



CLIMATE  CENTRAL

BLACKOUT: EXTREME WEATHER, CLIMATE CHANGE AND POWER OUTAGES

By Alyson Kenward, PhD, and Urooj Raja

2014

BLACKOUT: EXTREME WEATHER, CLIMATE CHANGE AND POWER OUTAGES

ABOUT CLIMATE CENTRAL

Climate Central surveys and conducts scientific research on climate change and informs the public of key findings. Our scientists publish and our journalists report on climate science, energy, sea level rise, wildfires, drought, and related topics. Climate Central is not an advocacy organization. We do not lobby, and we do not support any specific legislation, policy or bill. Climate Central is a qualified 501(c)3 tax-exempt organization.

Climate Central scientists publish peer-reviewed research on climate science; energy; impacts such as sea level rise; climate attribution and more. Our work is not confined to scientific journals. We investigate and synthesize weather and climate data and science to equip local communities and media with the tools they need.

Princeton: One Palmer Square, Suite 330 Princeton, NJ 08542

Phone: +1 609 924-3800

Toll Free: +1 877 4-CLI-SCI / +1 (877 425-4724)

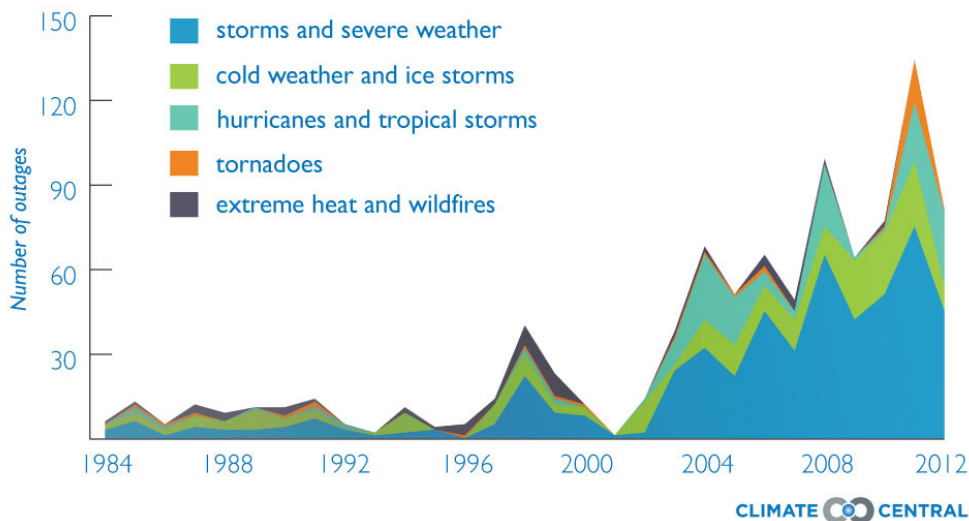
www.climatecentral.org

SUMMARY

Climate change is causing an increase in many types of extreme weather. Heat waves are hotter, heavy rain events are heavier, and winter storms have increased in both frequency and intensity. To date, these kinds of severe weather are among the leading causes of large-scale power outages in the United States. Climate change will increase the risk of more violent weather and more frequent damage to our electrical system, affecting hundreds of millions of people, and costing Americans and the economy tens of billions of dollars each year.

Extreme Weather Is Causing More Major Power Outages

(major = at least 50,000 customers affected)



Climate Central's analysis of 28 years of power outage data, supplied to the federal government and the North American Electric Reliability Corporation by utilities, shows:

- A **tenfold increase** in major power outages (those affecting more than 50,000 customer homes or businesses), between the mid-1980s and 2012. Some of the increase was driven by improved reporting. Yet even since 2003, after stricter reporting requirements were widely implemented, the average annual number of weather-related power outages **doubled**. Non-weather related outages also increased during that time, but **weather caused 80 percent of all outages** between 2003-2012.
- Michigan led all states with 71 major weather-related power outages between 2003 and 2012, averaging at least 800,000 customers affected each year during that decade. Texas ranked second with 57 outages and also averaged more than 800,000 customers affected annually. Ohio was third with 54, followed by Pennsylvania and Virginia with 52. The number of customers affected could not be estimated for these three states.

-
- **147 million customers lost power**, for at least an hour and often far longer, from weather-related outages since 2003, an average of **15 million customers affected each year**. Currently, there are 145 million customers in the U.S. A customer is a home or a business, or anyone who receives a bill from a utility, so the number of people affected by outages is likely much higher, from 300 million to perhaps half a billion or more over the decade analyzed.
 - 59 percent of weather-related outages analyzed were caused by storms and severe weather; nearly 19 percent by cold weather and ice storms; 18 percent by hurricanes and tropical storms; 3 percent tornadoes, and 2 percent by a combination of extreme heat events and wildfires.

Most of these outages come from damage to large transmission lines or substations, as opposed to the smaller residential distribution network.

Climate change is a threat multiplier. Major weather-related outages cost Americans between \$20 and \$55 billion annually according to recent estimates. Lack of preparedness for increasingly extreme weather puts people, infrastructure and the economy at growing risk. There is broad agreement with “very high confidence” that climate change-related extreme weather events damage critical infrastructure, disrupt the food supply, threaten water supplies and increase mortality worldwide (IPCC 2014).

Even in cases where the link to climate change is not well understood, extreme weather appears to be becoming more severe, as the case with hurricanes and thunderstorms. While only two Category 4 or 5 hurricanes have made U.S. landfall since 1990, average hurricane strength and the total number of Category 4 and 5 hurricanes is increasing. And while the trend in the incidence of severe thunderstorms is unknown due to lack of comprehensive monitoring, insurance companies are now paying out at least seven times more for thunderstorm damages than in the 1980s.

Climate change is, at most, partially responsible for this recent increase in major power outages, which is a product of an aging grid serving greater electricity demand, and an increase in storms and extreme weather events that damage this system. But a warming planet provides more fuel for increasingly intense and violent storms, heat waves, and wildfires, which in turn will continue to strain, and too often breach, our highly vulnerable electrical infrastructure.

CONTENTS

Executive Summary	p3
01 Introduction	p6
02 Data & Methods	p8
03 Trends in Weather-Related Power Outages	p9
04 Extreme Weather and Climate Change	p18
05 Conclusions	p21
06 References	p22

01. INTRODUCTION

The U.S. electrical system is one of the country's most critical infrastructure components. Distributing electricity to homes, businesses, and industry, as well as large sections of the transportation sector, the bulk power system is a vast and interconnected grid that people depend on in all parts of their daily lives. The reliability and resiliency of the grid system is consequently of utmost importance to all Americans. Yet, much of the nation's power system today looks remarkably similar to the way it did half a century ago, and it remains vulnerable to large-scale outages caused by several threats, including cascading power failures, cyber-attacks, and severe weather.

Several recent studies have highlighted the overall vulnerability of the U.S. electrical grid.^{1,2} A 2012 Department of Energy (DOE) report on U.S. infrastructure vulnerability showed that beyond the risk of power loss at individuals' houses (which cause lighting, heating, and air-conditioning losses), large-scale power outages also pose larger threats to entire communities and business sectors.³ Water treatment facilities depend on electricity, and extended power outages can interrupt flow of clean water and solid waste removal. Hospitals can lose power or clean water, raising health concerns. Power losses often force businesses to close, affecting sales and overall profitability, and potentially disrupting extended business-to-business supply chains. According to a 2001 report, the annual costs of U.S. power outages ranged from \$100 billion to \$164 billion,⁴ with the majority of the cost associated with indirect consequences of the power loss (like those described above) rather than the repair of damaged power lines.

The electricity system can be generally divided into four general components: power generation, high-voltage transmission, local distribution, and the end-use customers (Figure 1). An intricate power management system connects all four components together. Damage to power generators (power plants, primarily), high-voltage transmission lines and local power lines, can each threaten overall power supply to customers, as can an overall shortage of fuel for electricity generation. Most major power outages and disturbances (those which threaten power to tens of thousands of customers) are ones that disrupt high-voltage transmission.

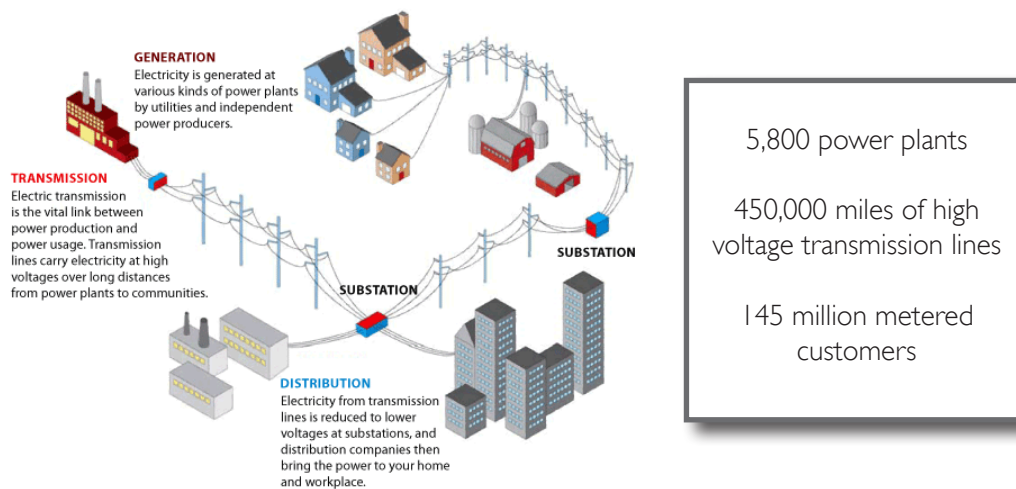


Figure 1. Electric Grid Representation

Source: U.S. Department of Energy, "Benefits of Using Mobile Transformers and Mobile Substations for Rapidly Restoring Electric Service: A Report to the United States Congress Pursuant to Section 1816 of the Energy Policy Act of 2005." 2006.

01. INTRODUCTION

Across the country, and particularly in the Midwest and eastern regions, much of the transmission and distribution network is still above ground, leaving them vulnerable to the effects of severe weather, including high winds, heavy rain, ice, snow, and electrical storms. Even in areas where power lines are buried, flooding caused by heavy rains or hurricane-related storm surges can lead to major power interruptions.

There is a general scientific consensus that climate change will increase some forms of extreme weather. Increasing concentrations of atmospheric greenhouse gases is already believed to have increased the frequency and intensity of some severe weather (see Section 4 for more details and relevant references). To better understand the electricity sector's vulnerability to future climate change, this report examines the proportion of reported large-scale power outages that were caused by severe weather.

02. DATA & METHODS

The power outage data used in our analysis was collected from the U.S. Department of Energy's (DOE) Office of Electricity Delivery & Energy Reliability, via their form OE-417 reports, and from the North American Electric Reliability Council (NERC).⁵ NERC data covered the period of 1984-1999. Typically, only sufficiently large electrical disturbances (or potential disturbances) meet the reporting criteria for OE-417, but there are a total of 12 possible criteria by which disturbances are evaluated.⁶ Most of the major disturbances reported to the DOE or NERC refer to power outages during which at least 50,000 customers lost power for at least an hour, there was a power supply interruption of at least 300 megawatts, or the demand for electricity exceeded the supply (load shedding) by at least 100 megawatts. The majority of these major outages take place during electricity transmission (damage to major power lines or substations), though some may reflect outages originating at power plants or during residential distribution.

The form OE-417 is an emergency reporting mechanism, and is not intended to create a historic record of thoroughly investigated electricity incidents. Because a form OE-417 is filed before the full scope of the event is understood, and is not updated later (even if a detailed investigation was conducted), the data provided is an estimate of the incident.

For the purpose of our analysis, we consider only power outages (including blackouts and voltage losses), fuel supply emergencies, and emergency appeals for reduced electricity usages where there was a reported number of customers affected or power lost (Box 1). We have not included reports of vandalism or cyber-attacks where there was no actual power lost or customers how lost power in our discussion or in our accounting of non-weather related events. Furthermore, we have excluded heat wave-related appeals for reduced usage from our count of total weather-related events (or customers) if there were no numbers provided for customers affected or associated megawatts. We have, however, included a separate count of these heat-related events to give an idea of the future threat posed by increasing heat waves.

Box 1. Definition of power outage used in this report.

Power Outage:

Large electrical disturbances (including blackouts, voltage losses, load shedding, fuel supply emergencies, and emergency appeals for reduced electricity usage) during which at least 50,000 customers lost power for at least an hour, there was a power supply interruption of at least 300 megawatts, or the demand for electricity exceeded the supply by at least 100 megawatts.

03. TRENDS IN WEATHER-RELATED POWER OUTAGES

INCREASES IN REPORTED WEATHER-RELATED POWER OUTAGES

Analyzing data from 1984-2012, we found the number of reported weather-related power outages increased dramatically in the 2000s (Figure 2), a conclusion similar to those found in previous studies.^{3,7,8} There were as many as 10 times more large-scale power outages each year in the 2000s compared to those reported each year in the 1980s and early 1990s.

Weather-Related Power Outages Increased Dramatically in the 2000s

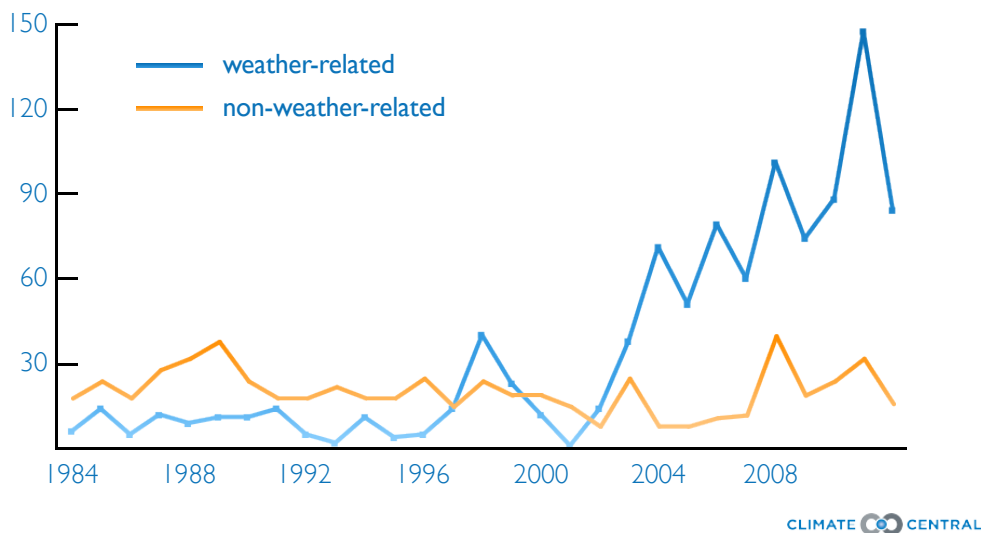


Figure 2. Annual number of reported weather-related and non-weather related power outages in the U.S., 1984-2012.

Since the late 1970s, the U.S. Department of Energy (DOE) has required power utilities to report large-scale power outages via an Electric Emergency Incident and Disturbance Report (Form OE-417) to monitor the overall reliability of the nation's bulk power system. Similarly, the North American Electric Reliability Corporation (NERC) has collected power outage data since 1984 via their System Disturbance Reports. Over the years, however, data collection requirements have changed, as has the way utility reporting is enforced. Some of the increase in the number of reported power outages since 2000 is likely related to these reporting changes.⁹ To help eliminate trends largely related to increased reporting, we are restricting the remainder of our analysis to DOE data from the 10-year period of 2003-2012.

03. TRENDS IN WEATHER-RELATED POWER OUTAGES

Focusing on the period of 2003-2012 reveals that both weather-related and non-weather related power outages have increased in recent years, which is an indication of the growing vulnerability of the nation's power system. As illustrated in Figure 1, since 2003, the average number of weather-related power outages each year has doubled.

Although the proportion of weather-related outages varies from year-to-year, weather-related outages made up the vast majority of reported incidents on average between 2003-2012. Of the 911 power outages we analyzed, 80 percent of them (726 outages) were weather-related (Figure 3). Moreover, weather-related and non-weather related outages did not consistently increase at the same rate over this time, which suggests that the increases were not solely a function of the changes to how these outages are reported.

Severe Weather Caused 80% of Large-Scale Power Outages and 88% of Customers Affected by Power Outages From 2003-2012

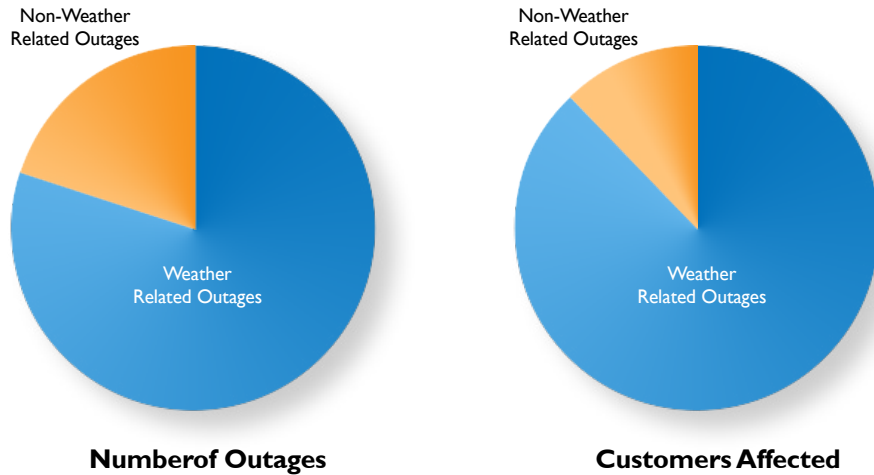


Figure 3. Percentage of power outages and total customers affected caused by severe weather from 2003-2012.

03. TRENDS IN WEATHER-RELATED POWER OUTAGES

More than 147 million customers were affected by these weather-related power outages between 2003-2012. While there is no way to identify exactly how many individual people this corresponds to, because a customer may be defined as a household (which, on average, would have multiple residents), a commercial business, or even an industrial building, we assume that at least this many people, if not significantly more, were directly affected by weather-related outages during this time.

Of all the customers reportedly affected by power outages and warnings of reduced electricity from 2003-2012, nearly 90 percent of them were due to weather-related incidents. As Figure 4 illustrates, only in 2003 were fewer than 80 percent of the customers affected by weather-related outages. The 2003 anomaly was related to a single non-weather related event: a massive blackout across the Northeast caused by cascade of failures at power plants across the region. With the exception of 2003, there was no year in the past decade where non-weather related power outages accounted for more than 20 percent of all customers affected, and there were only three years where non-weather related events caused outages affecting more than 10 percent of all customers.

Seven Out the Past 10 Years Had More Than 10 Million Customers Affected By Weather-Related Outages

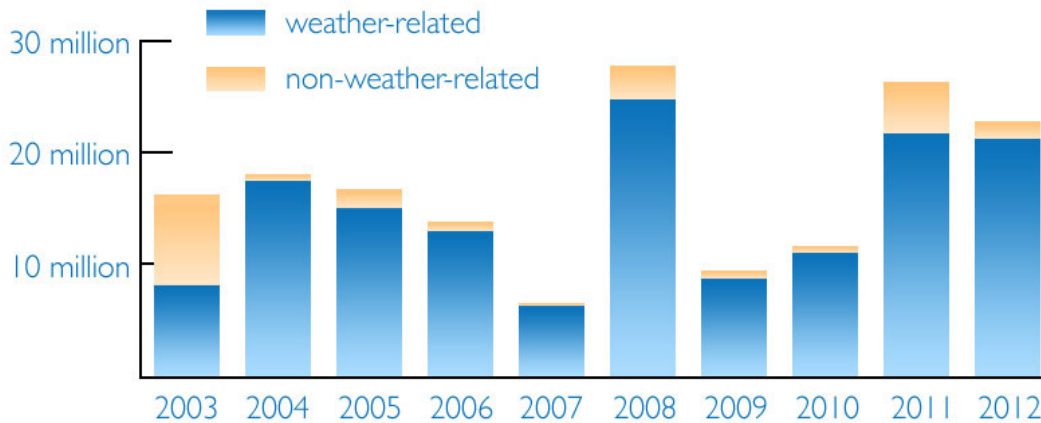


Figure 4. Number of U.S. customers affected each year by weather-related and non-weather related power outages from 2003-2012.

03. TRENDS IN WEATHER-RELATED POWER OUTAGES

WEATHER-RELATED POWER OUTAGES BY REGION

Our analysis demonstrates that while the entire country experiences severe weather that can interrupt electricity generation and transmission on a large scale, the Midwest, Mid-Atlantic and Southeastern states appear to be particularly vulnerable (Figure 5). NERC, a non-profit corporation that promotes reliability of the U.S. bulk power supply system, is divided into eight regional reliability entities and major outages (and other incidents) can be categorized by their NERC region (most of Canada and part of Mexico are also included in NERC regions but incidents in those areas have been excluded in this report). Box 2 defines each of the eight NERC regions.

Of the 911 weather-related outages studied, 64 percent occurred in the RFC and SERC regions. These regions encompass all states east of the Mississippi River (with the exception of New England states and Florida), as well as large parts of Illinois, Missouri, Arkansas, and Louisiana.

Box 2. Regional reliability entities of the North American Electric Reliability Corporation (NERC).

NERC REGIONS

Western Electricity Coordinating Council (WECC) - includes Arizona, California, Colorado, Idaho, Nevada, Oregon, Utah, Washington, Wyoming, most of New Mexico and Montana, and a small area of western South Dakota.

Midwest Reliability Organization (MRO) - includes Iowa, Kansas, Minnesota, Nebraska, North Dakota, most of Illinois, Minnesota, and South Dakota, as well as part of eastern Montana.

Southwest Power Pool (SPP) - includes Kansas, most of Oklahoma, and small areas of Arkansas, Louisiana, New Mexico and Texas.

Texas Reliability Entity (TRE) - includes most of Texas (was previously designated ERCOT).

Florida Reliability Coordinating Council (FRCC) - includes most of Florida.

Reliability First Corporation (RFC) - includes Delaware, Indiana, Iowa, Maryland, Pennsylvania and West Virginia, most of Michigan, and small areas of Illinois, Kentucky, Minnesota, and Virginia.

SERC Reliability Council (SERC) - includes Alabama, Georgia, Mississippi, Missouri, North Carolina, South Carolina, Tennessee, most of Arkansas, Illinois, Kentucky, Louisiana, and Virginia, small parts of Oklahoma, Texas and the Florida panhandle.

Northeast Power Coordinating Council (NPCC) - includes Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont.

03. TRENDS IN WEATHER-RELATED POWER OUTAGES

Two-Thirds of Reported Outages Occurred in the Eastern RFC and SERC Regions Between 2003-2012

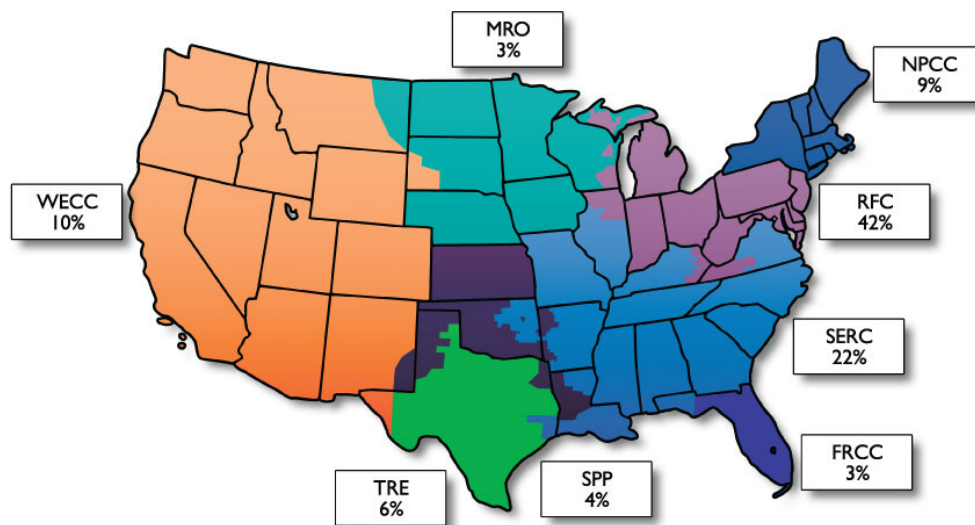


Figure 5. Percentage of total weather-related power outages from 2003-2012, by NERC region.

The concentration of weather-related events in the Midwest and East matches the distribution of customers affected by these events. About two thirds of customers affected by weather-induced outages were also in the RFC and SERC regions, although only about 45 percent of the U.S. population lives within these states. However, the higher population density and older infrastructure in these eastern states, compared to the rest of the country, likely makes the region more susceptible to large-scale power outages.

In contrast, the 11 westernmost states comprise 10 percent of outages and 14 percent of customers affected, even though the region has about 23 percent of the national population.

The top 10 states most affected by weather-related power outages (based on the number of incidents, not customers) are **Michigan, Texas, Ohio, Pennsylvania, Virginia, Maryland, North Carolina, California, Illinois, and Indiana**. Table 1 shows how many events were reported for each state (and the District of Columbia).¹⁰

03. TRENDS IN WEATHER-RELATED POWER OUTAGES

Table 1. State rankings of major weather-related outages between 2003-2012.¹⁰

Outages include reported blackouts, fuel shortages, and emergency appeals for reduced electricity usage.

State	Outages	State	Outages
Michigan	71	Massachusetts	15
Texas	57	Maine	12
Ohio	54	Missouri	12
Pennsylvania	52	Connecticut	10
Virginia	52	Minnesota	10
Maryland	50	Oklahoma	8
North Carolina	48	New Hampshire	7
California	46	Wisconsin	6
Illinois	39	Iowa	5
Indiana	39	Oregon	5
Georgia	37	Colorado	3
Louisiana	32	North Dakota	3
New York	32	Nebraska	3
Florida	31	Hawaii	2
Alabama	29	Idaho	2
Kentucky	29	Kansas	2
Mississippi	25	Rhode Island	2
Arkansas	22	South Dakota	2
New Jersey	22	Arizona	1
West Virginia	22	Montana	1
Washington	19	New Mexico	1
South Carolina	17	Utah	1
Tennessee	17	Vermont	1
District of Columbia	16	Wyoming	1
Delaware	16		

03. TRENDS IN WEATHER-RELATED POWER OUTAGES

Because of the interconnected nature of the grid, many electrical utilities often service large areas that can span several states. Furthermore, some types of extreme weather, including winter storms, tropical storms and hurricanes, affect large areas and can cause power interruptions in many states. Consequently, some electrical utilities are particularly prone to weather-related power outages. Table 2 shows the top 25 power utilities with the most reported outages between 2003-2012. Only six of these 25 utilities are not centered in the RFC and SERC regions. This ranking reflects how often areas serviced by these utilities are in harm's way, how large each of these utilities are, and whether they provide service to mostly urban or rural areas, among other factors;¹¹ it is *not indicative* of weaknesses specific to any one utility.

Table 3 highlights the top 25 power utilities with the most customers affected by weather-related outages from 2003-2012.

Table 2. Top 25 utilities with the most reported major weather-related outages from 2003-2012.

Utility	Event Count	States Affected
American Electric Power	42	OH, IN, MI, OK, WV, VA, AR, LA, TX, KY, TN
Dominion	35	VA, WV, NC
Southern Company	35	GA, AL, MS, FL
Detroit Edison	34	MI
Com Ed	33	IL
Duke Energy	32	NC, SC, OH, KY, IN
CenterPoint Energy	24	TX
Consumers Energy	23	MI
Entergy	21	AR, LA, MS, TX
Pacific Gas & Electric Company	20	CA
ISO New England	19	ME, CT, MA, NH, RI, VT
PECO	18	PA, DE
Baltimore Gas & Electric	16	MD
Potomac Electric Power Company (Pepco)	15	MD, Washington, DC
Tennessee Valley Authority	13	TN, AL, GA, MS
Allegheny Power	12	PA, WV, VA, MD
Progress Energy	12	NC, SC, FL
Midwest ISO	11	IA, IN, MO, IL, OH, KY, MN, ND, SD
Ameren	10	MO, IL
Puget Sound Energy	10	WA
Atlantic City Electric	8	NJ
National Grid	8	NY, MA, RI
PPL Electric Utilities	8	PA
Xcel Energy	8	MN, CO
Cleveland Electric Illuminating Company	7	OH

03. TRENDS IN WEATHER-RELATED POWER OUTAGES

Table 3. Top 25 utilities with the most customers affected by major weather-related power outages from 2003-2012.

Utility	Customers Affected	States Affected
Pacific Gas & Electric Company	12,313,868	CA
Duke Energy	9,208,708	NC, SC, OH, KY, IN
Com Ed	7,749,647	IL
American Electric Power	6,601,414	OH, IN, MI, OK, WV, VA, AR, LA, TX, KY, TN
Dominion	6,187,794	VA, WV, NC
CenterPoint Energy	5,267,683	TX
Southern Company	5,198,019	GA, AL, MS, FL
Entergy	5,182,967	AR, LA, MS, TX
ISO New England	4,454,695	ME, MA, NH, VT, RI, CT
Consumers Energy	4,333,070	MI
Detroit Edison	4,098,137	MI
Baltimore Gas & Electric	3,393,313	MD
PECO	3,910,896	PA, DE
Ameren	3,798,800	MO, IL
Progress Energy	3,678,974	NC, SC, FL
Oncor Electric Delivery Company	2,718,493	TX
Potomac Electric Power Company (Pepco)	2,709,747	MD, Washington, Dc
Puget Sound Energy	2,185,881	WA
Allegheny Power	2,051,673	PA, WV, VA, MD
Midwest ISO	1,879,479	IA, IN, MO, IL, OH, KY, MN, ND, SD
Tennessee Valley Authority	1,740,858	TN, AL, GA, MS
PPL Electric Utilities	1,690,222	PA
Jersey Central Power & Light Company	1,588,400	NJ
Public Service Electric & Gas Company	1,475,800	NJ
National Grid	1,365,000	NY, MA, RI

03. TRENDS IN WEATHER-RELATED POWER OUTAGES

POWER OUTAGES BY TYPE OF SEVERE WEATHER

When weather-related power outages are reported via Form OE-417, officials must include a description for the type of weather that caused the disturbance. However, there are no set criteria for how weather events are described, and in many cases, the causes of outage events are categorized simply as *storms* or *severe weather*. Consequently, for the purpose of our analysis we have maintained the category storms and severe weather, which herein refers to outages and disturbances caused by heavy rains, thunderstorms, high winds, lightning, and general severe weather.

Between 2003-2012, 59 percent of weather-related outages were caused by storms and severe weather (Figure 6). Nearly 20 percent of weather-related outages were caused by cold weather and ice storms, and another 18 percent were caused by hurricanes and tropical storms. Only 3 percent of outages were caused by tornadoes, and 2 percent were caused by a combination of extreme heat events and wildfires.

General Storms Caused Nearly 60% of All Weather-Related Outages Between 2003-2012

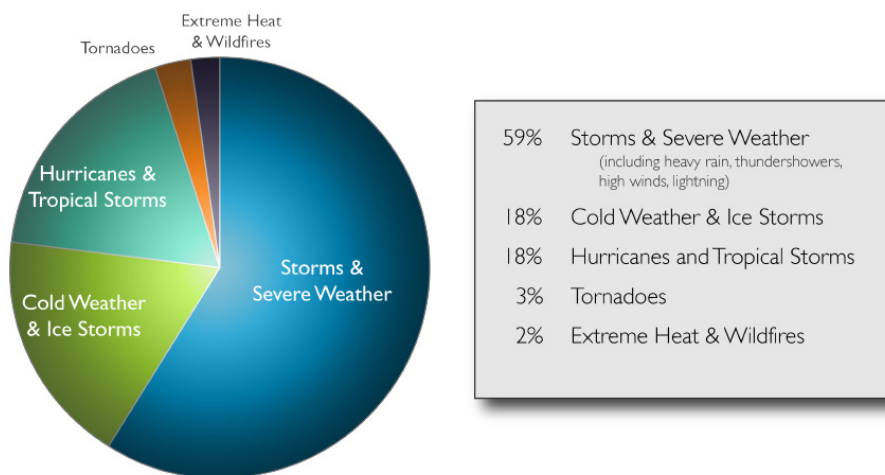


Figure 6. Types of severe weather responsible for all weather-related power outages from 2003-2012.

In addition to these outages, extreme heat was responsible for 64 restricted power advisories between 2003-2012. In some cases, extreme heat was likely related to other, uncounted outages, but due to limitations in the reporting structure, we are unable to confirm that heat was the cause of the outage. Across the country, extreme heat and heat waves pose a risk of power outages that is at least double the threat posed by tornadoes (there were 22 major outages caused by tornadoes from 2003-2012).

04. EXTREME WEATHER AND CLIMATE CHANGE

OBSERVABLE TRENDS OF INCREASING EXTREME WEATHER EVENTS

While some of the increased reports of weather-related power outage since the 1980s stems from changes in the way these events are reported, there are other risk factors that are likely also playing a significant role, including a growing population, aging power system infrastructure, and measurable increases in many extreme weather events.

According to the draft of the U.S. National Climate Assessment (full report due for release in April 2014), many types of extreme weather events have become more frequent and intense in recent decades, in addition to an overall rise in average temperatures and increase in average precipitation.¹² In many cases, there is evidence that these increases are, in part, caused by increasing concentrations of greenhouse gases in the atmosphere. In a 2011 special report titled *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*, the Intergovernmental Panel on Climate Change (IPCC) also reported observed increases in some types of extreme weather events in North America.¹³

Since 1990, heavy downpours and flooding have increased in most parts of the country, and the trend is most dramatic in the Northeast and Midwest.¹⁴ Some of this heavy rain is likely to be associated with high winds and thunderstorm activity. Researchers have found that these regions have already seen a 30 percent increase in heavy downpours compared to the 1901-1960 average. And across the country, more of each region's total precipitation is falling in heavy events. One study found that the Northeast has experienced a 74 percent increase in the amount of its total precipitation falling in heavy events, while the Midwest has seen a 45 percent increase and the Southeast a 26 percent increase (Figure 7).¹⁴

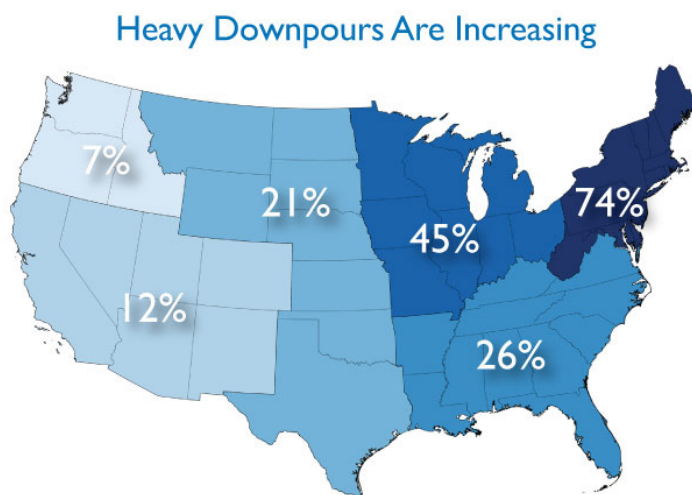


Figure 7. Percentage change of very heavy rainfall in the U.S. from 1958-2011.

Source: Karl, T.R., J.T. Melillo and T.C. Peterson. 2009. *Global Climate Change Impacts in the United States*. Cambridge University Press.

04. EXTREME WEATHER AND CLIMATE CHANGE

Trends in severe thunderstorm activity, which is often associated with strong winds and heavy precipitation, remain uncertain partly because of challenges in collecting consistent observations of these types of storm systems. However, a recent study drawing on results from an ensemble of global climate models demonstrated that rising atmospheric concentrations of greenhouse gases increases the risk of thunderstorms by adding more heat and water vapor to the atmosphere.¹⁵ The risk appears particularly strong in the eastern U.S. Consistent with this finding is the dramatic increase in average annual insured thunderstorm losses since the 1980s, as reported by Munich Re.¹⁶

Heat waves are also happening more frequently than they were just a few decades ago and in the West, the 2000s saw more heat wave events than in any decade of the previous century.¹² The National Climate Assessment has also recognized heat waves becoming more intense and drawn out and recent years, including 2011 and 2012, have seen several months of extended summer heat that was unprecedented.¹⁷ And while there are relatively few large-scale power outages that have, to date, been attributed to wildfires, the area burning each year, on average, in the western U.S. in large wildfires has been increasing over the past 40 years.¹⁸

Compared to changes in temperature and precipitation extremes, there is more uncertainty in changing storm trends across the U.S. However, evidence suggests that, in general, winter storms have increased in both frequency and intensity, and on average winter storm tracks are shifting northward.¹⁹ There has also been an observable increase in hurricane strength and the number of Category 4 and 5 Atlantic hurricanes since 1980s, partially driven by warming Atlantic Ocean sea surface temperatures associated with increased emissions of greenhouse gases.²⁰

PROJECTIONS FOR INCREASING EXTREME WEATHER EVENTS

Both the IPCC and U.S. Global Change Research Program have described projections for further increases in U.S. extreme weather events in the coming decades, if global greenhouse gas concentrations continue to rise.^{12,13} Heat wave frequency and intensity is expected to increase dramatically this century, and it is possible that by the end of this century the hottest days of the year will be at least 10°F warmer than the hottest days between 1981-2000. Even if an aggressive approach is taken to reduce greenhouse gas emissions, by the 2080s and 2090s the warmest days of the year will be several degrees warmer than during the 1980s and 1990s. One study found that what used to be a one-in-20 year heat event could happen every 2 or 3 years by the end of this century.

Similarly, heavy downpours and flooding are projected to keep increasing in some regions, and by 2100 the heaviest rainfall events could happen up to five times more often than they do today. In general, researchers expect that a greater proportion of rainfall will fall in heavy events, even in regions that are expected to see an overall decrease in total annual rainfall, like the Southwest.

04. EXTREME WEATHER AND CLIMATE CHANGE

The IPCC projects that Atlantic hurricane intensity will keep increasing in the coming decades and some studies suggest hurricane frequency may also increase, although there remains significant uncertainty about these future hurricane trends. As mentioned above, recent studies suggest that as average temperatures continue to rise as projected, the conditions for thunderstorm formation improve, although further studies are needed to better understand the future risk of more frequent or intense convective storms.

05. CONCLUSIONS

Our analysis demonstrates that a large majority of the major power outages and electricity disturbances that occurred from 2003-2012 were caused by severe weather, including storms, hurricanes, heat waves, and tornadoes. Nearly 150 million customers (which means likely well over 300 million people) were affected by these weather-related power outages.

In addition to individual power loss, interrupted business, and threats to most amenities people rely on daily, these major outages cost Americans billions of dollars. Recent studies estimate that weather-related power outages cost between \$20 and \$55 billion annually.^{3,4,8}

While some recent increases in extreme weather events in the U.S. can be, in part, attributed to increasing greenhouse gas emissions, it is not possible to say how much this has contributed to the rise in weather-related power outages. Climate change may be partially responsible, along with an aging grid infrastructure that is serving greater electricity demand. Yet, future climate change is expected to bring more severe weather, which will continue to strain our already vulnerable electrical infrastructure.

06. REFERENCES

- (1) National Research Council. **2012.** *Terrorism and the Electric Power Delivery System*. Washington, DC: The National Academies Press, 2012.
- (2) U.S. House. Staff of Rep. E.J. Markey and Rep. H.A. Waxman. **2013.** *Electric Grid Vulnerability*. May 21, 2013.
- (3) U.S. Department of Energy. **2012.** *Economic Benefits of Increasing Electric Grid Resilience to Weather Outages*. Available online at: http://energy.gov/sites/prod/files/2013/08/f2/Grid%20Resiliency%20Report_FINAL.pdf
- (4) Linweber, D. and S. McNulty. **2001.** *The Cost of Power Disturbances to Industrial and Digital Economy Companies*. Prepared by Primen for the Electric Power Research Institute. June 2001.
- (5) NERC data provided by Paul Hines, University of Vermont; Benjamin Carreras, Oakridge National Laboratory; Virgilio Centeno and Arun Phadke, Virginia Tech
- (6) U.S. Department of Energy. *Electric Emergency Incident and Disturbance Report: Form OE-417*, Office of Electricity Delivery and Energy Reliability.
- (7) Hines, P., J. Apt and S. Talukdar. **2009.** *Large Blackouts in North America: Historical trends and policy implications*. University of Vermont. Available online at: http://www.uvm.edu/~phines/publications/2009/hines_2009_blackouts.pdf
- (8) Mills, E. **2012.** *Electric Grid Disruptions and Extreme Weather*. U.S. Disaster Reanalysis Workshop (National Climatic Data Center), August 30, 2012. Available online at: <http://evanmills.lbl.gov/presentations/Mills-Grid-Disruptions-NCDC-3May2012.pdf>
- (9) Fisher, E., J.H. Eto and K.H. LaCommare. **2012.** *Understanding Bulk Power Reliability: The Importance of Good Data and A Critical Review of Existing Sources*. Electricity Markets and Policy Group at Lawrence Berkeley National Lab. January 2012.
- (10) Each NERC region regulates reporting of major outages and incidents in a slightly different way, and some of this state-by-state ranking reflects this. Furthermore, utilities in Texas (in the TRE region) are only subject to voluntary reporting, which means that the number of incidents that occurred in the TRE region over the past decade may have been higher than reported here.
- (11) Eto, J.H., K.H. LaCommare, P. Larsen, A. Todd and E. Fisher. **2012.** *An Examination of Temporal Trends in Electricity Reliability Based on Reports from U.S. Electric Utilities*. Lawrence Berkeley National Laboratory. Available online at: <http://emp.lbl.gov/sites/all/files/lbnl-5268e.pdf>
- (12) National Research Council. *A Review of the Draft 2013 National Climate Assessment*. Washington, DC: The National Academies Press, 2013. Available online at: <http://ncadac.globalchange.gov/>.

07. REFERENCES

(13) Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.) **2012**: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK, and New York, NY, USA.

(14) Karl, T.R., J.T. Melillo and T.C. Peterson. **2009**. *Global Climate Change Impacts in the United States*. Cambridge University Press.

(15) Diffenbaugh, N.S., M. Scherer and R. J. Trapp. **2013** "Robust increases in severe thunderstorm environments in response to greenhouse forcing." *Proceedings of the National Academy of Sciences of the United States of America*. 110(41): 16361-16366.

(16) Munich Re, Property Claims Service. **2014**. "2013 Natural Catastrophe Year In Review." Available online at: https://www.munichre.com/touch/site/touchnaturalhazards/get/documents_E2138584162/mr/assetpool.shared/Documents/5_Touch/Natural%20Hazards/NatCatNews/2013-natural-catastrophe-year-in-review-en.pdf

(17) Karl, T.R., B.E. Gleason, M.J. Menne, J.R. McMahon, J. R.R. Heim, M.J. Brewer, K.E. Kunkel, D.S. Arndt, J.L. Privette, J.J. Bates, P.Y. Groisman, and D.R. Easterling. **2012**. "U.S. temperature and drought: Anomalies of spring and summer 2011-12 and trends." *EOS Transactions, American Geophysical Union*. 93: 473.

(18) Kenward, A.L. and U. Raja. **2012**. *The Age of Western Wildfires*. Climate Central. Available online at: <http://www.climatecentral.org/wgts/wildfires/Wildfires2012.pdf>.

(19) Karl, Thomas R., Gerald A. Meehl, Christopher D. Miller, et al. (eds). **2008**. *Weather and Climate Extremes in a Changing Climate: Regions of Focus: North America, Hawaii, Caribbean, and U.S. Pacific Islands*. Report by the U.S. Climate Change Science Program.

(20) Mann, M.E. and K.A. Emanuel. **2006**. "Atlantic hurricane trends linked to climate change." *EOS, Transactions, American Geophysical Union*, 87:233.

ACKNOWLEDGEMENTS

Special thanks to Emily Fisher and Evan Mills (Lawrence Berkeley National Laboratory) and Ian Dobson (Iowa State University).

Princeton: One Palmer Square, Suite 330 Princeton, NJ 08542

Phone: +1 609 924-3800

Toll Free: +1 877 4-CLI-SCI / +1 (877 425-4724)

www.climatecentral.org