Lights Out?

Storm Surge, Blackouts, and How Clean Energy Can Help

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[EXECUTIVE SUMMARY]

As global warming pushes sea levels higher, the risk of coastal flooding from storm surge grows, posing a serious and worsening threat to electricity infrastructure along the U.S. East and Gulf Coasts. A large share of the major substations and power plants that provide electricity to more than 70 million coastal residents is already exposed to flooding from hurricanes, nor'easters, or other severe storms. Even more electricity infrastructure stands to be exposed, and to increasing floodwater depths, as seas continue to rise and drive storm surge higher.

Flood mapping of five major metropolitan regions along the East and Gulf Coasts conducted by the Union of Concerned Scientists suggests that if critical components of the electric grid are insufficiently protected, they risk inundation and the flood damage and failure that can ensue. The result can be widespread and long-lasting power outages.

To maintain the level of electricity reliability on which our safety, health, and daily lives depend, regulators and utilities evaluating threats to the electric grid must stop relying on historical data that greatly underestimate the risk of current and future flooding. At the same time, our states, towns, and cities should push for widespread deployment of resilient clean energy solutions that not only protect our communities when the centralized grid goes down, but also lower the electricity sector's global warming emissions, which will help limit longer-term sea level rise and other climate impacts.

The Steep Cost of Prolonged Outages

For communities hit by severe coastal storms, the devastation does not end when the skies clear and the floodwaters retreat. Because of outdated flooding assumptions and deteriorating electricity infrastructure, millions of citizens can emerge from being pounded by wind, waves, and water to find that the power is out—and stays out for days or even weeks.

The effects of such outages can be devastating. As arrestingly demonstrated by recent storms like hurricanes Katrina (2005) and Sandy (2012), lack of electricity following severe weather events can be another and separate disaster, triggering urgent patient evacuations from darkened hospitals, millions of gallons of raw sewage flowing into local waterways as treatment plants go dark, and hours-long lines at the few area service stations able to keep pumps running. Widespread post-storm outages can also cause major impacts closer to home, such as the loss of drinking water pumped from wells and throughout high-rise buildings, the inability to use ATMs or credit cards, and the failure of cell phone and Internet communications. Some populations—including the elderly, those with disabilities, and those with low income—are particularly challenged by power outages, and struggle to cope with their impacts.

Faltering Electricity Infrastructure

Power outages can occur because of damage to any part of the electricity system: the thousands of power plants generating electricity, the tens of thousands of substations enabling long-distance power transmission, and the millions of miles of transmission and distribution lines delivering electricity to our homes, businesses, and institutions. But despite our increasing reliance on electricity, our nationwide power grid is increasingly susceptible to failure due to old age and poor condition, and the rate of outages from severe weather has been rising.

With nearly one-quarter of the U.S. population living in counties along the East and Gulf Coasts, there is necessarily a large concentration of energy infrastructure built up in coastal areas. Inundation, or flooding of normally dry land, is the most direct hazard to these electric grid components. This type of flooding is typically associated with storm surge, where seawater presses far inland—sometimes at heights of 10 to 20 feet or more above typical high tide—due to strong winds. Because storm surge severity is determined by local geography, size and path of storm, and other factors, even an otherwise non-major storm system can produce severe surge. Submerged equipment can suffer catastrophic failure, and repairs—when possible—can be laborious and lengthy. But the alternative can be far worse:

complete replacement of substations can take more than a year and cost millions of dollars.

Many cities and towns along the East and Gulf Coasts have begun to confront the impacts of climate change now that high tides are routinely overtopping seawalls or backing up storm drains and causing nuisance flooding. Flooding precipitated by high tides alone are a harbinger of disruptive change to come; storm surges rolling in atop rising seas present increasingly grave concerns for coastal infrastructure.

Rising Risks: Present and Future Infrastructure Exposure to Coastal Flooding

To better understand how storm surge threatens East and Gulf Coast electricity infrastructure now and in the future, we modeled the projected inundation of large substations and power plants in five major metropolitan regions: the Delaware Valley, southeastern Virginia, the South Carolina Lowcountry, southeastern Florida, and the central Gulf Coast. Our findings can be considered an indicator of the general magnitude of risk that U.S. East and Gulf Coast cities face today, and can expect to face in the future.

Using a moderate, localized sea level rise scenario, we modeled the projected depth and extent of coastal flooding under a variety of hurricane strengths today, and factoring in additional sea level rise in 2030, 2050, and 2070. In this analysis, hurricane strength is used as a proxy for severity of storm surge; however, surge levels can vary widely from one storm to the next, including moderate levels from major storms and severe levels from moderate storms. To approximate impacts on the electric grid, in each region we characterized the potential inundation of power plants and higher-voltage substations. We selected those two grid elements because of their potential vulnerability to coastal flooding; their high installation, repair, and replacement costs; and their essential role in the power grid. If sufficiently protected, power plants and substations can be made less vulnerable to floodwaters. Across regions, we found:

- Electricity infrastructure in all five regions already displays significant exposure to storm surge from major storms today. For example, we found the share of exposed substations ranged from 16 percent in southeastern Florida to nearly 70 percent in the central Gulf Coast.
- While the electric grid has built-in redundancies that allow power to be routed around a few damaged generators or major substations, power loss becomes widespread once more than a handful of such key elements are knocked offline. In all regions examined, we saw evidence of the potential for such widespread losses if electricity infrastructure is unprotected, as floodwater depths often reach 5 to 10 feet, and even 10 to 15 feet, at exposed sites.
- As sea level rise continues to push flood levels higher, the depth of flooding will worsen, and storm surge could extend farther than it does today. For example, in southeastern Florida the number of major substations exposed to flooding from a Category 3 storm could more than double by 2050 and triple by 2070, while in the Delaware Valley, the number of substations facing floodwater depths of 10 to 15 feet or more grows by 15 between now and 2070.

The five assessments that follow in the main report illustrate the potential threat that coastal flooding poses to electricity infrastructure in these areas today and in the future. Importantly, while our results identify electric grid exposure (i.e., the presence of electricity infrastructure in areas that can expect substantial flooding), this does not mean that every substation or power plant in these areas is vulnerable to flooding, since some utilities may have already invested in reducing the vulnerability of some of this infrastructure (e.g., by elevating equipment). In other words, exposure does not necessarily result in impact. At the same time, our analysis does not capture additional, common storm risks such as wind damage to the grid or flooding associated with extreme precipitation. Finally, our results do not include the many lower-voltage, distribution-level substations that take electricity the last leg of the journey to most end users, and which may face risks similar to their larger counterparts.

Protecting Our Electric Grid Requires Foresight

In a warming world, building for today’s conditions leaves one unprepared for tomorrow. At present, it is common for a piece of infrastructure’s current floodplain location to dictate the scale and scope of flood protection applied to it. But with rising seas, that point of reference can shift over time. Using such a system as a basis for locating and designing long-lived infrastructure leaves major investments increasingly vulnerable to shifting realities. State or local governing boards can increase the stringency of flood protection requirements beyond those commonly informed by the Federal Emergency Management Agency's (FEMA's) static assessment, but few have taken the first step of conducting their own future risk analysis and vulnerability assessment to spark that change.

A variety of options are technically feasible for preparing new and existing electricity infrastructure for coastal flooding. These options can be grouped into three adaptation strategies:

- **Protection.** Continue to use vulnerable, unmodified equipment by building defenses, such as seawalls, bulkheads, or berms, around it.
- **Accommodation.** Modify new or existing infrastructure to enable it to operate normally in the presence of water. This can include elevating substations, using submersible equipment, and installing flood monitoring equipment to know when electricity loads should be redirected.
- **Retreat.** Retire or relocate at-risk infrastructure in situations where protection or accommodation may be technically, socially, or financially impractical.

Even with the availability of these solutions, many adaptation initiatives in the electricity sector have lagged due to an absence of best practices for determining when, and to what degree, such solutions should be deployed. Promisingly, some forward-looking policies and tools are beginning to emerge at the federal, state, and local levels to help address these gaps. They include broader cost-benefit analyses for adaptation measures, updated design standards to ensure "hardened" (flood-protected) infrastructure remains functional in the face of climate impacts, and providing local decision makers with the data they need to make informed adaptation plans.

Clean Energy: A Pathway to Resilient Power and Reduced Emissions

To maintain our present and future access to reliable electricity—and all the health, safety, and economic benefits such access allows—we must prepare our electric grid for increased coastal flooding. One necessary approach is adapting electricity infrastructure. However, it is also critical to simultaneously pursue solutions that go beyond intervening with specific pieces of equipment. For that, we can look to bolstering the overall electricity resilience of critical facilities and vulnerable populations.

Resilient power offers a system that is flexible, can respond to challenges, can quickly recover, and remains available when we need it most. Developing resilient power means shifting away from a centralized electricity system to a more decentralized one designed to meet critical needs even during extreme weather. When the power goes out, hospitals, water and wastewater treatment plants, community shelters, fire and police departments, and other critical facilities typically rely on backup diesel generators until the main electric grid can be restored. Backup diesel generators themselves, however, present a host of reliability and implementation challenges, including being prone to failure due to infrequent use.

Given the vital nature of the services provided by our critical facilities, the intrinsic flaws of the backup systems on which they rely, and the continued likelihood of power outages due to rising seas, it is essential for policy makers and utilities to look beyond current practices to create a more resilient power system. Clean energy technologies have the potential to be an important part of the solution, exceling where diesel generators and the centralized grid have struggled. Foremost among such solutions are:

- **Renewable energy with energy storage.** When coupled with storage systems such as batteries, renewable resources with variable output like solar and wind power are able to provide energy to users even when the sun sets, the wind stops blowing, or the centralized grid goes dark. In New Jersey, a multimillion-dollar initiative is under way to fund energy storage projects that support renewable energy systems at critical facilities.
- **Combined heat and power (CHP) plants.** CHP, also called cogeneration, produces electricity and captures thermal energy from a single fuel source; this dual-use approach can greatly increase fuel efficiency while independently supplying heat as well as power to critical facilities. During Hurricane Sandy in 2012, the CHP system at the Water Pollution Control Facility in Little Ferry, NJ, kept running, so the treatment facility—unlike many of its counterparts—did not need to dump raw or partially treated sewage into area waterways.
- **Microgrids.** These can be self-contained, self-sustaining systems that generate and consume all the energy within a compact geographical "island;" alternatively, they can be interconnected with the

broader electric grid and choose when to shift into island mode. During major outages, microgrids can turn into bright beacons of electricity amid widespread darkness. The Massachusetts Department of Energy Resources is currently hosting a $40 million, multi-year initiative to support municipal resilience with measures including microgrids.

The resilience-building attributes of these technologies include their location at or near where power is used (which eliminates reliance on long transmission lines or fuel supply chains), and their ability to start without a major outside electricity source (unlike most large generators). They can also provide power year-round, so absent an outage, consumers can either use that electricity directly to reduce their electric bills or, in some cases, sell it back to the grid or generate revenue through other grid support markets.

One of the best enablers of recent resilient power projects has been the decline in the cost of renewable energy and energy storage technologies. The 60 to 70 percent drop in the cost of wind and solar power over the past five years, combined with innovative financing methods emerging for funding such projects, has made these systems cost-effective for communities across the income spectrum, and vulnerable populations in particular can now be affordably buffered from the worst outage impacts.

Vitally, all these interventions must take place within a broader framework of purposeful reductions of the carbon emissions that drive climate impacts, including rising seas. Absent such a commitment, we face the prospect of increasingly severe future climate impacts. The strategic deployment of clean energy solutions enables us to reduce our fossil fuel use and support our communities with resilient power resources. And as the largest single contributor to U.S. global warming emissions—representing nearly one-third of total emissions in 2013—the power sector has a critical role to play in ensuring that we avoid the worst of future climate consequences.

Recommendations and Conclusions

The increasing threat of climate-related sea level rise and storm surge to our coastal electricity infrastructure is cause for serious concern. Ensuring reliable access to electricity now and into the future requires us to take thoughtful steps to consider the challenges not just of today, but also tomorrow. These include:

- **Protecting the grid from current and future impacts.** Utilities and regulators must take immediate action to protect electricity infrastructure from coastal flooding today, and ensure that interventions undertaken now incorporate the evolving context of climate impacts over the lifetime of investment decisions. Necessary immediate actions include consideration of the best available science by local decision makers, initiation of long-term adaptation plans by utilities, FEMA flood hazard maps that take climate impacts into account, and proactive use of federal disaster recovery funds.
- **Increasing the electricity resilience of communities.** We must move beyond the current focus on protecting the centralized grid and support our communities through the strategic deployment of distributed, resilient power resources. Regulators must enable cost recovery for utilities’ prudent investments in resilience, federal and state agencies must fund resilient power projects, and federal and state agencies must provide dedicated support to vulnerable populations.
- **Adopting strong policies to reduce carbon emissions.** We must place all actions within the broader framework of de-carbonizing the electricity sector in order to limit the severity of long-term climate impacts. Without such a plan in place, our adaptation approaches could eventually prove inadequate. Necessary steps include supporting strong state and federal carbon standards, adopting or strengthening renewable energy and energy efficiency standards, and increasing clean energy research, development, and deployment.

Our grid is already susceptible to coastal flooding. Rising seas and increasingly severe storms mean that unless we take purposeful action to adapt to worsening conditions, the electric power sector could become even more vulnerable to crippling outages over time. With our safety, health, and daily lives tightly intertwined with electricity, it has become increasingly critical that we limit the risk of such impacts. We must, therefore, apply foresight to long-term grid planning and encourage the purposeful adoption of clean energy solutions that bolster the electricity resilience of our communities, while limiting the scale and scope of future climate impacts.

[INTRODUCTION]

A Grid Submerged

Despite our increasing reliance on electricity, our electric infrastructure has deteriorated and the rate of outages from severe weather has been steadily increasing over the past few decades. As we look to a future of rising seas and more severe storms, we face an even greater challenge to ensure stable, reliable access to electricity. The situation is also highly ironic: the electric power sector remains the single largest contributor to the U.S. emissions of carbon dioxide and other heat-trapping gases driving the growing threats to the electric infrastructure itself, representing nearly one-third of total global warming emissions in 2013 (EPA 2015a).

This report focuses particularly on the vulnerability of our electricity infrastructure to coastal flooding from sea level rise and storm surge along the East and Gulf Coasts. Sea level rise intensifies the threat of inundation not only from higher sea level itself, but also from higher tides and major storm surge. By 2050, many coastal towns and cities are projected to see daily high tides more than a foot above present, and storm surges overtopping current flood levels (Spanger-Siegfried, Fitzpatrick, and Dahl 2014). But despite the long lifetime and high cost of electricity infrastructure, and the tremendous impacts felt by society when the power goes out, the majority of electricity planning decisions and flood protection policies continue to be informed by historical data that greatly underestimate the risk of future flooding exposures.

To protect our electricity infrastructure from these growing risks, and to develop a more resilient and dependable electricity system, we must prepare for rising seas and increasingly severe storms, among other climate impacts. Preparation includes adapting our energy infrastructure to manage evolving coastal flooding threats, as well as dramatically reducing carbon emissions to limit the degree to which these climate impacts will continue to grow over time. Cutting electric sector carbon emissions by deploying clean energy solutions can promote the development of a more resilient power system today, and help limit the worst of future climate threats.

Building upon two recent Union of Concerned Scientists reports *Power Failure* (Davis and Clemmer 2014) and *Encroaching Tides* (Spanger-Siegfried, Fitzpatrick, and Dahl 2014), we analyzed the growing vulnerability of our electric infrastructure to coastal flooding from storm surge and sea level rise over the next 55 years (to 2070). To better understand these risks, we modeled the projected inundation of power-generating plants and major substations in five metropolitan regions: the Delaware Valley, southeastern Virginia, South Carolina Lowcountry, southeastern Florida, and the central Gulf Coast.

Our findings indicate a societally unacceptable risk of major, widespread electric outages from storm surge along the East and Gulf coasts of the United States today. Storm surge is a major coastal-region hazard; it can accompany not just hurricanes but also other types of coastal storms such as nor’easters, and can be severe even if the storm itself is not categorized as a “major” hurricane. We document the faltering state of the electric grid, the current limitations of flood protection policies, and the immediate need for proactive investment in infrastructure to address those threats. Finally, we offer recommendations on how to reduce global warming emissions from the electricity sector by proliferating resilient, clean energy systems that not only improve our prospects for tomorrow, but also bolster community electricity resilience today.

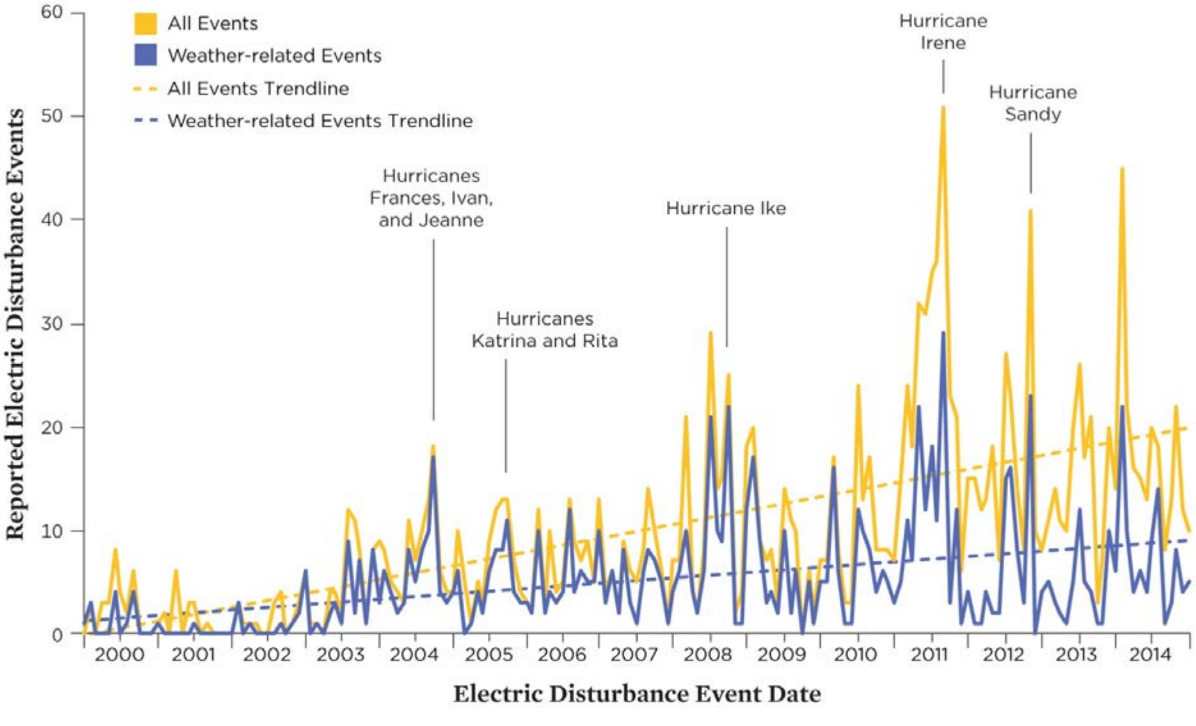
Faltering Electricity Infrastructure

U.S. electricity infrastructure is old and outdated. The deteriorating state of the electric grid leaves it highly susceptible to outages when faced with additional stressors like that of extreme weather. We detail here the current state of the electric grid, and the costs and impacts caused by these increasingly frequent power outage events. We also detail the growing threats near- and long-term coastal flooding present to our electricity system. If we must upgrade our electricity infrastructure just to attain the reliability on which our society's critical infrastructure—and livelihoods—have come to depend, we should do so in a way that comprehensively considers future threats facing the electric grid.

Power outages can occur because of damage to any part of the electrical grid, from the thousands of power plants generating electricity around the country, to the millions of miles of transmission and distribution lines delivering it to homes, businesses, schools, and hospitals. These many points of vulnerability are increasingly susceptible to failure due to their old age and poor condition; although there has been an uptick in investment in recent years, maintenance has been insufficient when compared to need (DOE 2015a). In 2013, the American Society of Civil Engineers (ASCE) issued the American energy sector a grade of D+, or "poor", in their *Report Card for America's Infrastructure* (ASCE 2013). The Department of Energy's 2015 *Quadrennial Energy Review* highlighted the serious need for investment in modernizing the electric grid, and noted the urgency required to address the vulnerabilities of energy transmission, storage, and distribution in the face of an increasingly electricity-dependent world (DOE 2015a).

Given the escalating vulnerability of the electric grid, and mounting stresses from extreme weather events, power outages have increased. According to government records tracking major outages at the transmission level (transmission means moving electricity long distances from power plants to communities, as opposed to distribution, which refers to moving electricity shorter distances to end users), from 1992 to 2011, there were 1,333 reported disturbances to the transmission grid. The disturbances ranged from physical attacks such as vandalism to extreme weather events such as tornados or thunderstorms (Mills 2012). Over those two decades, weather-related events caused an increasing share of total disturbances: from approximately one-quarter of tracked outages in 1992, to approximately three-quarters in 2011 (Mills 2012; OE n.d.; see Figure 1 for more recent 2000 through 2014 numbers). Notably, when extreme weather hits the electric grid, the impacts are relatively long-lasting compared to other types

FIGURE 1. **U.S. Electric Grid Disruptions**



The Department of Energy tracks major electric disturbance events through Form OE-417. Utilities submit information about qualifying incidents, including when they occurred, where they occurred, what triggered them, and how many customers were affected. Notably, while the reported number of non-weather-related events is high, the vast majority of incidents resulting in customer outages occur because of weather.

SOURCE: UCS ANALYSIS, BASED ON OE N.D.

of disturbances as storms can cover large areas and cause many points of damage across the grid. From January 2011 through August 2014, for example, while weather-related events made up fewer than half of all reported disturbances, they were the underlying cause of well more than 90 percent of customer interruption hours (DOE 2015a).

Growing Outage Costs

Electricity plays an essential role in supporting the critical facilities that form the backbone of our society, from hospitals to water treatment plants and communications systems to emergency response teams (PPD-21 2013). Among other things, such critical facilities and services support disaster response operations during emergencies, and enable efficient recovery by our communities following disasters. Managing disaster response is a tall order by itself; when compounded with the loss of electricity during and after a severe storm, the entire recovery process is hindered, and lives are placed at increased risk.

Beyond enabling our most vital support systems, reliable electricity access is a widespread assumption of modern day life. Society depends on electricity to power life-saving medical devices, pump drinking water from wells and throughout high-rise buildings, operate refueling pumps at service stations, move elevators up and down in apartment buildings, run air conditioners and furnace blowers, and enable communications via broadcasting, cellular telephone, and internet. Less visible but no less essential is our dependence on electricity for refrigeration to keep food fresh, traffic signals and street lighting to keep transportation safe, and the hosts of servers and electronic payment processes that keep businesses running. And with ever more daily activities becoming entirely dependent upon portable electronic devices, the scale and scope of outage impacts continue to increase dramatically. In short, very few commercial or social interactions are now untouched by electricity-based transactions.

Critically, several populations—including the elderly, those with disabilities, and the low-income— are particularly challenged by power outages, and often struggle to cope with the aftermath of severe weather events. These communities tend to shelter-in-place due to obstacles associated with managing and affording evacuations, alternative housing arrangements, and other post-disaster contingencies (CEG 2014; Kelly and Ross 2014). It is critical to recognize that when the power does go out, these populations are particularly affected, and in great need of support.

TEXTBOX 1. **Strictly Speaking: On Framing Climate Impacts**

Experts discussing climate change apply highly specific meanings to words also used in common parlance. Below are precise definitions of common words by the Intergovernmental Panel on Climate Change (IPCC 2014), and as they are used in this report:

Exposure: The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.

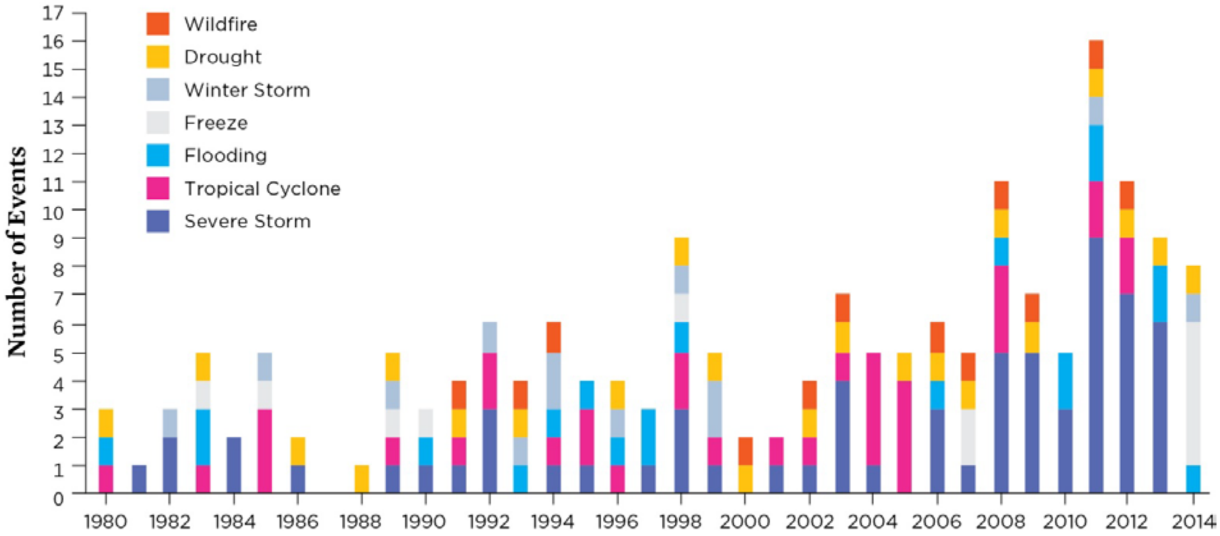
Hazard: The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. Here, the term *hazard* refers to climate-related physical events or trends or their physical impacts.

Vulnerability: The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

Risk: The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability or likelihood of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur.

In the IPCC's widely-used risk framework, *risk* results from the interaction of a climate *hazard*, *exposure* to that hazard, and *vulnerability* to the ensuing impacts. Our analysis considers the hazard of coastal flooding from sea level rise and storm surge, and analyzes the exposure of electricity infrastructure to that hazard by determining whether or not a component is located within a land area modeled as flooded. The analysis does *not* consider the vulnerability of individual substations or power plants to flooding; to do so would require a detailed assessment of the protective measures in place for each asset, a task outside the bounds of this high-level analysis.

FIGURE 2. **Billion-dollar Disaster Events by Year, 1980–2014**



Since 1980, the number of billion-dollar weather-related disasters has been on the rise. After adjusting for inflation, 178 weather and climate disasters have resulted in total damages reaching, and more commonly exceeding, $1 billion. Together, these events are estimated to have exceeded $1 trillion in costs.

NOTE: No billion-dollar weather disasters were reported for 1987.

SOURCE: NCEI N.D.

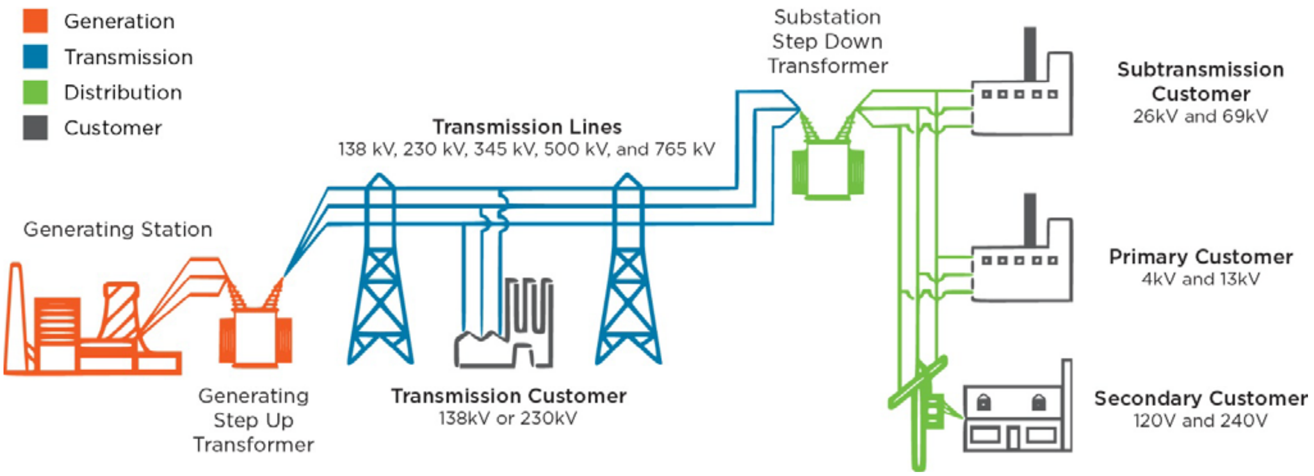
Moreover, cascading system dependencies can rapidly amplify the cost of power outages. A 2015 analysis estimated that a 30-minute service interruption could cost a medium or large commercial or industrial customer more than $15,000, while an outage over two-thirds of a day could cost those same customers more than $165,000 (Sullivan, Schellenberg, and Blundell 2015). Lost output is estimated to account for 20 to 25 percent of all weather-related outage costs, and estimates of the total cost of weather-driven outages vary between $18 and $70 billion per year (ranging in part because of the fluctuating number of major storms striking the nation each year) (Executive Office of the President 2013; Campbell 2012; see Figure 2).

When the power goes out, utilities face many costs that, typically, result in higher electricity bills for consumers. The most direct is that of repairing or replacing damaged electric infrastructure, including the labor hours required to complete the job. After a big storm such labor expenses can be significant, as overwhelmed utilities often draw upon workers from outside the region to help in completing repairs as fast as possible. Following Hurricane Sandy in 2012, for example, Consolidated Edison Company of New York (“Con Edison”) estimated the total storm damage costs for its electric operations at $310 million, nearly three-quarters of which was attributed to labor (Con Edison 2014). The remainder of costs is typically allocated to equipment repair and replacement, although lost revenue from disrupted grid services can also present losses to utilities. How much utilities are able to recover of expenses incurred before and after storms, including how much electricity consumers are forced to pay in additional monthly bill charges, varies widely across states (EEI 2014).

Rising Seas and Coastal Electricity Infrastructure

Approximately one-third of the U.S. population lives in ocean-shoreline counties (NOAA 2013). As a result, a large amount of energy infrastructure is built in coastal regions to support the commercial, industrial, and residential development in the area. When seas are calm, this proximity to the ocean provides a host of benefits to the energy sector, such as sources of water for power plant cooling, and ready access to ports for routing fuel supply chains. When storms

FIGURE 3. **The Centralized Electric Grid**



The centralized electric grid is designed to move electricity long distances, running power from a few large generating stations to many small end users. Substations are critical nodes through which transformers "step up" and "step down" voltage to allow for the efficient transmission of electricity from places of generation to places of use. If a few substations go down in an area network, outages can ripple throughout the grid.

SOURCE: DOE 2006.

strike, however, coastal locations face the risk of coastal flooding. As seas climb higher, coastal flooding hazards will increase.

TEXTBOX 2. **Coastal Flooding and the Grid**

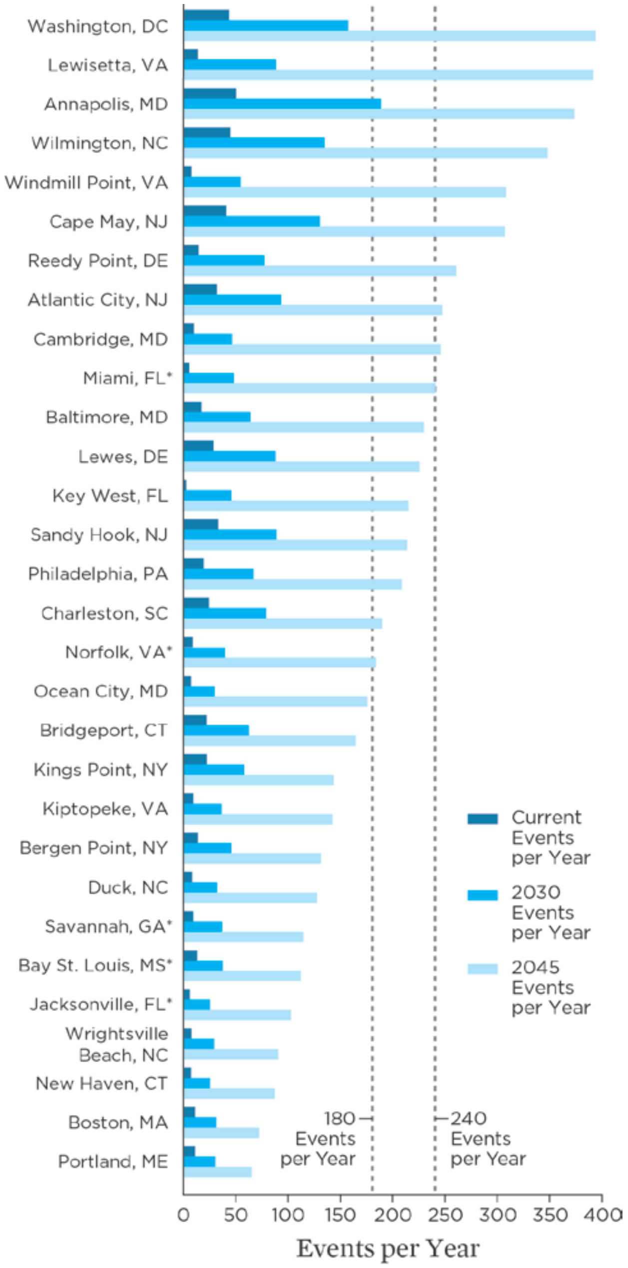
From power plants to transmission and distribution infrastructure, the electric power sector is highly vulnerable to severe storms and flooding. The 2005 hurricanes Katrina, Rita, and Wilma, and the 2008 hurricanes Gustav and Ike, wreaked havoc on the grid, knocking out power to between one and three million customers at a time. Over the course of the storms, Gulf states saw more than 300 substations off-line from Katrina, more than 500 from Rita, and more than 200 from Wilma; in 2008, both Gustav and Ike each caused more than 350 substations to stop running (OE 2009).

More recently, Hurricanes Irene (2011) and Sandy (2012) showed severe coastal storms could cause major damage further north, too. Those storms resulted in power outages for more than 6.5 million and 8.5 million customers, respectively, with many in the dark for days, and some even for weeks. Irene damaged at least 46 substations, and Sandy at least 165 (OE 2013).

Inundation, or flooding of normally dry ground, is the most direct hazard to electric grid components—including power generators, transformers, and substations—in coastal areas. Flooding is typically associated with storm surge, wherein seawater presses far inland—sometimes at heights of 10 to 20 feet or more above a typical high tide—due to strong winds. Resulting submersion can trigger catastrophic failure of equipment. When one major, transmission-level substation fails, utilities are typically able to work around the unit and maintain electricity across the lines. However, once more than two or three major substations go down, the resulting outages can be widespread. Major substations are central nodes within the electric grid, through which nearly all electricity must travel before it is distributed to customers. Thus, when a few major transmission substations go out, that can cut off electricity to everybody down the line, too; downstream power can come back on only once the critical substations have been restored (see Figure 3).

Repairs of electric equipment following submersion are lengthy, requiring the disassembly, cleaning, drying, and reassembly of all components within a device. While such repairs are time-consuming, the alternative can be even worse: lead times for replacement transformers or substations, for example, can range from one to two years,

FIGURE 4. **Tidal Flooding Today, in 2030, and in 2045**



Of the 52 locations examined in the Encroaching Tides analysis, 30 (shown here) can expect at least two dozen tidal floods per year, on average, by 2030. And tidal flooding will occur even more often in many locations. By 2045, one-third of the locations analyzed can expect 180 or more tidal floods per year, and nine locations could average 240 or more.

*Data for these locations are represented by nearby tide gauges.

SOURCE: SPANGER-SIEGFRIED, FITZPATRICK, AND DAHL 2014.

and cost millions of dollars (Kumagai 2012; PG&E 2010). See Textbox 2 for examples of recent coastal flooding events impacting the electric grid.

In addition to inundation, flooding presents multiple indirect threats to the power grid. For example, non-inundated power plants may have to reduce generation or even shut down if floodwaters in surrounding areas disrupt access to the plant's fuel supply. If trains hauling coal are stopped because tracks are flooded or damaged, or if natural gas pipelines are harmed in the storm, then generators could run out of fuel to burn to generate electricity. Transmission towers and other electricity infrastructure can also be damaged from storm erosion if land and support structures are undermined or washed away. Corrosion from saltwater can cause components to fail. Further, if electric grid operators predict that equipment is at risk of flooding from a storm, they may pre-emptively cut power to minimize damage, as submersion while equipment is running can be far more damaging than that which occurs if the component has been de-energized. Finally, because of overlapping infrastructure dependencies, when the electricity does go out, other elements of the broader energy system may be affected, such as oil and gas refineries, natural gas delivery to homes and businesses, and pumps for refueling cars and trucks at gasoline stations.

As our oceans rise, flooding will reach progressively farther inland, putting more coastal infrastructure at risk. All along the East and Gulf Coasts, cities and towns are increasingly confronting early indicators of a changing climate, wherein high tides themselves overtopping seawalls or backing up storm drains and triggering nuisance flooding. A recent Union of Concerned Scientists (UCS) analysis examined 52 sites along the East and Gulf Coasts from Portland, ME, to Freeport, TX, and found that by 2030, tidal flooding is projected to occur at least two dozen times per year in many coastal communities, and more than 150 to 200 times per year in a few particular locations (Spanger-Siegfried, Fitzpatrick, and Dahl 2014; see Figure 4). Furthermore, tidal flooding will increasingly cause extensive flooding, which now typically results only during high winds and storms.

Flooding events precipitated by tides alone are a harbinger of more disruptive change to come. Storm surges rolling in atop these higher seas present ever-graver concerns for coastal infrastructure policies and planning. As sea levels rise, storm surge can reach farther inland, and inundated areas may be flooded at greater depths.

Modeling Present and Future Infrastructure Exposure to Coastal Flooding

Over the past several years, a series of high-impact storms has made it arrestingly clear just how vulnerable today's electric grid can be to coastal flooding. To spur policy makers and utilities in coastal communities to take action to reduce risks before they have to experience devastation first hand, we need to better characterize the vulnerability of today's critical infrastructure, and understand how the threats facing this equipment are increasing over time. We begin that effort by analyzing the potential present and future exposure of electricity infrastructure to storm surge in five metropolitan areas spaced along the East and Gulf Coasts (see Textbox 1 for a discussion on the use of "exposure," "hazard," and "vulnerability" in this report).

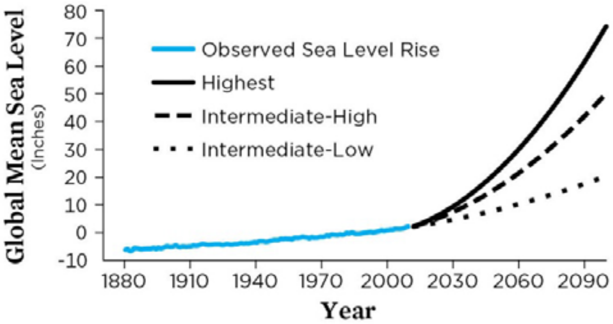
Using a moderate, localized sea level rise scenario based on an assumption of increasing ice sheet loss (Walsh et al. 2014; Climate Central n.d.; Parris et al. 2012; Figure 5), we modeled the projected depth and extent of flooding under a variety of hurricane strengths today, and while factoring in additional sea level rise in 2030, 2050, and 2070. In the model, hurricane strength is used as a proxy for severity of storm surge. However, storm surge levels can vary widely from one storm to the next, depending on radius of maximum winds, forward speed of storm, angle of approach, and local coastal features and offshore ocean depths (NHC n.d.a). No single storm will produce the flooding approximated by the approach followed here; instead, these maps present a worst case high water value based on a variety of variables including storm speed and trajectory (NHC n.d.b). See Textbox 3 for a summary of our methodologies, and our technical appendix (online) for a complete discussion.

We conducted our analysis in the following five metropolitan regions:

- Delaware Valley (including Camden, NJ, Philadelphia, PA, and Wilmington, DE)
- Southeastern Virginia (including Hampton, Norfolk, Portsmouth, and Virginia Beach)
- South Carolina Lowcountry (including Charleston, Georgetown, and Hilton Head Island)
- Southeastern Florida (including Fort Lauderdale and Miami)
- Central Gulf Coast (including Biloxi and Gulfport, MS, and New Orleans, LA)

Because our analysis is specific to storm surge, we limited our focus to sites along the East and Gulf Coasts, as that is where major surge-producing storms are more common. We chose the five analysis regions because of an

FIGURE 5. **Historical and Projected Sea Level Rise**



The 2014 National Climate Assessment used several different assumptions about how oceans and land-based ice will respond to future warming to project global sea level rise. The localized projections for sea level rise at our five locations are based on the assessment's intermediate-high scenario.

SOURCES: CLIMATE CENTRAL N.D., WALSH ET AL. 2014, PARRIS ET AL. 2012 array of factors, including their economic and cultural significance, the range of populations represented within and across sites, and the variety of federal-, state-, local-, and utility-level activities currently in place, including the heavy reliance on levee systems for risk protection displayed in the New Orleans area. We did not select these regions to highlight worst-case scenarios. As Table 1 documents, the regions represent a range of projected increases in local sea level; moreover, as the maps on the following pages illustrate, these regions also represent a diversity of electricity infrastructure density.

To approximate impacts on the electric grid as a whole, in each region we focused on the possible inundation of power plants and high-voltage substations because of their potential vulnerability to coastal flooding; their high installation, repair, and replacement costs; and their essential role in the power grid. We also chose to examine these key elements because both power plants and substations can be made less vulnerable to floodwaters. They are, therefore, prime targets for decision makers' attention when starting to build a more resilient electricity system. Finally, there is precedent for considering these components; power plants and high-voltage substations were used as indicators of the vulnerability of the electric grid to flooding from sea level rise, storm surge, or both in several recent studies, including those by the U.S. Department of Energy and the City of New York (Bradbury, Allen, and Dell 2015; OE 2014a; PlaNYC 2013).

While the electric grid has built-in redundancies that can overcome the loss of a few generating plants or major substations, widespread power losses arise once more than a handful of these key elements are knocked offline. Major substations are central nodes within the grid, so when more than one or two go down, all of the distribution-level substations that feed from them to deliver power to end-users can be knocked offline, too. That happened after major flooding from Hurricanes Katrina (2005), Irene (2011), and Sandy (2012), for example. Although outages because of generating plant inundation are far rarer than for substations, such outages have occurred, including during Hurricanes Katrina and Rita (OE 2005).

Strikingly, all the regions we considered already display significant exposure to storm surge from higher strength storms today. As sea level rise continues to push flood levels higher, the depth of this flooding will worsen, and weaker storms could produce more severe storm surge than they would today. Furthermore, evidence suggests that, as our climate continues to warm, an increasing number of hurricanes could reach the most intense levels (Categories 4 and 5) (Seneviratne et al. 2012).

In the case studies that follow, two maps are displayed for each region (with many additional maps available in digital format online; see www.ucsusa.org/lightsout for more). The top map illustrates the regional extent of potential storm surge from a Category 3 hurricane striking in 2012, 2030, 2050, and 2070. The 2012 values are the most recently available data, and serve as a conservative proxy for findings in 2015, or "today." The bottom map, on the other hand, displays the potential depth of inundation from a Category 3 hurricane striking the region in 2050. Within the lifetime of long-lived infrastructure investments such as power generators and major substations, 2050 serves as a possible checkpoint for the depth of inundation electricity infrastructure can expect over the life

TABLE 1. **Localized Sea Level Rise Projections**

Metropolitan Area	Tide Gauge Used for Sea Level Rise Projection	Sea Level Rise (Feet)		
		2030	2050	2070
Delaware Valley	Reedy Point, DE	0.5	1.3	2.3
Southeastern Virginia	Sewells Point, VA	0.6	1.4	2.3
South Carolina Lowcountry	Charleston, SC	0.4	1.1	2.1
Southeastern Florida	Vaca Key, FL	0.5	1.2	2.1
Central Gulf Coast	Grand Isle, LA	0.8	1.9	3.2

Information specific to each site's nearest tide gauge was used to model local sea level rise projections.

SOURCE: CLIMATE CENTRAL N.D.

of its operation. The histograms alongside the depth maps show how the depth of substation inundation shifts over time. With sea level rise driving storm surge ever higher, more and more major substations are exposed to greater depths of inundation.

Importantly, our results should not be read as marking every substation or power plant flagged as “exposed” as definitively vulnerable to flooding; exposure does not uniformly result in impact. Some utilities, for example, may have already invested in reducing the vulnerability of at-risk equipment through elevation, positioning of flood walls, or use of submersible components. Therefore, while the exposure of these grid elements may be high, their vulnerability may be low. On the other hand, our analysis does not capture wind damage to the grid, the threats to equipment posed by floating debris during flooding, or the additional inundation possible due to extreme precipitation during compound flooding events (Wahl et al. 2015); thus, our outage indicators are conservative by other measures. Furthermore, in areas of the central Gulf Coast heavily dependent on levees for flood protection, our modeling only captures subsidence in terms of relative sea level rise, and not reductions in levee height. Finally, our results nearly exclusively analyze higher-voltage transmission and sub-transmission substations, and very few of the many more lower-voltage distribution-level substations that take electricity the last leg of the journey to most end users. Although not captured here, the myriad smaller substations located in the same regions should be considered to be at similar risk of flooding exposure.

Ultimately, these findings help to illustrate the general magnitude of risk that our coastal cities face today, and can expect to face in the future. They should thus prompt more thorough, geographically and grid-specific vulnerability assessments—and action—at the local level, factoring in, for example, specific defensive measures already in place, and redundancies that may be built into the regions’ transmission and distribution networks. Such local assessments will require concerted effort and collaboration by government agencies and decision makers alongside utilities.

TEXTBOX 3. **Modeling Inundation of Electricity Infrastructure Over Time**

This report characterizes inundation of electricity infrastructure from sea level rise and storm surge in five metropolitan regions along the East and Gulf Coasts. The analysis is based on best practices established by the NOAA Coastal Services Center, as found in the *Mapping Coastal Inundation Primer* (Coastal Services Center 2012). Here we summarize our inputs and methods; for a complete description, refer to the report’s technical appendix.

Sea Level Rise. We used localized sea level rise projections for each region for the years 2030, 2050, and 2070 (Climate Central n.d.; Table 1 below). These projections are based on the Intermediate-High scenario of the 2014 National Climate Assessment (Walsh et al. 2014). This scenario is drawn from the higher end of the range of projections from semi-empirical models, which incorporate historical observations of sea level rise (Parris et al. 2012, and references therein).

Storm Surge. We modeled storm surge at each region using the National Weather Service Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model’s maximum of maximums (MOMs) and high-resolution digital elevation models, primarily from the U.S. Geological Survey’s National Elevation Dataset. The resulting maps show worst-case-scenario flooding given all possible storm paths for a hurricane of a particular strength. To model the evolution of storm surge over time given sea level rise, we linearly added the projected sea level rise for future time horizons to the SLOSH MOM and mapped the future depth and extent of inundation.

Electricity Infrastructure. We mapped power plant units and substations in each of the study regions as indicators of major electricity infrastructure. For power plants, we accessed geographic and operational data from SNL Financial LC (SNL n.d.), including only those plant units listed as “Operating” in 2014. For substations, we used data from Platts (Platts 2015), which predominantly captures transmission and sub-transmission substations (e.g., 115, 230, and 500 kV). This analysis does not reflect adaptation measures that may be in place at power plants or substations, such as equipment elevation, waterproofing, or constructed sea walls.

Each region’s analysis resulted in maps: 1) delineating the extent of storm surge over time for category 1, 3, or 5 hurricanes (or 4 in northern regions where category 5 storms are unlikely), and 2) demarcating the depth of inundation in each year for each category. For both series of maps, power plants and substations were listed as “exposed” to flooding if their point coordinates placed them fully within the mapped inundation areas.

[CASE STUDY 1]

Delaware Valley

Between its bucolic start in the Catskill Mountains of New York and its triumphant finish at the Atlantic Ocean through the shores of Delaware and New Jersey, the Delaware River serves as a major conduit for industrial activity within the region. Upon passing by Morrisville, PA, and Trenton, NJ, the river becomes a tidal estuary. From there to the sea, it has facilitated the development of concentrated industrialized areas, including Camden, NJ, Philadelphia, PA, and Wilmington, DE. Industries include shipping, chemical manufacturing, and refining. Critically, when hurricanes strike the coast, the Delaware Bay provides an opening for water to push back up the channel toward the cities and industrial sites along its shores.

Given the heavy riverine development in the region—and the electricity demand that such industrial development requires—it is no surprise that so much regional infrastructure is exposed to inundation. A Category 3 hurricane today has the potential to expose 79 substations to flooding (Figure 6a). By 2050, that number climbs to 84, more than a third of which could be exposed at a depth of 10 to 15 feet or more (Figure 6b). Parts of New Jersey west of Camden are projected to be particularly hard hit, with more than 20 major substations exposed, and many at high flood levels.

The Delaware Valley also illustrates the piecemeal approach currently being applied to regional challenges. In the aftermath of Hurricane Sandy, for example, policy makers in the region's three states (Delaware, New Jersey, and Pennsylvania) have reacted in different ways and to different degrees in terms of readjusting flood protection requirements. And as the president and CEO of Public Service Electric and Gas Company (PSE&G) noted in early 2015, his utility builds to the guidelines required of it by policy makers, even when the states around them require more or less, and even if a stronger storm could still knock out their electrical infrastructure (Birriterri 2015).

Summary Facts

Regional Population: 2.8+ million

Projected Sea Level Rise by 2050: 1.3 ft

Main Utilities: PECO, PSE&G, Atlantic City Electric, Delmarva Power

Power Plants: 71 (11,553 MW)

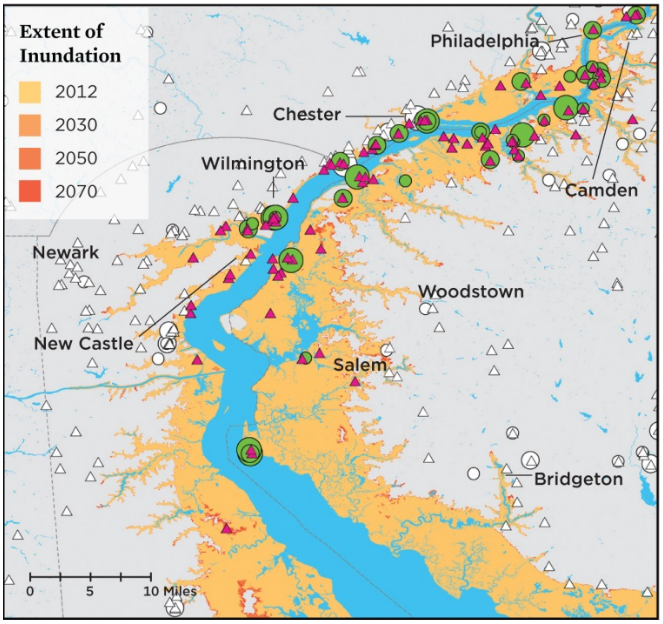
- 2 regulated, 69 merchant
- 2 nuclear, 21 gas, 4 coal, 13 oil, 22 solar, 7 biomass, 2 other

Substations: 263, including 75 x 138 kV, 76 x 230 kV, 13 x 500 kV, and 99 others

Recent Actions: PSE&G has launched a major gas and electricity upgrade in New Jersey following Hurricanes Sandy and Irene, as has Atlantic City Electric. For both, the initiatives involve tree trimming, transmission line hardening, and the elevation or relocation of equipment known to be vulnerable to inundation.

FIGURE 6. **The Electric Grid's Growing Exposure to Coastal Flooding in the Delaware Valley**

a. Flooding Extent from a Category 3 Hurricane



LEFT: *The potential reach of inundation up the Delaware River from a Category 3 hurricane today could leave 79 major substations and more than 8,800 MW of generating capacity in New Jersey, Delaware, and Pennsylvania exposed. By 2070, sea level rise drives potential storm surge even farther inland, and puts additional electricity infrastructure at risk.*

BELOW: *In the Delaware Valley region, the potential depth of inundation from a Category 3 hurricane in 2050 is significant. Even tens of miles up the river, substations and power plants could face floodwaters of 10 to 15 feet or more. When broken out by flood depth interval over time, an increasingly large number of substations could face floodwater depths of more than 15 to 20 feet.*

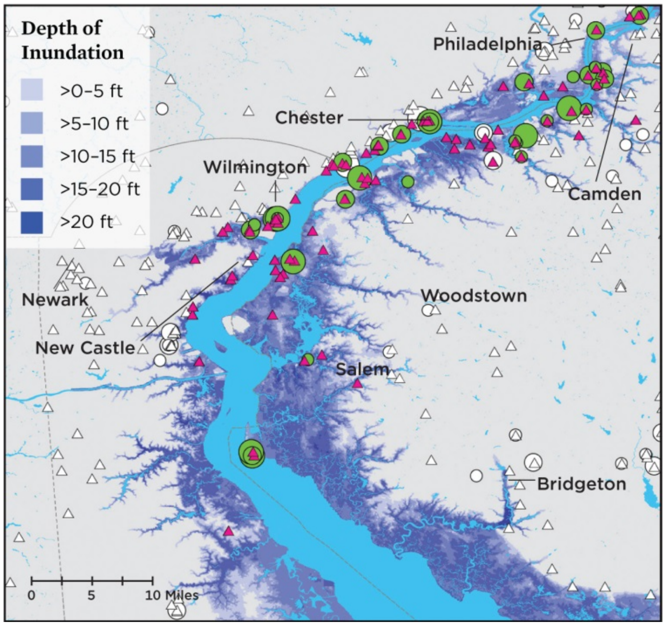
Power Plants

Exposed	Unexposed
● >0-20 MW	○ >0-20 MW
● >20-200 MW	○ >20-200 MW
● >200 MW	○ >200 MW

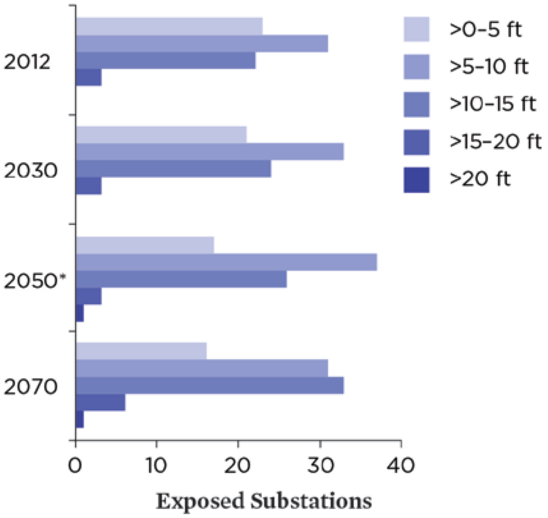
Substations

▲ Exposed   △ Unexposed

b. Flooding Depth from a Category 3 Hurricane, 2050



c. Potential Depth of Inundation of Regional Substations from a Category 3 Hurricane



*Scenario mapped at left

NOTE: These maps are for discussion and research purposes only. They are not appropriate for detailed analysis.

[CASE STUDY 2]

Southeastern Virginia

With its abundance of inlets and bays, the Hampton Roads region of southeastern Virginia is defined by its coastal location. The historical towns and cities dotting the densely populated shorelines—including Norfolk, Portsmouth, Hampton, Newport News, and Virginia Beach—are tightly tied to the waters that surround them, and the area's economy is driven by its proximity to the sea. The region is home to the U.S. Navy's largest naval base, and has one of the highest concentrations of military bases and facilities in the world; the Army, Air Force, Coast Guard, Marines Joint Forces, and North Atlantic Treaty Organization (NATO) command all have a presence.

In a 2008 analysis, the Norfolk–Virginia Beach area ranked 10th out of the world's 136 largest port cities in terms of assets exposed to coastal flooding (Nicholls et al. 2008). Our analysis finds that when just electricity infrastructure is considered, coastal flooding still poses a major threat to the region. With the sheer volume of exposed substations and power plants captured in the following maps and figures, it is likely that southeastern Virginia could face widespread, long-lasting outages should storms of sufficient strength crash through. Given the region's dependence on its coastal resources, prolonged outages are likely to be of tremendous economic and potential national security significance.

Figure 7a makes it immediately apparent that if a Category 3 hurricane were to strike today, vast swaths of the region are at risk of inundation. Our analysis reveals that four power plants and 57 out of 132 major substations are at risk of flooding today, including 15 of the 18 major substations in Norfolk and nine of the 11 major substations in Hampton. Figure 7b illustrates how the potential depth of flooding from such a storm will shift over time; between now and 2050—well within the lifetime of major equipment being installed today—an additional 13 major substations could face flood waters five to 10 feet deep, and an additional three could be exposed to depths of 10 to 15 feet.

Summary Facts

Regional Population: Around 1.7 million

Projected Sea Level Rise by 2050: 1.4 ft

Main Utility: Dominion Virginia Power

Power Plants: 12 (4,026 MW)

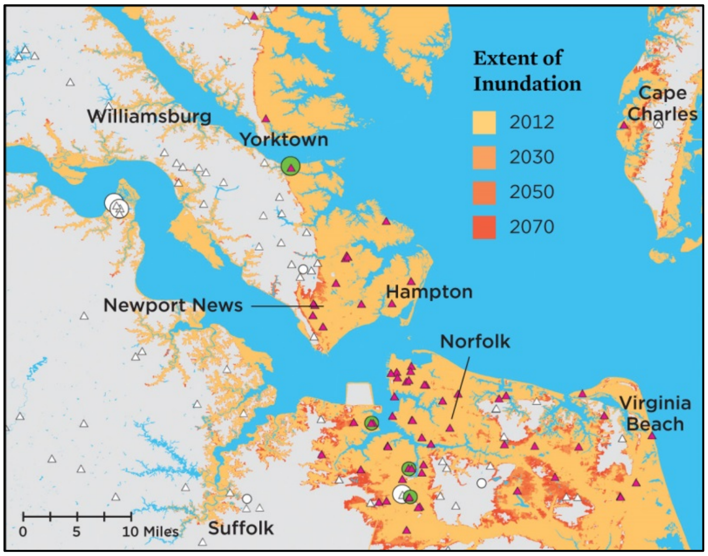
- 5 regulated, 7 merchant
- 1 nuclear, 1 coal, 2 gas, 4 biomass, and 4 oil

Substations: 132, including 58 x 115 kV, 48 x 230 kV, 7 x 500 kV, and 19 others

Recent Actions: Dominion Virginia Power recently initiated a $500 million, decade-long effort to upgrade and harden its substations. Much of this investment will emphasize protecting against physical assaults through the installation of such equipment as safety fences and security cameras.

FIGURE 7. **The Electric Grid’s Growing Exposure to Coastal Flooding in Southeastern Virginia**

a. Flooding Extent from a Category 3 Hurricane



LEFT: *The regional extent of storm surge washing over southeastern Virginia from a Category 3 hurricane today differs modestly from what we project in 2070. However, for locations on the margins, this difference can be everything; by 2070, a Category 3 hurricane could potentially expose some 15 percent more substations than it would today.*

BELOW: *In southeastern Virginia, 27 230-kV substations fall within areas potentially inundated by a Category 3 hurricane in 2050, as do an additional 26 115-kV substations and four power plants. Half of these exposed substations could be inundated at floodwater depths of five to 10 feet or more by 2050, and 62 percent by 2070.*

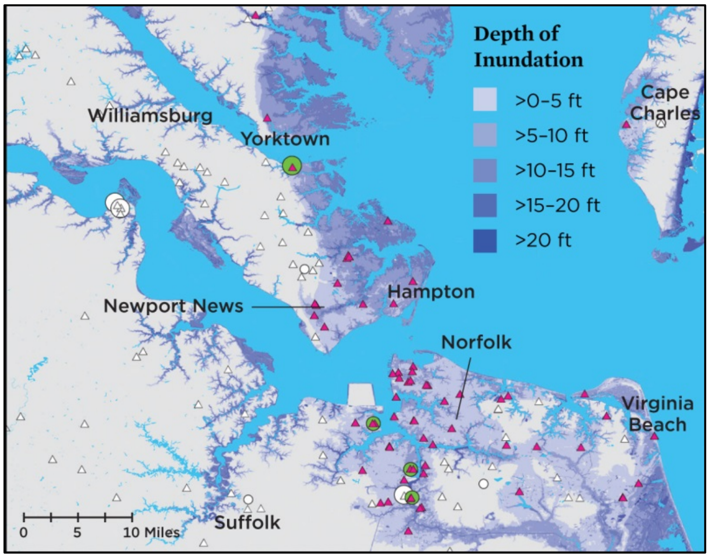
Power Plants

Exposed	Unexposed
● >0–20 MW	○ >0–20 MW
● >20–200 MW	○ >20–200 MW
● >200 MW	○ >200 MW

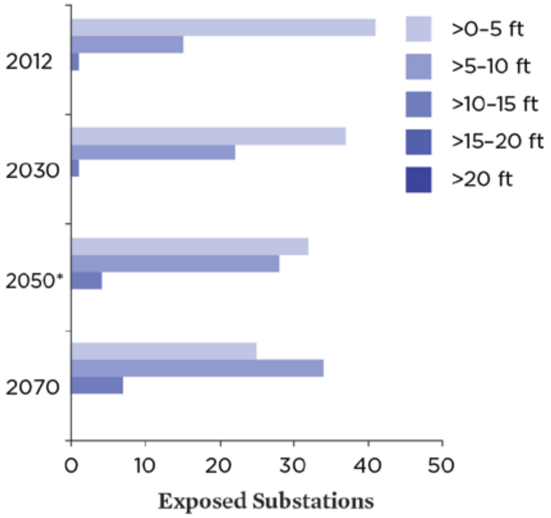
Substations

▲ Exposed   △ Unexposed

b. Flooding Depth from a Category 3 Hurricane, 2050



c. Potential Depth of Inundation of Regional Substations from a Category 3 Hurricane



*Scenario mapped at left

NOTE: These maps are for discussion and research purposes only. They are not appropriate for detailed analysis.

[CASE STUDY 3]

South Carolina Lowcountry

The South Carolina coast is a region deeply tied to the waters that surround it. Picturesque towns and cities dot the inlets that carve its shores. Today, these historical areas serve as major tourist destinations, as do the breathtaking beaches and estuaries that stretch the length of the state. Much of the region's population is low density compared to the coasts to its north and south, with the exception of the clustered Charleston, North Charleston, and Mount Pleasant areas. As tourism-oriented as much of the South Carolina coast is, however, the region also boasts a busy port and several major corporations.

Given its low-lying geography and the development of businesses and residences alongside coastal estuaries, the region is becoming a view of not just the past, but of the future: already, it wrestles with tidal flooding caused by sea level rise to date. A recent UCS analysis found that Charleston currently suffers more than 10 tidal floods per year, and will potentially see more than two dozen such floods per year by 2030 (Spanger-Siegfried, Fitzpatrick, and Dahl 2014). By 2050, the region is projected to see more than a foot of sea level rise.

If storm surge from a Category 3 hurricane rolls in atop these higher seas, the impacts on coastal South Carolina could be severe (Figure 8a). By 2050, seven power plants—totaling over 1,100 MW of generating capacity—could be exposed to flooding. Four risk being exposed at a depth of five to 10 feet, and one at a depth of 10 to 15 feet (Figure 8b). In the densely populated Charleston region, most of the major substations transporting this power to end users are at risk of exposure to deep and widespread inundation: nearly two-thirds of the 59 potentially exposed substations in 2050 are in locations projected to be inundated by more than five feet of water, and of these, 14 could face floodwater depths of more than 10 to 15 feet.

Summary Facts

Regional Population: Around 950,000

Projected Sea Level Rise by 2050: 1.1 ft

Main Utilities: SCE&G, Santee Cooper

Power Plants: 18 (5,197 MW)

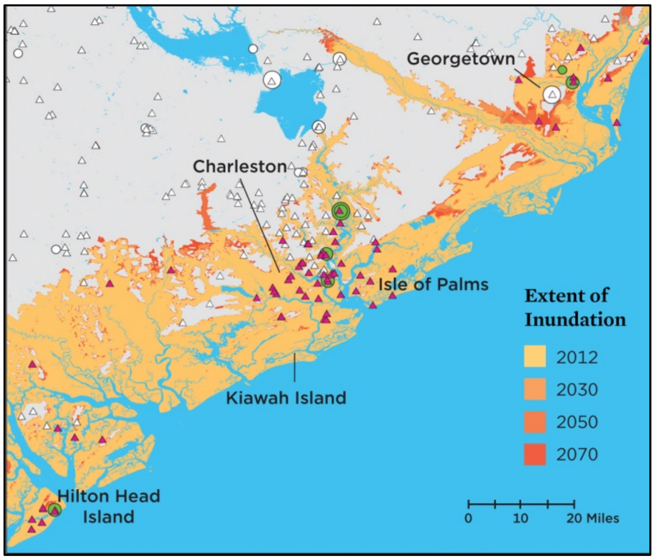
- 4 regulated, 14 merchant
- 2 gas, 4 coal, 3 oil, 5 biomass, 3 hydro, and 1 solar

Substations: 196, including 75 x 115 kV, 38 x 230 kV, and 83 others

Recent Actions: Though South Carolina has been hard hit by coastal flooding events in the past, state policy makers have been slow to acknowledge the threat of worsening floods due to sea level rise, and utilities have primarily focused on transmission line hardening when tackling system resilience. Meanwhile, local towns and cities including Charleston are reckoning with rising tides and coastal flooding, and adjusting their infrastructure to cope with the attendant challenges.

FIGURE 8. **The Electric Grid's Growing Exposure to Coastal Flooding in the South Carolina Lowcountry**

a. Flooding Extent from a Category 3 Hurricane



LEFT: *In the South Carolina Lowcountry, the extent of possible storm surge from a Category 3 storm today leaves 54 major substations and seven power plants (representing more than 1,100 MW of generating capacity) potentially exposed. As sea level continues to rise, storm surge can drive farther inland; by 2070, 67 major substations in the mapped area are exposed.*

BELOW: *Particularly around South Carolina's many coastal estuaries, floodwaters have the potential to push overland at damaging depths. In 2050, nearly a quarter of potentially exposed substations (14) and one power plant could face floodwater depths of 10 to 15 feet or more. By 2070, that number grows by an additional seven substations.*

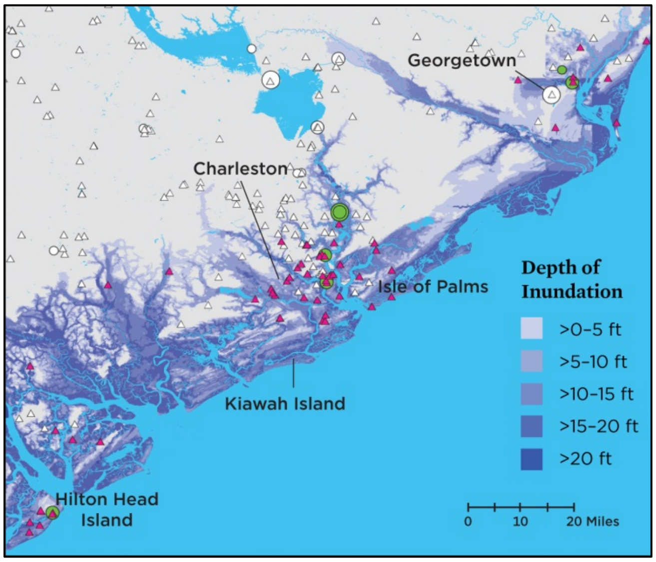
Power Plants

Exposed	Unexposed
● >0–20 MW	○ >0–20 MW
● >20–200 MW	○ >20–200 MW
● >200 MW	○ >200 MW

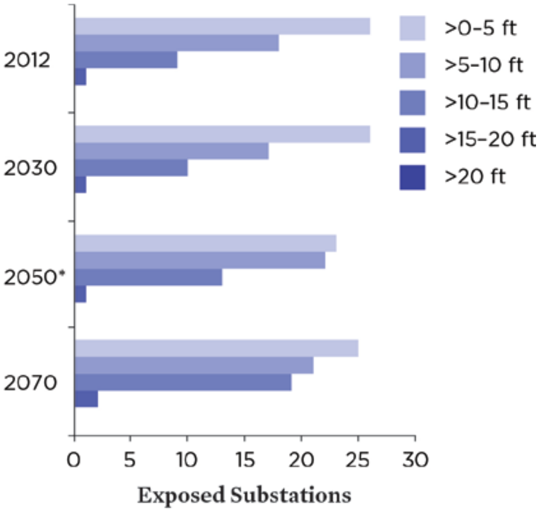
Substations

▲ Exposed △ Unexposed

b. Flooding Depth from a Category 3 Hurricane, 2050



c. Potential Depth of Inundation of Regional Substations from a Category 3 Hurricane



*Scenario mapped at left

NOTE: These maps are for discussion and research purposes only. They are not appropriate for detailed analysis.

[CASE STUDY 4]

Southeastern Florida

As a prime domestic and international tourism destination, southeastern Florida is a treasured cultural resource for the state and the nation. It is also a critical economic engine, with its booming real estate market and bustling cargo and passenger ports. Proximity to the ocean plays a central role in southeastern Florida's identity. But as much as the ocean now supports the area's successes, it also threatens to take them away; the region's low-lying geography leaves it positioned to experience some of the country's worst impacts of sea level rise.

Flooding is not a new threat to southeastern Florida. Indeed, in a 2008 analysis, Miami was ranked first of all the world's major port cities in terms of value of assets exposed to inundation today, and fourth in terms of exposed population (Nicholls et al. 2008). A frequent target of hurricanes, the region has struggled with severe storms causing widespread outages, particularly during the stormy 2004 and 2005 hurricane seasons. Our analysis finds that the region's utility, Florida Power & Light, must ensure that sea level rise is accounted for in its flood protection planning; without it, some critical substations may be at risk.

Figure 9a maps the evolving extent of storm surge inundation from a Category 3 hurricane today through 2070. While initially much of the major flooding may be limited to coastal areas, as sea level rises, parts of Fort Lauderdale, Miami, and Homestead are projected to experience inundation in increasingly inland locations. Such an increase results in the tripling of potentially exposed substations over time, from 37 today to 119 in 2070. Although Turkey Point, a large nuclear facility along the coast, is unlikely to be flooded by a Category 3 storm, everything around it is likely to be, and damage to nearby major substations could still prompt widespread outages in the region (see Figure 9b).

Summary Facts

Regional Population: 4+ million

Projected Sea Level Rise by 2050: 1.2 ft

Main Utility: Florida Power & Light (FPL)

Power Plants: 11 (6,133 MW)

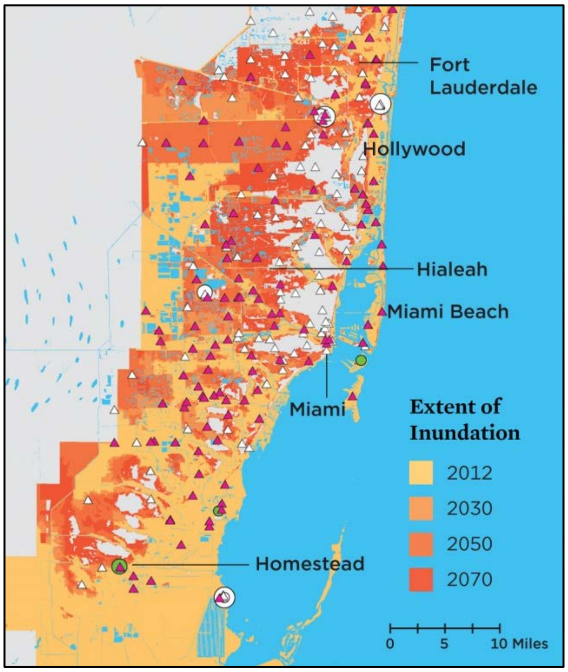
- 7 regulated, 4 merchant
- 1 nuclear, 5 gas, 4 biomass, and 1 oil

Substations: 222, including 70 x 138 kV, 97 x 230 kV, 6 x 500 kV, and 49 others

Recent Actions: Since a series of hurricanes tore through FPL's service territory in 2004 and 2005, the utility has poured more than $1.8 billion into storm hardening, much of which was used for strengthening power lines and poles. Following the damages witnessed in the Northeast from Hurricane Sandy in 2012, FPL began adding flood monitoring equipment to its most vulnerable substations.

FIGURE 9. **The Electric Grid’s Growing Exposure to Coastal Flooding in Southeastern Florida**

a. Flooding Extent from a Category 3 Hurricane



LEFT: *In southeastern Florida, sea level rise drives a large increase in the amount of electricity infrastructure potentially exposed to flooding from a Category 3 hurricane over time. In total, 37 substations and two power-generating plants are at risk of inundation from a Category 3 hurricane today, compared with 119 substations and three power plants by 2070.*

BELOW: *For most of southeastern Florida, the broad extent of potential flooding from a Category 3 storm in 2050 is more notable than the potential depth of inundation, with the number of potentially exposed substations more than doubling between now and then. However, for infrastructure in the southern portion of the mapped area, the depth of potential inundation is great.*

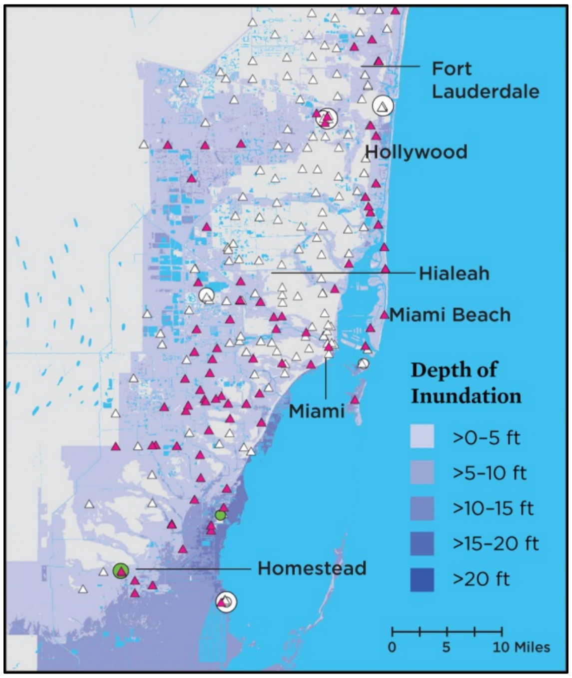
Power Plants

Exposed	Unexposed
● >0–20 MW	○ >0–20 MW
● >20–200 MW	○ >20–200 MW
● >200 MW	○ >200 MW

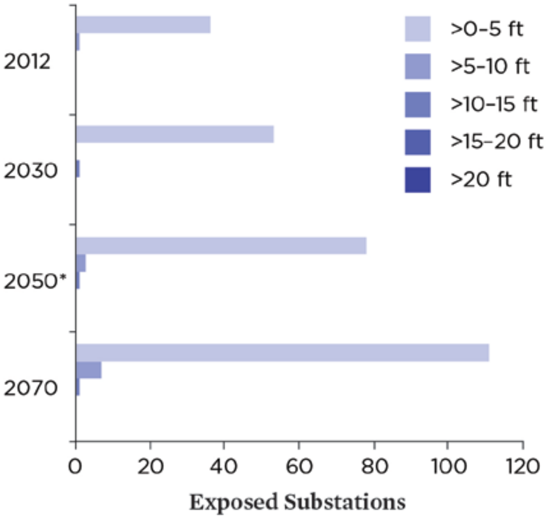
Substations

▲ Exposed	△ Unexposed

b. Flooding Depth from a Category 3 Hurricane, 2050



c. Potential Depth of Inundation of Regional Substations from a Category 3 Hurricane



*Scenario mapped at left

NOTE: These maps are for discussion and research purposes only. They are not appropriate for detailed analysis.

[CASE STUDY 5]

Central Gulf Coast

Along the Gulf Coast, it can be hard to tell where the water ends and the land begins. Outflowing rivers and streams divide the region's shorelines, and slow-moving, brackish bayous mingle land and sea. The local culture and economy are similarly intertwined with the waters that surround them; from fishing to offshore drilling to transporting goods, Gulf Coast livelihoods are inextricably linked to the sea. But with sea level rising and land rapidly subsiding back into the Gulf from natural and anthropogenic causes, the viability of this enduring closeness is called into question.

In our analysis of the central Gulf Coast—running from Port Fourchon, LA, to Biloxi, MS—local sea level (including subsidence) is projected to rise approximately 1.9 feet by 2050. As a low-lying delta, the region is already vulnerable to severe storms. When its susceptibility to major hurricanes is coupled with a quickly rising sea, the region's potential for experiencing severe damage from storms becomes even worse.

Over time, this area has invested heavily in defenses like levees and storm surge barriers as a response to flooding threats. However, as sea level climbs higher and subsiding land drops lower—including the land supporting these structures—these protective measures could become even less effective over time.

Our results highlight just how important it is for the region to incorporate future risks into current coastal flood protection policies. Already, the extent of land area potentially exposed to storm surge from a Category 3 hurricane today is striking (Figure 10a). Over time, the depth at which this land area could be inundated climbs rapidly (Figure 10b). Given that so many of the substations sited in these areas are critical enablers of the surrounding economy—including imports, exports, and refining—the potential economic fallout from any widespread outages could be significant.

Summary Facts

Regional Population: 1.5+ million

Projected Sea Level Rise by 2050: 1.9 ft

Main Utilities: Entergy, Mississippi Power

Power Plants: 21 (9,322 MW)

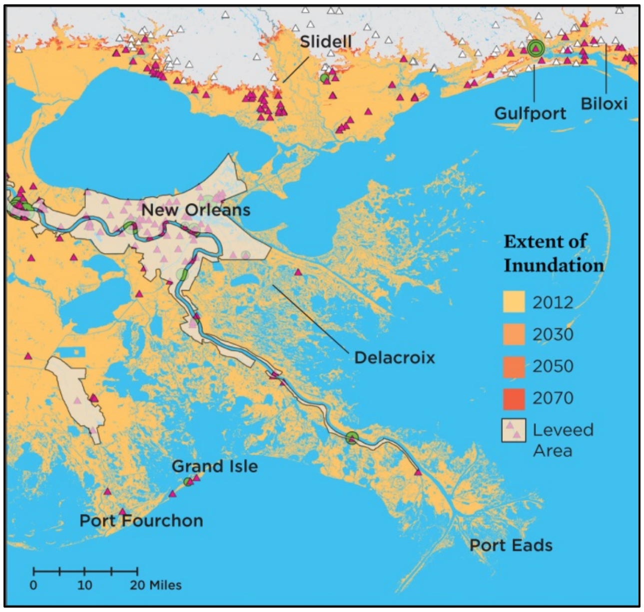
- 10 regulated, 11 merchant
- 1 nuclear, 16 gas, 1 coal, 2 oil, and 1 other

Major Substations: 274, including 97 x 138 kV, 100 x 230 kV, 6 x 500 kV, and 71 others

Recent Actions: Entergy and partners conducted a 2010 study finding the potential for regional economic losses from environmental impacts on the order of hundreds of billions of dollars over the next two decades. However, much of the corporation's resulting activities have been focused on prompting political action at the local level, rather than investing in long-viewed upgrades itself.

FIGURE 10. **The Electric Grid’s Growing Exposure to Coastal Flooding along the Central Gulf Coast**

a. Flooding Extent from a Category 3 Hurricane



LEFT: *The extent of inundation from a Category 3 hurricane today covers a large portion of the mapped Gulf Coast region, and leaves more than 9,300 MW of generating capacity and 188 major substations (108 of which are located in leveed areas) potentially exposed to flooding. By 2070, the number of potentially exposed substations grows to 207.*

BELOW: *For the central Gulf Coast, the depth of potential inundation from Category 3 hurricane grows increasingly severe as localized sea level rise drives storm surge higher. Today, 119 substations are facing floodwater depths of 10 to 15 feet or more; by 2050, that number jumps to 141 substations and 12 power plants.*

Power Plants

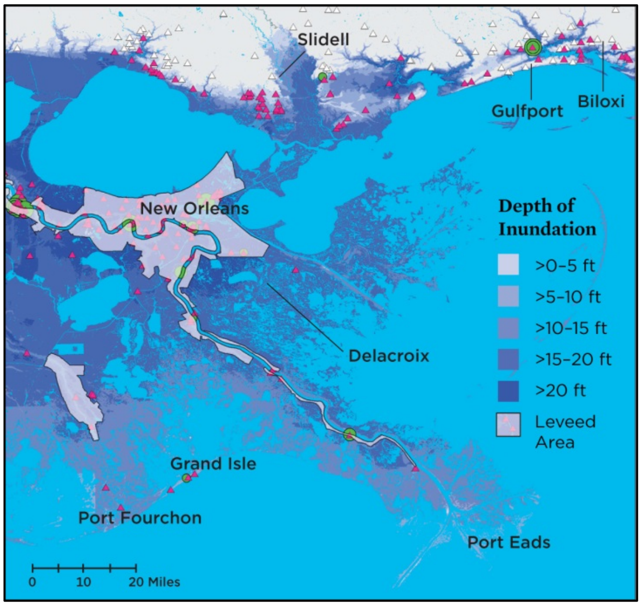
Exposed	Unexposed
● >0–20 MW	○ >0–20 MW
● >20–200 MW	○ >20–200 MW
● >200 MW	○ >200 MW

Substations

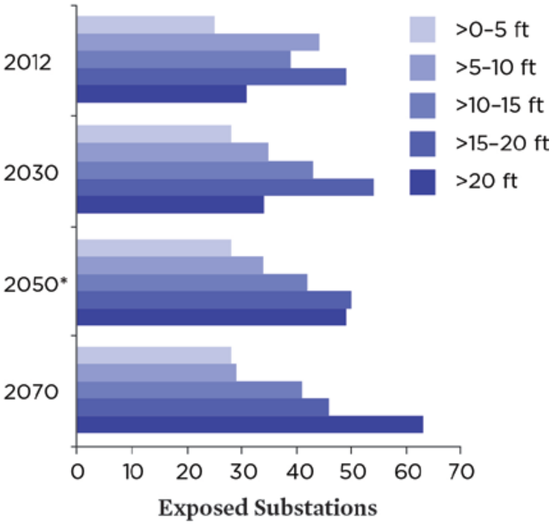
▲ Exposed

△ Unexposed

b. Flooding Depth from a Category 3 Hurricane, 2050



c. Potential Depth of Inundation of Regional Substations from a Category 3 Hurricane



*Scenario mapped at left

NOTE: These maps are for discussion and research purposes only. They are not appropriate for detailed analysis. The highlighted areas depict major leveed regions; while such barriers can hold back water against lower-strength storms, certain Category 3 hurricanes could be sufficient to overtop them. The elevation model used for the New Orleans area incorporates levee height, but recently built protective structures may not be captured. Refer to the Technical Appendix (www.ucsusa.org/lightsout) for more.

Strengthening and Protecting Electrical Infrastructure: The Need for Foresight

In a warming world, building for today's conditions leaves one unprepared for tomorrow. With rising global temperatures, we can be confident that over the next several decades, there will be a significant enough increase in global mean sea level to alter our local landscapes (Sweet et al. 2014; Walsh et al. 2014). To build an electric grid resilient to sea level rise, policy makers and utilities have to plan for sea level rising over the lifetime of electricity infrastructure investments—otherwise, the infrastructure could eventually be inundated by floodwaters. With few exceptions, however, electric grid planners—and the decision makers who guide them—have yet to sufficiently reckon with these considerations. Adaptation requires foresight, and here most current efforts have fallen well short of adequately addressing the problem.

A Static View in a Dynamic World

Traditionally, the siting process for coastal infrastructure has been informed by flood hazard zones from the Federal Emergency Management Agency (FEMA). The highest-risk base flood zone is an area that has a 1-percent chance of flooding in a year (that is, can expect to be inundated once every 100 years). Also shown are zones at moderate risk, such as those having a 0.2-percent annual chance (can expect flooding every 500 years) (FEMA 2015a). These maps are integral to informing building design codes around the country, and typically serve as default standards for building and infrastructure flood protection requirements.

To date, however, FEMA flood hazard zones have been retrospective in nature: they are based on historical data, and do not yet incorporate future sea level rise into their designations. Therefore, using them as a basis for locating and designing long-lived infrastructure leaves major investments increasingly vulnerable to shifting realities, as over the useful life of a project, sea level rise could widen a flood zone and surround previously unexposed investments. State or local governing boards can increase the stringency of flood protection requirements beyond those informed by FEMA's static assessment, but few have taken the first step of conducting their own future risk and vulnerability assessments to spur that change.

At present, it is common for a piece of infrastructure's current floodplain location to dictate the scale and scope of flood protection applied to it. But with rising seas, that point of reference can shift over time. Given that the average age of large power transformers within substations in the U.S. is 40 years (OE 2014b), and that our coasts are projected to see about a foot of sea level rise by 2050, a static consideration of the threat of coastal flooding leaves such long-lived infrastructure increasingly exposed. Indeed, over the life of a new 40-plus-year investment, storm surge could eventually submerge equipment where no such flooding had ever been experienced or was ever expected.

Defining a New Perspective

Promisingly, some forward-looking policies and tools are emerging at the federal, state, and local levels. This includes a handful of recently developed initiatives specific to the electricity sector, driven by utilities and the public utility commissions that oversee them. For example, Entergy Corp.—a company that delivers electricity to 2.8 million customers across Arkansas, Louisiana, Mississippi, and Texas; owns and operates 30,000 megawatts of generating capacity; and runs a system with approximately 1,500 substations and many thousands of miles of transmission lines (Entergy 2015)—teamed up with America's WETLAND Foundation to assess threats to the Gulf Coast region from environmental risks. Together with Swiss Re, a global reinsurer leading efforts to assess climate risks, the group performed cost-benefit analyses for adaptation measures applicable to the area (Entergy [2010]).

Similarly, in the wake of Hurricane Sandy (2012), the New York State Public Service Commission ordered Con Edison to study the vulnerability of its infrastructure to climate change, and adjust its operations accordingly in the face of those threats (Con Edison 2014). This action—a collaborative effort by public officials and academic and nonprofit groups—included updating Con Edison's design standards to "harden" infrastructure so it would remain functional in the face of climate impacts, and adjusting the company's risk assessment framework to incorporate anticipated future climate-change events, including higher storm surge (NYPSC 2014a).

A number of other proactive initiatives have been launched at the state and local levels; here we highlight just two of many. Massachusetts, for example, has devised an approach for equipping decision makers with relevant, localized information. Through its Office of Coastal Zone Management, the commonwealth has begun to provide an array of resources for local communities to use in planning for sea level rise and storm surge, including data and impact scenarios to assist with modeling vulnerability, grants to support research and deployment of resilient coastal community initiatives, and an online mapping portal to help communities visualize areas at risk (MA CZM 2015). Earlier, the City of Annapolis, MD, also undertook a major effort to better understand its local vulnerability to sea level rise and storm surge inundation, developing projections of impacts specific to the area, and recommending revisions to the city's code in light of such evolving risks (Annapolis 2011).

Lastly, several promising federal initiatives have begun to take root. In the wake of Hurricane Sandy, multiple Federal agencies collaborated to design the Sea Level Rise Tool for Sandy Recovery to inform rebuilding efforts in New York and New Jersey (Global Change n.d.). The tool empowered decision makers to consider the evolving threat of sea level rise over the lifetime of planned investments, although it had no regulatory implications and was geographically limited in scope. In another progressive effort, the Federal Flood Risk Management Standard, released in draft form in January 2015, requires all federal actions—meaning official policies, programs, plans, and projects—to be resilient to a flood elevation level determined by one of three measures: climate-informed science, the current base flood elevation plus 2 to 3 feet (depending on the criticality of the infrastructure), or the 500-year flood elevation (FEMA 2015b). Such an approach, if applied across all levels of infrastructure decision making, would help to usher in a new era of preparedness.

Adapting to a Changing Landscape

Many options are technically feasible for preparing electricity infrastructure—both existing and new—for the climate-change impacts of worsening coastal flooding from sea level rise and storm surge (EEI 2014; Boggess, Becker, and Mitchell 2014). The options can be sorted into three adaptation (preparing for or adjusting to climate impacts) strategies: protect, accommodate, and retreat.

- **Protect:** Continue to use potentially vulnerable, unmodified equipment by building protective defenses. Protection strategies include:
    - Build seawalls, bulkheads, and other artificial barriers around coastal power plants and electricity infrastructure.
    - Build dunes, wetlands, and other natural buffers around coastal power plants and electricity infrastructure.
- **Accommodate:** Modify new or existing infrastructure to enable it to continue to operate at full functionality in the presence of water. Accommodation approaches include:
    - Elevate substations.
    - Use submersible equipment in at-risk locations.
    - Fortify underground equipment to protect against floodwater intrusion.
    - Install flood monitoring equipment to alert utilities when to tactically redirect loads.
    - Deploy smart grid technologies to reroute electricity around faults.
- **Retreat:** Retire or relocate at-risk infrastructure in situations where protection or accommodation may be technically, socially, or financially impractical. Retreat options include:
    - Retire or relocate electricity infrastructure at risk.
    - Limit the construction of new investments in at-risk locations, unless accompanied by

protection or accommodation strategies such as those described previously.

Not only are many solutions available to prepare electricity infrastructure for coastal flooding; utilities already employ such strategies when infrastructure is determined to be at risk. Largely missing, however, are best practices for understanding when, and to what degree, to deploy such solutions in the face of climate-change impacts. The lack of guidelines results from a combination of factors, including the absence of data to enable comprehensive local vulnerability assessments, and misaligned incentives resulting in skewed cost-benefit analyses.

For the former, utilities need sufficient data about future coastal flooding risks to be able to conduct accurate analyses. Obtaining adequately detailed, region-specific assessments will involve the collaboration of federal, state, and local officials. For the latter, the populations bearing the brunt of widespread, long-lasting blackouts are not the same as the individuals making the decision to incorporate costly equipment upgrades. Therefore, regulators should require utilities to expand their cost-benefit analyses to consider societal-level pros and cons when evaluating a particular modification. Such cost-benefit analyses should also consider more than just infrastructure adaptation options, as discussed in the Con Edison substation deferral plan described below. In a valuable first step, the U.S. Department of Energy recently initiated the Partnership for Energy Sector Climate Resilience, which brings together owners and operators of energy assets to create resources for informing risk-based decision making and developing cost-effective strategies for improving the climate resilience of our nation’s energy infrastructure (DOE n.d.a).

Clean Energy Solutions: A Pathway to Resilient Power and Reduced Emissions

To maintain our present and future access to reliable electricity—and all the health, safety, and economic benefits such access allows—we must prepare the electric grid for increased coastal flooding. One necessary approach is adapting electricity infrastructure. However, it is also critical to simultaneously pursue solutions beyond specific equipment interventions. In addition to working to protect the power grid as a whole, we must also bolster the overall electricity resilience of both critical facilities and vulnerable populations, so that if and when the broader electric grid goes down, those entities can stay powered up.

Vitally, all interventions must take place within a broader framework of purposefully reducing emissions of carbon dioxide, methane, and other global warming gasses driving climate impacts, including sea level rise. Without this parallel effort, adaptation approaches may eventually prove inadequate as unabated climate change will drive sea level ever higher. And as the single largest emitter of global warming emissions in the United States from investments that can have very long lifetimes, the electric power sector has a vital role to play in ensuring that we—and it—avoid the worst consequences of climate change.

Strategic deployment of clean energy solutions enables us to reduce use of fossil fuels, support communities with resilient power resources today, and drive down emissions to limit the scope of future climate impacts.

Building Electricity Resilience Through Clean Energy Solutions

A resilient power system is flexible, responds to challenges, enables quick recoveries, and is available when we need it most. Developing resilient power resources means shifting away from relying on a centralized grid to a more decentralized system designed to meet essential grid loads, even during extreme weather events. Most importantly, a resilient approach that places efficient and clean energy technologies at the core of its solutions helps our communities prepare for a climate-impacted future while also reducing the emissions that are driving those effects.

When the power goes out, critical facilities in our communities—including hospitals, water and wastewater treatment plants, community shelters, and fire and police departments—are forced to rely on backup systems until the main electric grid can be restored. Traditionally, diesel generators have been used to fill this electricity access gap, cranking on to generate backup power when the grid goes down. However, backup systems can themselves present a host of reliability and implementation challenges, including:

- Failure to operate when called upon as a result of being rarely used (50 to 60 percent of backup generators were reported to have failed during Hurricane Sandy in New York [Ton 2015]);
- Difficulties with securing fuel supplies during and after severe storms;
- Noisy and heavily polluting machinery;
- High costs for equipment and fuel; and
- Usefulness limited to power outages, greatly limiting overall cost-effectiveness.

Given the vital nature of the services provided by our critical facilities, the intrinsic flaws of the backup systems on which they rely, and the continued likelihood of future power outages due to rising seas, it is essential for policy makers and utilities to look beyond current assumptions to create a more resilient power system. Clean energy has the potential to be an important part of the solution.

In particular, an assortment of clean energy solutions have the means to excel where, historically, the centralized grid and diesel generators have struggled. Foremost among these are renewable energy sources—such as rooftop solar and distributed wind power—coupled with energy storage, microgrids, and combined heat and power (CHP) plants. Energy efficiency and demand management programs also play a critical supporting role by allowing resilient power resources to be sized as cost-effectively as possible. The resilience-lending aspects of these technologies include:

- Independent fuel supply, limiting vulnerabilities to severe-weather disruptions to supply chains;
- Capability to start supplying power independent of an outside electricity source, unlike most large generators; and
- Year-round utility, so the resource has value to its owners well beyond being backup power during a grid outage.

Recently, a movement has been growing to initiate and support clean, resilient power projects (Leon 2015; Sanders and Milford 2015). From states, cities, and utilities, to critical facilities, businesses, and homeowners, efforts are underway and early ventures are showing affordable promise to buffer communities from the worst impacts of power outages. Recent declines in the cost of renewable energy and energy storage technologies, combined with innovative financing methods for funding renewable energy projects, are allowing communities across the income spectrum—including those most vulnerable to power outages and their impacts—to move forward with installing projects (Sanders 2014).

Below, we describe four leading technology options along with case studies.

DISTRIBUTED RENEWABLE RESOURCES

Shifting our electricity system away from relying on a few large fossil-fuel-powered generators and toward one that embraces smaller, distributed renewable generators allows for increased electric grid flexibility and decreased vulnerability to widespread outages. Moreover, when coupled with storage systems such as batteries or flywheels, variable renewable resources can provide energy even when, for example, the wind stops blowing or the sun sets. And even without storage, if distributed renewable energy systems are coupled with specialized inverters, they can at

New Jersey Program Couples Clean Energy with Storage to Support Critical Facilities

In 2015, the Office of Clean Energy, within the New Jersey Board of Public Utilities, issued the first round of awards for its Renewable Electric Storage Incentive, granting $3 million to 13 projects. The state program, which specifically targets storage projects supporting renewable energy systems at critical facilities, was motivated in part by the widespread power outages caused by Hurricane Sandy. During the 2012 storm, power was lost at residences, businesses, and critical facilities alike, and in the aftermath, there was a strong push for incentivizing projects that addressed the state infrastructure's exposed vulnerabilities.

All the awarded projects involve solar or wind generation plus storage setups and will be able to operate for 2 to 10 hours. Six will power municipal buildings and wastewater treatment plants, and seven will power schools that double as public shelters during emergencies. All 13 projects are expected to regularly support electric grid operations through ancillary services such as frequency regulation, providing significant revenue to supplement the state's investments.

(New Jersey's Clean Energy Program n.d.)

Florida SunSmart E-Shelters Foster Community Resilience and Educate Students

The Florida Solar Energy Center, part of the University of Central Florida, has supported the installation of more than 115 photovoltaic and battery systems at schools doubling as emergency shelters around the state. The SunSmart E-Shelters use 10-kW systems, and can provide electricity for selected critical functions in an emergency. The Center used the installations to help develop a curriculum to inform students and educators about photovoltaics, other renewable resources, and preparing for disasters. The program was launched with $10 million from the 2009 American Recovery and Reinvestment Act, and later received supplemental funding from area utilities.

(Florida Solar Energy Center n.d.)

least allow users to access electricity while it is being generated, regardless of whether or not the centralized grid is functioning. Following Hurricane Sandy, for example, wind turbines at a wastewater treatment facility in Atlantic City were ready to head back online and start generating electricity for the facility shortly after the storm rolled through, even though the main electric grid was down. However, due to a limited interconnection agreement with the local utility, the facility was not allowed to operate independently from the centralized grid (Hotchkiss et al. 2013).

The benefits of such a paired system are immediately apparent during a power outage. With solar-plus-storage, for example, not only can critical facilities and vulnerable consumers stay powered up during the day while the sun shines, but they can also access battery-stored electricity overnight. While most current setups are not sized to meet the typical daily loads of consumers, existing equipment is capable of covering a subset of functions deemed critical for operations (Mullendore and Milford 2015).

Another important resilience aspect of renewable resources is that some of them (notably solar panels) have "black-start" capability: they do not need to rely on another major electricity source to begin operations. This stands in stark contrast to the large generators in a centralized grid system, which often require a complex, interconnected, and lengthy sequence of events in order to come back online, presenting significant challenges in restoring power after an outage.

Over the past five years, the average cost of wind power and solar photovoltaics in the U.S. has declined by more than 60 percent (Wiser and Bolinger 2015; Lazard 2014; SEIA 2014). As these renewable technologies have become more cost-effective, U.S. wind capacity has nearly doubled and solar capacity has increased by more than 15-fold (AWEA 2015; SEIA/GTM 2015).

The benefits of pairing renewable energy sources with storage systems extend beyond power failures, contributing significantly to their cost effectiveness as primary and backup power supplies (Sanders 2014), especially when compared against diesel generators. Solar panels and wind turbines can generate electricity regardless of whether the main grid is online; when there is no outage, consumers can either use that electricity directly to reduce their electric bills, or, in some cases, sell it back to the grid. Further, battery systems allow consumers to shift their power demand from the grid to the least expensive time of day, and receive revenue by providing important grid reliability and security services such as frequency regulation (Mullendore 2015). In turn, wind- and solar-plus-storage systems are becoming valuable, effective tools in the shift toward resilient power.

COMBINED HEAT AND POWER

Combined heat and power (CHP) systems, also called cogeneration systems, both capture heat and produce electricity from a single fuel source. During blackouts, many such setups have continued supplying power and thermal support to residential complexes, hospitals, universities, and water and wastewater treatment plants during blackouts (Chittum 2012). Further, because CHP plants are always running, they do not encounter the reliability concerns facing backup diesel generators that stand idle between power failures.

Even absent a power failure, CHP significantly increases the fuel efficiency of power plants. Typically, U.S. power plants capture only about a third of their fuel's total energy in producing electricity, with the remainder lost as heat (EPA 2015b). CHP systems, on the other hand, capture that heat to use in other heating, cooling, or manufacturing processes. This dual-use approach brings CHP system efficiencies up to 60 to 80 percent (EPA 2015b), which enables significant fuel savings. CHP plants are powered by a range of fuels, including biomass, biogas, natural gas, and oil. The systems are commonly located in schools, hospitals,

CHP System Keeps Wastewater Treatment Plant Running Despite Widespread Outages

Sewage treatment plants naturally generate a lot of biogas (methane). Why waste that byproduct? In 2008, the Bergen County Utilities Authority (BCUA) installed a 2.8 megawatt combined heat and power (CHP) system adjacent to its Water Pollution Control Facility (WPCF) in Little Ferry, NJ. The CHP system primarily runs on the treatment facility's biogas with natural gas as a backup, and generates enough electricity to meet approximately 85 percent of the treatment facility's electric load. The system also generates enough heat to heat the building and the sludge digester system. When Hurricane Sandy hit the region in 2012, the WPCF continued to operate without issue, unlike many of its counterparts in the region that, when left without power, were forced to dump raw or partially treated sewage into area waterways. (ICF International 2013) industrial and commercial facilities, or other campus-type environments where there is direct local consumption of the thermal energy. However, smaller "micro-CHP" (mCHP) systems are recently becoming more widespread. CHP designs often involve microgrids (see section below), so when the centralized grid goes down, CHP-powered microgrids continue to power and heat local "islands."

MICROGRIDS

Microgrids, which commonly operate on the scale of a few buildings or a small community, can be completely self-contained, self-sustaining closed systems that permanently generate and consume all of the energy within a relatively small geographical "island." Alternatively, microgrids can be interconnected with the broader electric grid and selectively choose when to shift into island mode. That means if the centralized grid is down during and after a storm event, the facilities supported by a microgrid can remain powered up. During major outages, microgrids—operating under their own power—can turn their facilities into bright beacons of electricity amid widespread darkness. For critical facilities such as hospitals, such an enduring power source literally can be a lifesaver.

Within a microgrid, electricity can be generated from fuels ranging from renewables (wind and solar power), highly efficient CHP systems, or traditional fossil-fuel resources including diesel generators and natural gas turbines. Microgrids can also incorporate energy storage systems and fuel cells to add flexibility when renewables are the primary power sources. Microgrids are highly successful at achieving the twin goals of long-term community resilience and emission reductions, as many years of DOE research and collaborative projects are demonstrating (DOE n.d.b).

MADOER's Community Clean Energy Resiliency Initiative

The Massachusetts Department of Energy Resources (DOER), within the Executive Office of Energy and Environmental Affairs, is hosting a $40 million, multi-year Community Clean Energy Resiliency Initiative. The funding initiative aims to increase community resilience to electricity disruptions caused by severe weather and climate impacts through clean energy technologies, including microgrids. The initiative has already issued 18 project implementation awards during two funding rounds, totaling more than $25 million. The initiative also includes a technical assistance program, which provides applicants with consulting support regarding project feasibility and design at no cost.

The initiative is focused on projects supporting such critical facilities as community shelters, municipal fueling stations, emergency response operations, and wastewater treatment plants. Thus far, projects have included CHP installations, storage to couple with solar and wind projects, and microgrid setups for increasing the resilience of critical facilities. For example, Northampton, MA, was awarded over $3 million for developing a microgrid, supported in part through on-site renewable energy, CHP, and battery storage, to maintain power to a community shelter, a hospital, and the local Department of Public Works. (MA DOER n.d.)

ENERGY EFFICIENCY AND ELECTRICITY DEMAND MANAGEMENT

Energy efficiency (whereby buildings, appliances, and other equipment are designed to consume less energy) and demand management (which works to lower electricity users' consumption during periods of grid-wide stress) can prove

Energy Efficiency, Demand Management, and Distributed Generation Delay Need for Expensive New York City Substation

In 2013, power demand in Brooklyn and Queens began to overload Con Edison's Brownsville, NY, substation. The company projected that by 2018, the overload could be as much as 69 MW. Faced with limited additional capacity in the surrounding network to meet the anticipated higher demand, Con Edison was tasked by the New York State Public Service Commission to consider developing non-traditional load relief plans to reduce demand rather than increase supporting infrastructure.

After an involved process of engaging community stakeholders, the utility successfully delayed construction of a $1 billion substation by at least 10 years through developing a nontraditional Brookyn/Queens Demand Management (BQDM) plan. Customers will reduce peak demand through energy efficiency, demand management, and distributed generation. Con Edison will employ a range of atypical approaches, such as a distribution management system, an apartment complex microgrid, and battery storage. (NYPSC 2014b).

highly beneficial during power outages. Resilient power systems must be scaled to meet need. Thus, demand management and energy efficiency services enable the limiting of non-critical loads, and allow the most efficient demand required by critical loads.

Both can reduce the size of a needed resilient system and ensure that the limited power available during a power outage is most efficiently consumed. For example, while an array of solar panels may provide only a fraction of typical daily electricity usage, in an emergency when users are limited to what the panels are providing, they may shut off all electric appliances except those deemed critical, such as refrigerators to keep food or medicine cold, elevators to transport senior or disabled citizens in high-rise buildings, furnace blowers to keep buildings warm in the winter, and air conditioning to keep buildings sufficiently cool in hot and humid weather.

Even absent a power failure, designing buildings for energy efficiency can benefit consumers. For example, incorporating solar heating, daylighting, and other energy saving approaches into building designs allows consumers to save on electricity bills throughout the year, while also setting themselves up to be more comfortable should the power go out.

The increasing threat of climate-related storm surge to our coastal electricity infrastructure is cause for serious concern. Ensuring reliable access to electricity now and into the future requires us to take thoughtful steps to consider the challenges not just of today, but also tomorrow. These include:

- Taking immediate action to protect our electricity infrastructure from coastal flooding today, while ensuring that contemporary interventions incorporate the evolving context of climate impacts over the lifetime of investment decisions;
- Moving beyond the current focus of protecting the centralized power grid, and bolstering communities through the strategic deployment of distributed, resilient power resources; and
- Placing all actions within the broader framework of de-carbonizing the electricity sector to limit the extent and severity of long-term climate impacts.

Here, we consider each of these three essential actions, and offer specific recommendations for how to facilitate their deployment.

Protecting the Electric Grid Today, While Preparing it for Tomorrow

Efforts to protect our electricity infrastructure exposed to storm surge today should incorporate the threat of coastal flooding over the entire lifetime of the equipment, thus invoking need for an analysis of the additional exposure from sea level rise. Actions to begin implementing *now* include:

- **Apply best available science.** In order to appropriately consider the risks facing facilities and equipment, utilities and communities must conduct vulnerability and risk assessments, then develop standards to protect equipment over its entire lifetime. These assessments must be locally specific to account for the many differences in geography, infrastructure, and climate impacts facing an area.
- **Initiate long-term planning.** The sooner long-term adaptation plans are established by utilities and municipalities, the better. While adapting infrastructure may be phased in over years, unexpected severe storms that destroy equipment can present windows of opportunity for implementing updated design plans. Therefore, public utility commissions should require utilities to develop these plans as soon as possible so they are ready when needed.
- **Press for FEMA flood hazard maps to include projected sea level rise.** FEMA flood hazard maps commonly inform how design standards are set and how equipment is sited. FEMA has an opportunity to update these resources to reflect future sea level rise through recommendations from the ongoing Technical Mapping Advisory Council process. Such changes would allow communities to plan for impending risks, especially when designing policies for long-lifetime investments.
- **Support proactive use of federal disaster recovery funds.** Federal disaster recovery funds are largely limited to rebuilding activities and can generate perverse incentives for staying in high-risk areas. However, pre-disaster planning and post-disaster rebuilding provide a chance to learn from disaster, and to upgrade or relocate facilities and infrastructure proactively. The New Jersey Energy Resilience Bank, supported with post-Sandy recovery funds from the U.S. Department of Housing and Urban Development, is an example of how federal funds can be applied to plan for the future (NJ ERB n.d.).

Bolstering the Electricity Resilience of Communities

It is impractical to protect our electricity infrastructure against all possible power outage threats, including those from coastal flooding; there remains a non-trivial chance of major outages into the future. Therefore, adaptation plans should incorporate additional approaches beyond simply protecting infrastructure. Foremost among these are deploying energy systems that bolster the electricity resilience of our communities to prolonged power outages, with particular attention being paid to critical facilities and vulnerable populations. Such an approach will also return benefits far beyond those limited to coastal flooding threats; indeed, such electricity resilience empowers communities during any type of power failure.

- **Enable cost recovery for resilience investments.** State utility commissions vary widely in their allowance of recovery for prudent investments that support near- and long-term system resilience through rate setting. Commissions should require utilities to take actions that factor in a long-term perspective on system performance, while subsequently providing room for rate relief for low-income electricity consumers.
- **Create resilient power project proposals.** States and municipalities can play a lead role in deploying resilient power projects that will buttress their communities during and after power outage events. Support can be explicit (such as issuing resilience-specific calls for proposals for funding) or indirect (such as prioritizing projects that support resilience within broader renewable energy funding programs). States can also lower the hurdles sometimes faced by new programs by such steps as enabling and encouraging innovative financing by municipalities.
- **Support vulnerable populations.** Award funds to projects that make clean, resilient energy solutions available to populations most vulnerable to the impacts of power outages today.

Taking a Long-Term Clean, Low-Carbon Approach

As the largest emitter of global warming emissions in the United States, the electric power sector has a vital role to play in enabling the nation to avoid the worst consequences of climate change, including threats from climate-related storm surge. This will inevitably mean greatly reducing reliance on fossil fuels to generate electricity.

To cut electricity sector emissions significantly, we should readily embrace the pathways that favor wide-scale implementation of energy efficiency, renewable energy, and other low carbon technologies. Recent UCS analyses showed that renewable resources and energy efficiency could greatly reduce electric power sector emissions with the benefits greatly exceeding the costs (Cleetus et al. 2014), and that an increasing reliance on natural gas would force a more costly path to a clean energy future as investments in natural gas infrastructure now could become stranded assets over time (Deyette et al. 2015).

- **Support renewable energy research, development, and deployment.** By encouraging the development of an electric grid that incorporates low- and no-carbon resources, we can hasten the deployment of renewable technologies, which will facilitate the de-carbonization of our electricity sector, stave off the worst scenarios of climate impacts like sea level rise, and lend resilience to the system. This means implementing policies that recognize the value of distributed resources to the grid, and encouraging their participation in additional grid services like frequency regulation, black start capability, and voltage control.
- **Adopt or strengthen state energy efficiency and renewable energy standards.** Policy makers have the opportunity to drive the deployment of renewable energy and energy efficiency within their states by adopting Renewable Electricity Standards RESs) and Energy Efficiency Resource Standards (EERSs). All of the Northeastern coastal states have RESs and most have EERSs. However, in the southeastern coastal and Gulf Coast states, only North Carolina and Texas have RESs and EERSs (DSIRE n.d.). In states where RES and EERS policies have already been put in place, further progress can be made by strengthening such standards as technologies improve and prices continue to fall.
- **Support strong federal carbon standards.** The EPA's Clean Power Plan encourages states to switch from high- to low- or no-carbon energy resources by aiming to reduce nationwide carbon emissions from existing power plants 32 percent below 2005 levels by 2030 (EPA 2015c). The more aggressively states invest in energy efficiency and renewable energy solutions in the near-term, the better prepared they will be to continue to reduce emissions in the future. Critically, to avoid worst-case future climate impacts, including aggressive rates of sea level rise, we will need to achieve even deeper economy-wide reductions beyond those required by the Clean Power Plan, so establishing energy efficiency and renewable energy as first-best strategies

situates states well for likely additional future reductions.

Summary: Building for a Bright Tomorrow

Our power grid is susceptible to coastal flooding today. Rising seas and higher storm surge mean that unless we take purposeful action to adapt to worsening conditions, the electric power sector will become even more vulnerable to crippling outages over time. With our safety, health, and daily lives tightly intertwined with electricity, it has become increasingly critical that we limit the risk of such impacts. We must, therefore, apply foresight to long-term planning for the power grid; encourage the purposeful adoption of distributed clean energy solutions that bolster the electricity resilience of our communities to help them cope with unavoidable future disasters; and pursue electricity generation policies that prioritize clean energy to limit the scope of future climate impacts.

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