section below). Emergency responders and utility providers can use this information to better serve these individuals.

Traffic signals are another critical city service that can benefit from continuous power. A 2009 summary of battery backup systems (BBS) for traffic signals found that costs of BBS ranged from $5–$100, for batteries that can provide backup power for 2–10 hours. DER + BBS systems, for example natural gas-fuels systems like that installed in Overland Park, Kan. cost $30,000, but can operate for as long as natural gas supplies are available. Across the country, BBS have been found to reduce traffic accidents up to 90 percent. Industry practices value a car accident at $44,900, making BBS cost-effective based on the continuous power benefit alone.[49] Solar + BBS traffic signals are too newly available to have typical pricing values, although they are attracting interest, for example in Miami-Dade County, FL where a few temporary solar-power traffic lights were deployed in the power outage that followed Hurricane Irma in 2017.[50]

Improved Local Air Quality

The current default choice for backup power for many critical services is diesel generators. While these generators are reliable (so long as fuel supply is sufficient) and affordable, they do generate criteria air pollutants. Criteria air pollutant emissions from diesel generators cause negative health and environmental effects, and the carbon monoxide they emit can be fatal when diesel generators are used without sufficient ventilation, as sometimes happens in homes during prolonged power outages.

While EPA requires pollution controls on diesel generators, emissions are not eliminated and still occur during use. A study following a 2001 blackout event in California estimated that the use of diesel generators during the outage resulted in the emission of 14.7 tons of nitrogen oxides, 0.3 tons of sulfur dioxide, 0.4 tons of particulate matter, 2.5 tons of carbon monoxide, and 0.1 tons of volatile organic compounds.[51] Important to note, however, is that this power outage was planned in advance, lasted about 5 hours, and did not result in loss of power to critical services. In the case of long duration unplanned power outages, emissions of criteria pollutants would be expected to be much higher. Using a renewable energy DER option instead of diesel backup would reduce or, eliminate all of these emissions.

Reduced Greenhouse Gas Emissions

DER systems that use solar can also reduce the use of fossil fuels, even during normal power conditions, which provides a greenhouse gas benefit. The Las Vegas Metro Police Department installed solar + storage systems to power three emergency response communication towers. Those systems generate 165,973 kWh annually and will avoid 4,643,747 pounds of greenhouse gas emissions over their lifetime.[52]

For CHP systems, most of the greenhouse gas reduction benefit comes from the efficiency of combined heat and power, as opposed to the carbon intensity of the fuel used for electricity generation (see "Tools" section below for an EPA calculator). For example, a CHP system at South Oaks Hospital in Amityville, N.Y. with a 250 kW natural gas-fired generator and a 47 kW solar system uses 29 percent less fuel than separate electricity- and steam-generating systems would, resulting in 2,600 tons of avoided carbon dioxide each year (and $900,000 in annual energy savings for the hospital). The hospital has been able to provide continuous services through major blackouts since its installation, including Hurricane Sandy.[53]

Public Health and Safety

By providing power during widespread and long-duration power outages, resilient DER lets critical service providers continue their work of protecting public health and safety. Power outages are often responsible for the indirect deaths caused by hurricanes—through exposure to heat or cold, vehicle accidents when traffic signals don't work, and carbon monoxide poisoning from improper ventilation of diesel generators. A Florida law, passed in 2018, requires nursing homes and assisted living facilities to have emergency backup power; the law passed following the deaths of eight nursing home residents in the power outage that followed the landfall of Hurricane Irma.[54]

IMPLEMENTATION EXAMPLES

- Sterling, Mass. installed a 2 MW/3.9 MWh battery storage system that can provide up to 12 days of backup power to its police station.[55] The project cost $2.5 million to install. During normal conditions, the system generates electricity in the afternoon and evening hours, and it saved $400,000 in energy costs in its first year of operation.[56]
- A new transit-oriented development in Denver, Peña Station NEXT, used a public-private partnership to identify multiple stakeholders in a solar-powered microgrid with battery storage. Stakeholders Panasonic, Xcel Energy, Younicos, Denver, and the Denver International Airport all benefit from the project. The battery storage helps to integrate solar energy into the local grid during normal operations, thus helping both the utility and city achieve renewable energy goals, while Panasonic will have guaranteed back up power from the batteries in case of power outages.[57]
- The Acton-Boxborough Regional School District in Massachusetts examined two options for adding islanding capability to two schools that also serve as emergency shelters for the community. The schools have existing natural gas-fired backup generation and solar PV. Adding batteries and the electrical equipment necessary to allow islanding would cost $1,040,000 upfront with annual O&M costs of $13,000. Alternatively, replacing the existing gas backup with an islandable CHP system would cost $475,000 upfront with annual O&M costs increasing $22,513 relative to the existing system.[58]
- A hospital in Southern California is upgrading its existing CHP system with solar + storage and the electrical control equipment to form an islandable microgrid.[59] The project will provide three hours of electricity demand for the hospital when a power outage affects the grid. The system will reduce the hospital's demand for electricity purchased from the grid, both because of the onsite solar + storage and automatic demand response capabilities. The annual energy cost savings are estimated to be $141,000, and the annual greenhouse gas emissions reductions are estimated at 263 tons.

BUILDING ENERGY EFFICIENCY

Policies to promote energy efficiency, especially in residential buildings, improve community resilience to power outages. After major events, power may not be restored for several days. If ambient temperatures are extremely hot or cold during these outages, it can become a public health emergency. For example, of the 159 U.S. fatalities attributed to Hurricane Sandy, 50 were due to power outages that followed the storm, with hypothermia being a key cause of death.[60]

Efficient buildings retain their space conditioning (cooling or heating) longer during power outages, making building occupants more resilient to severe storms. A study of buildings in New York City found that if single family homes undertook efficiency upgrades, they could retain indoor temperatures of over 60 degrees during a week-long power outage in the winter, as opposed to falling below 35 degrees in just three days under existing, average efficiency performance.[61] This could improve health outcomes for residents living in such conditions and avoid burst pipes and other costly impacts associated with wintertime power outages.

Additionally, increasing energy efficiency can reduce peak electricity demand on hot summer days. Increasing daytime and nighttime temperatures due to climate change stress the power grid, and transmission lines do not work as efficiently.[62] This increases the risk of blackouts and brownouts due to system overloading during heat waves. Thus, energy efficiency provides resilience benefits in two ways: it can improve people's ability to withstand the outages that do happen because of storms or other extreme weather and help avoid outages from heat waves.

Energy efficiency projects that increase resilience to storm-induced power outages include increasing building insulation, window caulking, and repairing roofs. Each of these projects helps extend the period of time that a building can maintain a comfortable temperature when the power is off. Other efficiency projects like lighting upgrades share some co-benefits identified below, but they provide limited resilience to outages.

COSTS

Building energy efficiency upgrades that increase resilience vary in costs by project type and by location. Many of these upgrades are currently funded through the Low Income Home Energy Assistance Program (LIHEAP) and Weatherization Assistance Program (WAP). Both of these federal programs are administered by states and can fund energy efficiency improvements in eligible residential buildings. In Washington, D.C., the project expenses in its WAP program include attic air sealing at $2.53 per linear foot, spray foam insulation for $4.10 per linear foot, and wall insulation for $3.50 per square foot.[63] The Department of Energy reports that the average cost of all efficiency measures in WAP households is $3,545 per home.[64]

BENEFITS

Reduced energy costs

Building efficiency improvements lower costs for the homeowner and for broader society. The typical household wastes $200–$400 annually on heating and cooling expenses that arise from leaks and other inefficiencies, so reducing these leaks can save money right away.[65] Single family homes participating in WAP save an average of $283 in annual energy costs.[66] For low-income households, who tend to spend a larger share of their income on energy bills, the greater spending power that lower energy costs provides increases their ability to withstand unforeseen expenses.[67] This benefits the community at all times, not just in the aftermath of severe storms.

Societal benefits accrue from the avoided costs of new power generation and other electricity infrastructure that energy efficiency provides. Climate change is estimated to require an additional $50 billion in U.S. power system costs by 2050 because of the greater need for cooling as the Earth warms.[68] Efficiency can help offset these increased energy costs.

Reduced greenhouse gas emissions

Energy savings from efficiency can also reduce greenhouse gas emissions by reducing the consumption of fossil fuels. Evaluating the greenhouse gas reductions of individual building efficiency is difficult, because air sealing and other insulation improvements tend to be part of whole-house programs that also include, for example, lighting replacements. Nonetheless, a meta-analysis of residential energy efficiency programs finds that air sealing provides larger efficiency gains than lighting upgrades, and the greenhouse gas reductions from efficiency programs are around 1,000 tons per year (actual reductions will depend on the local carbon intensity of the electricity grid).[69]

Improved Public Health

Sealing leaks in the building envelope can reduce the amount of outdoor allergens and dust that can enter a home, leading to fewer asthma attacks, since these allergens are usual asthma triggers. Increased attic and wall insulation makes homes less drafty, keeping internal temperatures closer to a healthy range, and reducing incidence of thermal stress for residents. A survey of residents before and after home efficiency improvements found that asthma sufferers had 11.5 percent fewer emergency room visits in the year after weatherization, total medical care needs for cold-related illness fell 1.4 percent, and total medical care needs for heat-related illness fell 1.1 percent.[70] These health benefits over the first year of improved building efficiency are valued at $202.00 (asthma), $17.29 (cold), $8.52 per person (heat) per person.[71]

COMMUNITY PREPAREDNESS OUTREACH

Local governments have strong expertise in planning for hurricanes, tornadoes, blizzards, and other extreme storms. However, as climate change makes these extreme events more intense, planners should at least make sure they are using best practices for preparedness. Climate resilience can be improved by making sure that preparedness steps account for worst case scenarios (e.g., a severe heat wave following a hurricane) and cascading failures from power outages (e.g., loss of water treatment plants after prolonged outages). Some groups may need targeted preparedness information like people with disabilities or people with limited English language proficiency.

A variety of non-structural solutions exist to prepare communities to better withstand power outages. Readiness campaigns, using social media and other channels of communication, can encourage residents and businesses to stock up on critical supplies and educate them about what to do and where to go if the power is out. Early warning systems and emergency notifications, using text messages or conventional media like radio or television, can tell people when they might consider evacuation. All messages should be made available in as many locally-spoken languages as possible. When resources are not available to translate materials into multiple languages, community-based organizations or other trusted messengers can help spread information throughout non-English speaking communities. Emergency recovery efforts after prolonged power outages may need to consider additional health concerns, for example whether food in refrigerators and freezers is still safe to eat.

Emergency preparedness outreach can extend beyond being prepared to withstand power outages. Outreach to residents about securing objects that can be blown around by wind inside can prevent damage caused by flying debris.[72] Property owners can also be educated about tree plantings, maintenance, and pruning near utility wires, since many power outages after storms are the result of fallen trees or branches from private property, over which the local utility has no control.

COSTS

Many emergency preparedness outreach documents already include information on how individuals can prepare for power outages. Typical preparation steps involve monitoring weather reports, keeping batteries and flashlights on hand, charging cell phones in advance of a storm, and keeping refrigerators closed to preserve food.[73] Ensuring that emergency preparedness outreach also includes information on improving preparedness for power outages may not carry additional costs since this is part of current best practice.

Programs to improve tree maintenance on privately- or municipally-held land near power lines (in order to avoid outages due to falling branches) vary in cost. A study of Connecticut vegetation management programs advised municipalities in the state to budget $5,000 per mile for tree pruning, removal, and planting near roadways.[74] In Washington, D.C., enhancing the utility's vegetation management programs to remove dead or dying trees was estimated to cost an additional $3,000 to $5,000 per mile more than routine maintenance.[75]

BENEFITS

Improved public health

Communities that improve their resilience to storms will see fewer fatalities and faster return to normal economic activity following storms. A review of kidney patients affected by Hurricane Sandy found that those who received dialysis treatment in advance of the storm (a type of emergency preparedness action commonly undertaken by health professionals when power outages are anticipated) were 21 percent less likely to be hospitalized than patients who did not receive the early treatment. The early treatment patients also experienced a 28 percent lower 30-day mortality rate.[76]

Improved Awareness of Climate Change Risks

An emerging approach to emergency preparedness is a "Whole Community" approach, one that involves regular engagement with the full diversity of groups within a community.[77] This type of engagement allows emergency managers to better understand the climate risks and vulnerabilities of community members. This direct outreach also gives local government officials the opportunity to educate members of the public about climate risks facing the community. The benefit of improved awareness of climate change risks is a social outcome, and social outcomes are rarely assessed as part of program evaluation. However, evidence from community interviews suggests that preparedness outreach results in improved social capital and higher levels of trust between government and the public.[78]

IMPLEMENTATION EXAMPLES

- Leaders in Long Beach, Calif. held multiple community workshops focused on climate resilience. In these workshops, leaders gained a better understanding of the base level of knowledge of climate risks in the community.[79] Following the community outreach, a personal action guide was created to communicate to individuals the actions they could take to build resilience, including how to use less energy on hot summer days to avoid the risk of power brownouts and blackouts.[80]

- PEPCO, an electric utility serving Washington, D.C. and parts of Maryland, administers the Emergency Medical Equipment Notification Program. Utility customers can voluntarily participate in the program to receive advanced notifications of scheduled power outages and severe storms that could disrupt service.[81]

ENHANCING COMMUNITY EMERGENCY SHELTERS

Shelters can provide basic needs to residents who may be displaced because of storms. Similarly, community cooling centers can provide life-saving respite from extreme heat, and they may be especially critical when power outages prevent residents from running fans and air conditioners at home. Cities often use existing municipal properties, like schools, libraries or community centers, for these purposes.

To maximize the resilience benefits of these emergency shelters, local governments should take steps to ensure there is sufficient backup power (from traditional diesel generators or DER/solar+storage as discussed above) at these shelters during extended power outages.

COSTS

Using an existing building as a shelter generally imposes little additional cost. A 2014 survey of cooling centers in Maricopa County, Ariz. found that 33 of 53 cooling centers managers, or 62 percent, incurred no additional costs. The others did have extra costs from providing bottled water, higher energy bills, and extra staff hours, though many of these costs were lowered through community donations.[82] For short power outages or brownouts that might occur during a heat wave, existing buildings can improve community resilience without modifications. However, if buildings are to serve as emergency shelters during long-duration events, onsite backup power is required.

Select Florida schools that serve as emergency shelters have been retrofit with solar + storage systems that cost $74,000–$90,000 per school for 10kW solar panel installations and a 40 kWh battery. These shelters remained open with power following Hurricane Irma in October 2017 (even when gas supplies ran out for other backup generators). Additionally, these systems are estimated to save the school $1,500–$1,600 annually in electricity costs.[83]

BENEFITS

Public health and safety

Lives are saved when cooling centers are available during heat waves—times when the grid can be down or people may be forced not to use air conditioners because of high costs. Despite the clear connection between reduced heat exposure and reduced heat stress, very little observational data exists to attribute cooling centers to reduced fatalities. However, there is strong evidence that cooling centers, as part of a wider heat response plan, saved hundreds of lives during heat events in Chicago and St. Louis in 1999.[84]

IMPLEMENTATION EXAMPLE

- Broward County, Florida has distinct Special Needs Shelters for evacuation of people who require electricity for medical equipment. These shelters all have back-up power onsite. Additionally, the county provides transportation to the shelter, when needed.[85]

CASE STUDY: NEW ORLEANS IMPROVES ITS ELECTRICITY SYSTEM RESILIENCE

Hurricanes are a recurring threat in New Orleans. Since the destruction that followed Hurricane Katrina in 2005, many electricity system hardening actions were undertaken to improve the city's electricity resilience. Although power outages still do follow hurricane landfalls, the power restoration times have improved. A review of the power restoration following Hurricane Isaac's impact in 2012, for example, found that the local utility Entergy New Orleans beat industry standards in returning power service (although many residents still called for improvements, especially regarding the way that power outage duration estimates are communicated).[86]

TABLE 1: Co-Benefits of Resilience Strategies for Power Outages

	BENEFITS						
	LOSS AVOIDANCE	ENERGY SAVINGS	CONTINUOUS POWER	IMPROVED AIR QUALITY	REDUCED GHG EMISSIONS	PUBLIC HEALTH AND SAFETY	CLIMATE RESILIENCE COORDI-NATION
Microgrids	▲	▲	▲	▲	▲	▲	
Combined Heat and Power	▲	●	▲	●	●	▲	
Solar PV	▲	●	▲	●	●	▲	
Backup power/Battery Storage/EVs	●	▲	●	▲	▲	●	
Building Energy Efficiency		●			●	●	
Hardening Distribution Systems	●		▲			▲	
Smart Grid		●		●	●		
Emergency Preparedness outreach	▲					●	●
Enhanced Shelters						●	▲

Table 1. The benefits and costs of the strategies overviewed in the factsheet are summarized above, with dots indicating a benefit that could be expected from each of the strategies. When weighing different strategies for use in a community, consider the greatest local vulnerabilities, which benefits would address them and choose strategies that offer these benefits. Be aware of gaps in benefits offered by the strategies prioritized. The yellow triangles indicate benefits and costs that could apply in certain areas and depending upon the design characteristics of the strategy.

Building on this history of progress, the city of New Orleans is implementing additional programs that will improve the city's resilience to power outages. Some of these programs are included in the city's comprehensive resilience strategy, released in 2015, that identified electricity system vulnerabilities to stronger tropical cyclones and hotter summers.[87] Example programs include:

- Researchers from Sandia National Laboratory used computer modeling to simulate a "worst-consequence" hurricane impacting the city, and then mapped the locations for microgrids that would provide the greatest benefits to community well-being following a hurricane. Locations of hospitals, grocery stores, and municipal services all factored into the decision for priority locations.[88] In all, 22 locations for microgrids were identified, and the city is pursuing implementing these projects.
- The City Council developed the Energy Smart New Orleans program in 2011, which is administered by Entergy New Orleans. Homes and businesses can receive energy audits and receive subsidized weatherization and other efficiency improvements through the program—qualified

low-income households receive weatherization upgrades up to $3,000 in value at no charge to them. Between 2014 and 2016, low-income households received upgrades resulting in 1,644 kW in annual electricity demand reductions.[89] Efficiency savings from other programs in Energy Smart New Orleans, including businesses and commercial buildings, have generated even greater savings, relieving stress on the electricity grid and thereby decreasing the risk of power outage during hot weather.

- The city's hurricane preparedness information is located in a single place, and includes information on pruning trees ahead of storms, preparing for power outages, registering as someone who needs electricity for medical equipment, and other best practices. The preparedness guide is available in three languages.[90]

INSIGHTS

Severe storms and extended power outages may be rare occurrences, but when they do strike they can devastate an entire region. Climate change is strengthening these storms, making it more likely that when they do occur they will be stronger than in the past. While many examples of best practices come from hurricanes, cities across the country face risks of power outage and can apply the same lessons. There are many steps communities can take to increase resilience to storm-related power outages, and they have co-benefits like reduced energy costs, cleaner air, and improved public health and safety. Many of these strategies are low cost, and even those that are more expensive (like distributed energy resources) are seeing rapid cost declines and technology advances.

A critical determinant of a community's storm resilience is the resilience of its local electricity supply, and this is often outside the jurisdiction of local government. However, local leaders can be partners and allies of electric utilities as they work together to increase resilience. New technologies like rooftop solar and electric vehicles have a large potential to increase community resilience, but only under certain conditions. To ensure that deployment of these new technologies comes with resilience benefits, local leaders can explore programs to incentivize battery systems and V2B/V2G for rooftop solar and EVs, respectively. Education programs may also be needed so that residents have appropriate expectations of the resilience these technologies provide.

KEY TOOLS

Several tools are available to support decision making around adoption of resilience strategies to severe storms.

CHP ENERGY AND EMISSIONS SAVINGS CALCULATOR

This calculator, provided by EPA, is a spreadsheet-based tool to compare fuel consumption and emissions of carbon dioxide, sulfur dioxide, and nitrogen oxides for CHP systems and traditional separate systems. Emissions are region-specific, and take into account the local electricity mix.

https://www.epa.gov/chp/chp-energy-and-emissions-savings-calculator

ENERGY STAR PORTFOLIO MANAGER

This federal tool can be used to benchmark energy consumption of buildings, allowing policymakers to track the greenhouse gas emissions reductions that building efficiency programs deliver. The Portfolio Manager can be applied in a variety of building types and is being used by several cities in implementing building benchmarking policies.

https://portfoliomanager.energystar.gov

HHS EMPOWER MAP

The U.S. Department of Health & Human Services records the location of every Medicare beneficiary who uses electric medical equipment. These 2.5 million people have an especially critical need for continuous electricity service. Community plans to increase resilience to power outages can use this map to identify neighborhoods and municipal services that may take higher priority in planning.

https://empowermap.hhs.gov

HOME ENERGY SAVER

Homeowners can use public tools like DOE's Home Energy Saver, to calculate energy and cost savings for different efficiency upgrades, including wall and attic insulation, that also improve resilience to severe storms.

http://hes.lbl.gov/consumer

ICE CALCULATOR

The Department of Energy's Interruption Cost Estimate (ICE) calculator estimates the economic losses of power outages and can help assess the cost-benefit ratio of backup power or distributed energy resources.

http://www.icecalculator.com

LOCAL ENERGY EFFICIENCY POLICY CALCULATOR (LEEP-C)

This tool, created by the American Council for an Energy-Efficient Economy (ACEEE), calculates the community-wide energy and cost savings of policies that local governments might implement to improve efficiency. It includes 23 different policy types and can be tailored by the user.

http://aceee.org/research-report/u1506

SOLARRESILIENT

This tool, developed by the U.S. Department of Energy and the City of San Francisco, helps facility managers identify the backup power needs of a building and appropriately size a solar + storage system to meet those needs. It is particularly designed for use in resilience planning for city critical services.

https://solarresilient.org

WEATHER READY NATION

The National Weather Service provides up-to-date emergency preparedness information for a variety of natural hazards, including severe storms. The tips and tools provided on this platform can help communities better prepare for approach storms, thus reducing the damage they cause and enabling faster recovery.

http://www.weather.gov/wrn

C2ES thanks Bank of America for its support of this work. As a fully independent organization, C2ES is solely responsible for its positions, programs, and publications.

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