Physical Attack on the Power Grid

A malicious actor causes physical damage to an aspect of the power grid, resulting in a loss of power in one or more metropolitan areas for three or more hours.[1]

Data Summary

In the following table, note that the low and high likelihoods do not correspond to the low and high impacts. In addition, low and high impacts are not necessarily correlated with each other between different impact categories.

Category	Description	Metric	Low[2]	Best[3]	High[4]
Health and Safety	Fatalities	Number of Fatalities	0[5]	0[6]	90[7]
	Injuries and Illnesses	Number of Injuries or Illnesses	0[8]	2[9]	400[10]
Economic	Direct Economic Loss	U.S. Dollars (2011)	\$15 million	\$46 million	\$5.7 billion
Social	Displacement	Displaced from Homes ≥ 2 Days	0[11]	0[12]	0[13]
Psychological	Psychological Distress	Qualitative Bins	TBD	TBD	TBD
Environmental	Environmental Impact	Qualitative Bins	*De Minimus*[14]		
LIKELIHOOD	Frequency of Events[15]	Number per Year	0.013[16]	1 every four years[17]	1 to 3 per year[18]

[1] Some studies have chosen to examine a nationwide or near-nationwide power outage in the continental United States for at least six months. However, experts differ on how realistic this scenario could be. Because of the uncertainty regarding feasibility of a nationwide power outage, the scenario included here is scoped to a significant but reasonable event.

[2] For the Physical Attack on the Power Grid event, low, best, and high impact estimates are correlated across impact axes because they represent three physical scenarios (such correlation should not be assumed for other SNRA events). Note that the low, best, and high estimates of likelihood are not correlated to these scenarios: they represent the low estimate, best estimate, and high estimate of the overall frequency of any scenario within the scope of the event (any of the three impact scenarios defining the SNRA's reported range and any other scenario meeting the thresholds which define the scope of the Physical Attack on the Power Grid event).

The low impact estimates assume a successful attack on the grid infrastructure that causes physical damage, but which does not result in a power outage with significant impacts. This outcome could be because the grid is able to offload power and prevent a power outage or disruption, or because there is an outage of 3 or more hours which occurs at night (critical facilities and industries are assumed to have backup power sufficient for several hours).

[3] The best impact estimates assume a successful attack on the grid infrastructure that causes physical damage and a power outage to a broad metropolitan area in the continental U.S. at daytime, with the power outage lasting 3 hours. The best estimate duration is based on the lengths of the accidental outages discussed in the Event Background section. In order to estimate the impacts of an outage for the best estimate scenario, this assessment assumes the size of the population affected is 2,138,460. This population size represents the median population size for the 50 largest metropolitan urban areas as captured in the 2010 census.

[4] The high impact estimates assume a successful attack on the grid infrastructure that causes physical damage and a power outage to a broad metropolitan area in the continental U.S., similar to the best estimate. However, the outage lasts for one day, resulting in net impacts to the Nation similar to those of the Northeast Blackout in August 2003.

[5] Zero by assumption.

[6] Scaled from high estimate in proportion to total person-days without power.

[7] Injuries and fatalities from power grid failures generally result from heat stroke and respiratory ailments, which can occur when outages occur during the summer months. However, it is difficult, if not impossible, to directly tie heat stroke victims to a power outage. Determining the role of heat (versus other concurrent factors) in a death can be complicated, and different jurisdictions use different criteria for considering deaths heat related. For the high estimate, the 90 deaths in New York City associated with the 2003 Northeast Blackout, as determined by Anderson et al (2012), are used. This figure is likely to be inflated because of the city's population density; however, studies of the New York City-specific impacts from 2003 blackout remain the most defensible high estimate for the scenarios articulated in the Economic Impacts section of this paper.

[8] Zero by assumption.

[9] Scaled to the high estimate in proportion to total person-days without power.

[10] Mean estimate of excess hospitalizations for complications of respiratory illnesses in New York City for August 14-15 attributed to the loss of electric power in the 2003 Northeast Blackout (Lin et al (2011)) minus the three fatalities due to respiratory illness found (Anderson et al (2012), on the assumption that these deaths were most likely pronounced in hospital. This epidemiological study examined hospitalizations for respiratory,

Event Background

> Utility executives and Federal energy officials have long worried that the electric grid is vulnerable to sabotage. That is in part because the grid, which is really three systems serving different areas of the U.S., [had failures impacting a large number of customers] when small problems such as trees hitting transmission lines created cascading blackouts. … Many of the system's most important components sit out in the open, often in remote locations, protected by little more than cameras and chain-link fences.[19]

From 2011[20] to 2014,[21] there were 322[22] reported incidents of alleged or confirmed sabotage, physical attack and vandalism[23] to different parts of U.S. utilities. These cases represented about 35 percent of all incidents[24] reported to the U.S. Department of Energy that posed a risk to the grid. Most had little effect,[25] but some resulted in measureable impacts. The well-known incident at the Pacific Gas & Electric (PG&E) Company's Metcalf Transmission Substation outside of San Jose, California, for example, had widely reported estimates of $15 million[26] in damages and the potential for more serious impacts because the PG&E Metcalf substation provides power to California's Silicon Valley.

In the U.S., there is no single interconnected national grid. Instead, the continental U.S. is served by three separate grids, which are largely not impacted by the failure or resiliency of the others. It is feasible for coordinated events to impact more than one of the grids within the U.S., but it is highly unlikely that an attack within one grid could cascade and impact the others.

cardiovascular, and renal diseases: only respiratory diseases showed statistically significant hospitalizations over prior year averages (from a subset with comparable temperature ranges) of the same days in August. Other studies have examined excess hospitalizations for severe diarrheal illnesses caused by eating spoiled meat products due to loss of refrigeration (Marx et al (2006)) and other measures of increased burdens on emergency responders and the hospital system in New York City due to the blackout (Prezant et al (2005)) but did not provide quantitative estimates which could be extracted for this summary sheet.

[11] SNRA project team assumption.

[12] SNRA project team assumption.

[13] The SNRA project team could not find defensible estimates of the number of people displaced from their homes due to the August 2003 blackout, for instance to cooling centers (temperatures were elevated in New York City, Anderson et al (2012)), used as the physical model for the high impact estimates: it is likely this number is non-zero, though perhaps very small.

[14] Provisional estimate by the 2015 SNRA project team by analogy with the environmental impact estimate description for the Cyber Attack against Physical Infrastructure event, elicited from EPA experts in 2011. Note that this estimate has NOT been reviewed by the original subject matter experts. See Environmental Impacts section.

[15] Based on data from Department of Energy's OE-417 Filings from 2011-2014 (most complete data for which physical attacks were tracked). Data are available at www.oe.netl.doe.gov/oe417.aspx. For over 100 incidents representing 1/3 of reported physical attacks, the impacts were listed as unknown. This analysis presumes that there were no impacts from these incidents.

[16] One incident in the United States FBI (1982) pp 29-30 (Thomas (1981)) in the 80 year period since 1936, chosen as the longest observation period where terror attacks causing blackouts in the United States have been a reasonable possibility. 1936 is sometimes used as a reference point for the maturation of the large-scale, integrated electric grid in the U.S.: it marked the first large scale accidental blackouts and the first appearance in popular culture of the suggestion that the electric grid could be a vulnerable target for terrorists in the Hitchcock film *Sabotage*. The first large scale deliberate blackouts occurred in the U.S. in 1939, when they were used by striking electrical workers as a tool to pressure employers: the power supply to Times Square and Broadway was shut off in 1941, and the entire city of Pittsburgh was shut down twice in 1946 by striking electrical workers including a month long blackout of the central business district. Nye (2010) pp. 2, 59-64, 70-72, 182.

[17] Assumes continuing average of one event every four years that causes a confirmed *and* measurable loss of power and effect on customers. Also assumes that these types of events have the potential to cascade into a blackout.

[18] Assumes continuing average of about one event with impact (defined as loss of power *or* an effect on customers) per year and that this type event holds the potential of cascading into a blackout.

[19] Smith (2014a).

[20] The first year the Department of Energy began collecting this information via OE-417 filings.

[21] Most recent, complete year of data available from the Department of Energy's OE-417 filings.

[22] OE-417 filings are considered emergency forms. Depending on the specific circumstances, they must be filed either within one hour or six hours of the incident.

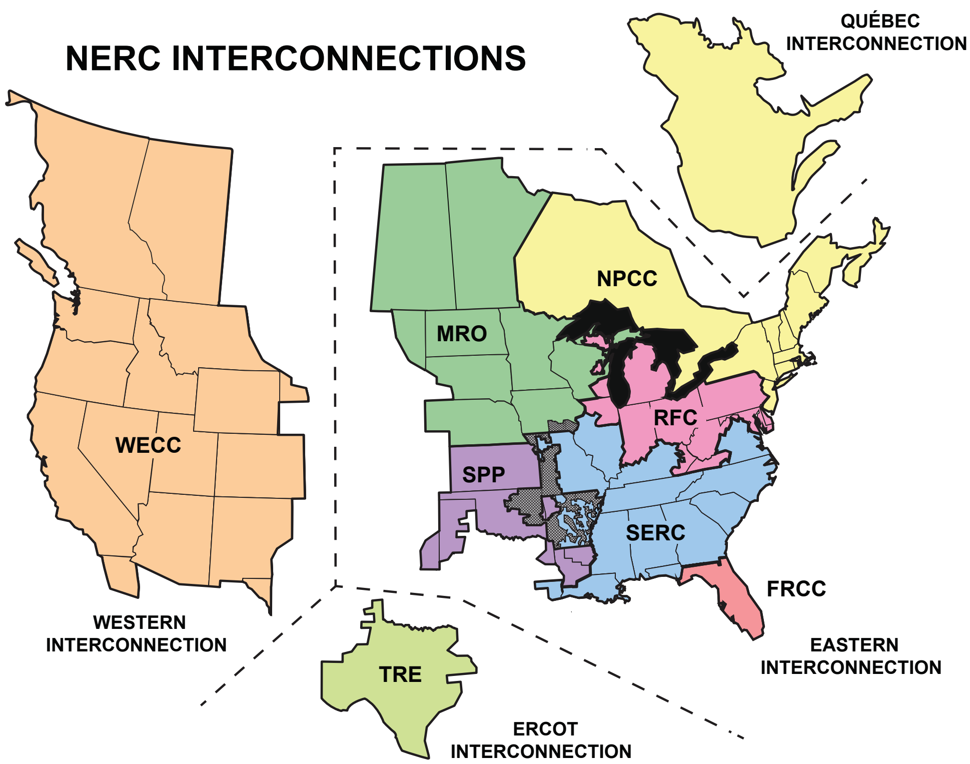
[23] Due to similar definitions and time frame for data submission by owners and operators, sabotage, physical attack and vandalism are all considered physical attacks for purposes of this analysis.

[24] Other incident types include weather and natural disasters, fuel supply deficiency, and operator actions.

[25] For over 100 incidents representing 1/3 of reported physical attacks, the impacts were listed as unknown. This analysis presumes that there were no impacts from these incidents. For many other incidents, it was reported that there was no load shedding or loss of power to customers, so these are presumed to have had little-to-no effect.

[26] Baker (2014).

Figure 1: Interconnections and Reliability Regions[27]



The three separate networks are:

- The Western Interconnection, which serves those contiguous states west of the Rockies as well as their Canadian neighbors and portions of Northwestern Mexico.
- The Electric Reliability Council of Texas, which serves only the state of Texas.
- The Eastern and Quebec Interconnection which serves all states (and Canadian Provinces) east of the Rockies and south of the Great Lakes and New York. The Eastern Interconnection is actually made up of multiple interconnected but separately managed grids, allowing some cascading failures but also additional resiliencies within this large, heavily populated area.

To date, “no major power outage in the Western world has originated from an antagonistic attack, [and]… there are few publicly reported sabotage attempts (near-misses).”[28] However, two recent accidental causes of domestic power outages are worth noting, as they serve as examples of what malicious attacks could feasibly achieve:

- In February 2008, a small, isolated fire in a substation on the outskirts of Miami “caused a cascading regional grid collapse—including the Turkey Point nuclear power plant south of Miami—as electricity demand suddenly outstripped what was being produced. Some three million people from South Beach to Tampa to Daytona Beach lost power”[29] for a few hours.

[27] NERC (2012).
[28] Holmgren et al (2007).
[29] Padgett (2008).

- In 2011, a human error at an Arizona substation tripped a 500 kilovolt (kV) transmission line and cut power to 1.6 million customers in Arizona and southern California. The majority of customers were located in the San Diego Gas & Electric service territory, and about four million customers were without power. Most customers were without power for just a few hours; however, about 1.4 million of those affected were without power for anywhere from 11[30] to 13[31] hours.

Overall, a significant limitation to estimating risk from this threat is a lack of publicly available information on the electric grid and its resiliency. "Detailed analyses of these grids are, naturally, conducted by the network operators, but are seldom published for business and operational security reasons."[32] Generally speaking, anyone could learn about "transformer vulnerabilities from engineers and operators experienced with this technology, either domestically or abroad, since the same technology is used in power grids throughout the world."[33] Furthermore, knowledge of transformer locations themselves is also relatively easy to gain, such as by viewing images on mapping websites or following the path of high-transmission power lines back to their source.

For the purposes of this assessment, the 2003 Northeast Blackout could be used as a starting point to estimate potential impacts, but it would be difficult to estimate[34] how long a blackout caused by this type of an event would last. Rather than a nationwide or near-nationwide outage, this analysis assumes the outage will affect a metropolitan area. For any blackout, the amount of time[35] it lasted would dictate the severity of the impacts. If a large blackout were to happen because of an adversarial attack, there is one variable that makes it difficult to know how long it would last: the unproven domestic manufacturing capacity to rapidly replace damaged transformers.[36] "Today, there is limited manufacturing capacity in the United States for [high-voltage] transformers. Five U.S. facilities[37] state that they can manufacture transformers rated 345 kV or above, although it is not clear how many units in this range they have actually produced. Canada and Mexico have five additional [high-voltage transformer] manufacturing plants."[38] The estimated capacity of the five U.S. plants is about a typical year's imports, which in 2013[39] was almost 500 transformers of various types. However, it is still unclear how rapidly these facilities could build and transport the high-voltage transformers necessary to rapidly fix a critical substation. It will be important to monitor demonstrated domestic manufacturing capacity, as measured by domestic plants successfully manufacturing high-voltage transformers for domestic utilization.

At the most extreme, there a nationwide failure across multiple interconnections of the U.S. power grid because of an adversarial attack could lead to a catastrophic outage across the country. One scenario could result from attackers causing the loss of power for one of the three grids through a coordinated attack on the critical substations for a specific grid: "four in the East,

[30] Los Angeles Times (2011a).
[31] Los Angeles Times (2011b).
[32] Holmgren (2006).
[33] Parformak (2014).
[34] This scenario is implied by the nationwide option, but it is not clear if a similar 18-month window would apply.
[35] The large-scale loss of electricity for a few days, or if localized a few weeks at most, is a common enough occurrence that American society is relatively resilient to it: people cope, or (as power is restored in localized areas) go to friends, family, or temporary shelters with power, heat or air conditioning, and water.
[36] Large or high-voltage transformers must be custom designed and built (U.S. Department of Energy (2014)).
[37] These plants are located in Alabama, Georgia, Missouri, Tennessee and Wisconsin (U.S. Department of Energy (2014), Thornton (2015)).
[38] Parformak (2014).
[39] Thornton (2015).

Added 2015

three in the West and two in Texas."[40] However, there is a high degree of uncertainty around whether it would even be possible to simultaneously sabotage critical substations across the interconnections and how many substations would need to be sabotaged in order to cripple the grids, so it is only mentioned here as an area of further study.

Some scholars have created electric grid models to project and estimate potential effects, and they found that consequences were more likely to come[41] from attacks executed by organized groups as opposed to opportunistic individuals. However, "trying to quantitatively evaluate the probability of such low-probability–high-consequence potential terrorist attacks is very challenging, resource-demanding, and subject to inaccuracies."[42] Ultimately, because of this type of uncertainty, this analysis does not make a determination as to the feasibility or probability of a successful attack causing a nationwide or near-nationwide blackout. To more clearly establish the potential risk of attacks, more complete data is needed from owners and operators regarding the impacts of incidents, identification and prioritization of critical assets, models of scenarios and outcomes, and tests of the grid's resiliency. Without additional information, "the true vulnerability of the grid to a[n]…attack remains an open question."[43] However, there is data to conclude that physical attacks on the electric grid are a documented, reoccurring risk, and they will likely continue to happen. Additionally, based on the historical evidence on accidental incidents causing outages, it remains possible for well-planned adversarial actors to cause a blackout.

Assumptions

There are two types of motivations that frame how an adversarial actor could approach an attack: causing as much damage as possible to the grid itself or causing a blackout to a large area. Attacks to the grid that cause medium-term load shedding require significant resources and "will lead to a longer-lasting system 'pain,' and the element replacement/repair costs might be higher."[44] However, these impacts are largely not visible to the public. On the other hand, causing short-term cascading outages requires fewer resources and causes less damage[45] to the grid itself; however, because of automated self-protection measures built into the system itself, these types of events are more likely to cause blackouts. Because so much economic and societal activity is dependent on electricity, blackouts have the ability to cause wider damages beyond the grid itself. Plus, "the U.S. electric power grid has historically operated with such high reliability that any major disruption, either caused by weather, operational errors, or sabotage, makes news headlines."[46]

Therefore, while it is "difficult to accurately understand the objective of the terrorists"[47] or others with malicious intent, it is assumed that the intent of an adversarial attack would be to cause a blackout rather than maximize damage to the grid itself. There is also evidence of this method being a preferred approach of adversarial actors. For example, one white supremacist group posted the following in a manual on sabotage:

> The power generation and distribution systems of most major Western cities are surprisingly vulnerable.... Attacking during peak consumption times (Winter in cold climates and Summer in

[40] Smith (2014b).
[41] Holmgren (2006).
[42] Wang et al (2014).
[43] Parformak (2014).
[44] Wang et al (2014).
[45] Sequential system protection actions are triggered and do not directly damage the facilities.
[46] Parformak (2014).
[47] Wang et al (2014).

> hot climates) will make power diversion impossible.... Arson, explosives or long-range rifle fire can be used to disable substations, transformers and suspension pylons. A simultaneous attack against a number of these targets can shut down power ... with the advantage that service cannot be quickly restored by diverting power from another source. Each broken link in the power grid must be repaired in order to fully restore service. An individual, equipped with a silenced rifle or pistol, could easily destroy dozens of power transformers in a very short period of time.[48]

The magnitude (the size of the outage) and duration (length of disruption), of an outage affect the impacts of an event.[49] For the purposes of this assessment, the low, best, and high estimates, we have made the following assumptions.

- For the low estimate magnitude, the assumption is that there is a successful attack on the grid infrastructure that causes damage but that the grid is able to offload power and prevent a power outage or disruption. In the low scenario, assumptions about timing and duration are insignificant.
- However, for the high estimate scenario, this assessment assumes that the attack is successful and causes a power outage, the outage affects a metropolitan area in the continental U.S., and the outage lasts for one day, which is consistent with the outage across the Northeast in August 2003.[50]
- The best estimate scenario assumes the attack is successful and causes a power outage, the outage affects a metropolitan area in the continental U.S., and the outage lasts for three hours. The best estimate duration is based on the lengths of the accidental outages discussed in the event background section. In order to estimate the impacts of an outage for the best estimate scenario, this assessment assumes the size of the population affected is 2,138,460. This population size represents the median population size for the 50 largest metropolitan urban areas as captured in the 2010 census.[51]

In order to inform the impact estimates, this summary sheet assesses the risk from a national perspective, average and general data is used in the economic impacts section. This allows for a general calculation to be made; however, if this risk were to be assessed for a specific locality or metropolitan area, specific factors would need to be considered:

- Industries that make up the local economy—especially those in manufacturing or information technology that can be significantly affected by even momentary lapses in power
- Mitigation measures for blackouts that have been taken by companies with significant local economic output
- Seasonal changes in weather patterns (i.e., very hot or very cold temperatures) and their potential stress on the electric grid
- Resiliency of the electric grid in that particular community

[48] Parformak (2014).
[49] Although timing is important in determining the impacts, this assessment did not make assumptions about the time of year or time of day.
[50] While there is research to suggest catastrophic disruption to the grid that could leave a portion of the country without power for an extended period of time, there was not sufficient evidence at the time of this research to estimate the impacts of a catastrophic disruption and further research is warranted.
[51] Census Bureau (2010). The estimate is derived from taking the mean of the top 50 metropolitan areas according to the 2010 population in the Large Metropolitan Statistical Areas—Population data set.

Health & Safety Impacts

Based on the assumptions made in this assessment about the magnitude and duration of a potential outage for the low and best estimate scenario, any health and safety impacts would most likely be limited to a few individuals and would likely be within a community's existing public health capacity to address. At the low end, the power being out for a few minutes or even a few hours, it is unlikely to cause any noticeable impact. Instead, the most pronounced impacts are likely to be caused by any power disruptions themselves.

However, there is historical evidence to suggest that health and safety impacts for a multi-day outage, as assumed in the high estimate, would be significant. The August 2003 blackout's impact in New York City (not the entire region) presents a potential scenario. In this case, "respiratory device failure (mechanical ventilators, positive pressure breathing assist devices, nebulizers, and oxygen compressors) was responsible for the greatest burden"[52] on the city's Emergency Medical Services (EMS) system. These issues were primarily caused by heat, poor air quality and exertion from disabled mass transit systems, but they may also have been "aggravated by a fourth factor: the psychological stress of not knowing what had happened, not knowing what else might happen, not knowing how to get home, and worrying about loved ones."[53] Subsequent studies identified approximately 90 excess fatalities and 400 excess illnesses attributable to the blackout in New York City.[54,55]

As noted above, the low and best estimates of fatalities and injuries/illnesses were zero by assumption. The best estimates were scaled to the high estimate, in proportion to the total population without power and outage duration. As noted above, of the physical parameters defining the best estimate across impact categories total population affected numbered totaled 2,138,460 and duration 1/8 of a day (3/24 hours). Scaled in proportion to the 90 fatalities and 400 illnesses from the high estimate event with 50,000,000 people out of power for one day (see below), this scenario results in 0.48 fatalities and 2.13 illnesses. Because the best estimate physical model is derived from a median and because of the uncertainties involved, these were rounded to the nearest integer for best estimates of 0 fatalities and 2 illnesses rather than kept as fractional numbers in the manner of other SNRA best estimates representing averages of a distribution or set.

Economic Impacts

There are several types of economic impacts that the Nation could face from an adversarial attack on one or more continental U.S. interconnections. There is the cost to the utility owners to repair damage to their electrical infrastructure (e.g. transmission lines, transformers, and substations). These costs can be significant, particularly since transformers are difficult to build and are typically customized to their exact location, which makes stockpiling supplies difficult. This assessment relies on the 2013 Metcalf incident to form the low economic damage value. In the case of the Metcalf attack, estimates of $15 million[56] in damages were widely reported for transformers that were damaged but not in need of replacement. Had all of the 17 transformers

[52] Prezant et al (2005).
[53] Lin et al (2011).
[54] Anderson et al (2012), Lin et al (2011). Excess respiratory illnesses: other illness causes, including diarrheal illness from spoiled food, did not result in detectable excess illnesses (Marx et al (2006)). Each of these studies used epidemiological methods similar to those used for counting excess fatalities due to influenza and influenza-related illnesses.
[55] Because of New York City's large population size, this figure is higher than what would intuitively be expected in smaller localities. To cite Anderson et al (2012), "among US cities, New York, NY, may be particularly vulnerable [to fatalities from power outages] because of its many high-rise buildings and substantial dependence on public transportation."
[56] Baker (2014).

suffered damage and needed to be replaced, it could have cost as much as $102 million, based on an approximate cost of $6 million[57] per transformer. In the case of the Metcalf substation disruption, there were no outages, so for the purpose of this assessment $15.11[58] million in direct economic costs forms the low estimate for economic impacts.

In addition to the physical damage to infrastructure, a successful outage (as is assumed in the best and high estimate scenarios) would cause additional direct economic loss. For the best estimate, which assumes that a U.S. metropolitan city of 2,138,460 experiences a three-hour outage, this assessment uses the benefit-cost analysis (BCA) methodology developed by FEMA in 2011. According to the BCA methodology, electricity disruption[59] on economic activity would cost $114.39 per capita per day in direct economic costs.[60] Since the analysis assumes the outage is three hours, the economic cost per three hours in 2015 terms is $14.30 per capita. By multiplying it across the population, the best estimate for direct economic impact is $30.58 million for the cost of the outage itself, or $46 million for total direct economic impact including the $15.11 million cost of damaged infrastructure.

For the high estimate, this assessment again uses the BCA guidance from FEMA. Based on historical evidence from the Northeast Blackout, the high estimate assumes there will be 50 million people affected for one day and using the direct impact on the economy of $114.39 per capita per day (in 2015 terms) from FEMA's BCA, the outage would cost $5.72 billion in direct economic loss.[61]

Due to the limitations of available research, there are other variables that would affect economic impacts that were not included in the scenario development—namely the fragility of businesses, mitigation steps that has already been taken, and the timing of the event. These variables warrant further discussion and study, but it is worth noting that some businesses are more fragile than others with regards to a power outage. Some sectors[62] are particularly vulnerable to even momentary lapses in power. One researcher notes "even a one-second outage can damage equipment and disrupt highly sensitive operations to the point where labor becomes idled as systems are reset and brought back online."[63] Nationally, these types of highly electricity-dependent companies "account for approximately 40 percent[64] of U.S. gross domestic product

[57] According to (U.S. Department of Energy (2014)), a large power transformer is estimated to cost $2 to $7.5 million plus expenses for transportation and installation, which can cost 25 to 30 percent more. A simplified figure of $6 million per transformer is used based on the midpoint of the range of cost plus an additional midpoint percentage increase to reflect transportation and installation expenses.
[58] This figure is adjusted for inflation in 2015 terms.
[59] FEMA (2011). FEMA's BCA methodology is as follows: 1. Estimate the physical damages to the electric power system in dollars, 2. Estimate the functional downtime (system days of lost service), 3. Obtain the number of people served by the electric power utility, and 4. Calculate the economic impacts of lost electric power service, using the per capita economic impacts and the affected population.
[60] FEMA (2011). Using 2010 numbers, FEMA determined that the direct economic cost of an electricity disruption is $106.27 per capita per day. $114.39 reflects this value adjusted for inflation in 2015 terms.
[61] It is worth noting that by using the FEMA BCA methodology on the Northeast Blackout, the direct economic costs in 2003 would equate to $4.48 billion. However, other methodologies can be used to determine the economic cost, but these figures take into account some indirect as well as direct costs. Using a proportional relationship between electricity consumption and national GDP, one calculation of the impacts of the 2003 Blackout showed that "50 million people were without electric power for a day, and so it estimated to have cost $5.6 billion, which is within the range of [other, more complex] estimates that have been published." (Zimmerman (2005)).
[62] Continuous manufacturers and digital/IT companies would be examples.
[63] Lineweber et al (2001).
[64] The specific industries and their Standard Industry Classification (SIC) codes came from Lineweber et al (2001) and are as follows: Apparel and other Finished Products Made from Fabrics and Similar Materials - 23; Biological Research - 873101; Chemical & Allied Products - 28 (Does not include 2836); Chemical Manufacturing - Biological products, except Diagnostic - 2836; Communications - 48; Computer And Office Equipment - 357; Custom Computer Programming Services - 7371; Data Processing and Preparation - 7374; Depository Institutions - 60; Electronic And Other Electrical Equipment And Components, Except Computer Equipment - 36; Fabricated Metal Products, Except Machinery and Transportation - 34; Food and Kindred Products - 20; Furniture and Fixtures - 25; Gas and Sanitary Services - 49 (does not include 4911 or 4931); Holding And Other Investments Offices - 67; Hospitals - 806; Industrial and Commercial Machinery and Computer Equipment - 35 (Does not include 357); Information Retrieval Services - 7375; Insurance Agents, Brokers, and Service - 64; Insurance Carriers - 63; Leather and Leather Products - 31; Local and Suburban Transit And Interurban Highway Passenger Transportation - 41; Lumber and Wood Products, Except Furniture ; Measuring, Analyzing, And Controlling Instruments; Photographic, Medical And Optical Goods; Watches And Clocks - 38; Miscellaneous Manufacturing Industries - 39;

(GDP)"[65] even though they represent less than 20 percent of all U.S. business establishments. In order to evaluate the vulnerability of businesses to a blackout, it is important to understand how companies have mitigated their vulnerability to blackouts. Some companies have installed backup generators to prevent lapses in power, while other businesses and economic activities are naturally more resilient[66] to lapses in power. For example, an analysis[67] based on self-reported estimates from businesses estimated that three-quarters of companies would experience no costs from a one-second outage, half of all businesses would not suffer measurable costs from a three-minute outage, and a quarter would not experience real costs from a one-hour outage. Additional research would need to be done to determine how widespread these mitigation actions may be on a national level and how instantaneously they can provide replacement electricity.

The direct costs associated with a loss of power are also impacted by the time of year when the blackout happens. For example, some costs, such as food spoilage and transportation, are dependent on season/weather and time of day. Residential costs—such as the purchase of wood for home heating, alternative light sources, food spoilage, or damage to electrical equipment—are "a fraction of those incurred by end-users in the other sectors"[68] and largely dependent on the timing[69] of a blackout.

Although rigorous study on the indirect costs of an outage was not fully analyzed within this assessment, research has been done to look at the indirect costs of an outage. Researchers noted "there are several types of indirect costs (e.g., accidental injuries, looting, vandalism, legal costs, loss of water supply, insurance rate increases) with monetary impacts that, in some cases, may exceed direct costs. In fact, an analysis of the interruption costs incurred as a result of the 1977 New York City blackout estimated that the indirect costs of the blackout exceeded direct costs by a margin of 5 to 1."[70] While this has the potential to significantly increase the economic impacts of an intentional disruption to the electrical grid, additional research is required to determine the impacts of indirect costs.

Social Displacement

For the purposes of the SNRA, social displacement was defined as the number of people forced to leave home for a period of two days or longer. Note that there are limitations to this measure of social displacement, as the significant differences between temporary evacuations and permanent displacement due to property destruction are not captured.

Unlike the Space Weather event, the physical scenarios used as the basis of the impact estimates for the Physical Attack on the Power Grid event included only comparatively short-term outages. Additionally, the SNRA project team was not able to find records of people who were displaced from their homes from two or more days due to the 2003 East Coast Blackout, the historical event used to model the high impact estimates.[71] For these reasons, the SNRA project team made

Noncommercial Biological Research - 873301; Non-Depository Credit Institutions - 61; Nursing And Personal Care Facilities - 805; Paper & Allied Products - 26; Petroleum & Coal Products - 29; Pipelines, Except Natural Gas - 46; Primary Metals Industries - 33; Printing, Publishing, and Allied Industries - 27; Railroad Transportation - 40; Real Estate - 65; Rubber & Misc. Plastics Products - 30; Security And Commodity Brokers, Dealers, Exchanges, and Services - 62; Stone, Clay & Glass Products - 32; Systems Integration Services - 7373; Textile Mill Products - 22; Tobacco Products - 21; Transportation By Air - 45; Transportation Equipment - 37; United States Postal Service - 43; Water Transportation - 44.

[65] Lineweber et al (2001).

[66] For example, workers who use laptops with built-in batteries.

[67] Lineweber et al (2001).

[68] Balducci et al (2003).

[69] To think if it in practical terms, losing power for a few hours in the middle of the night could easily be unnoticed by those who are asleep at the time.

[70] Balducci et al (2003).

[71] Hospitalizations are not included in the social displacement metric of the SNRA, as this would result in double counting with the Injuries/Illnesses metric.

the assumption that the number of persons displaced from their homes would be zero for all three of the low, best, and high estimates.

Psychological Impacts

The SNRA metric of psychological distress includes a scaling factor for each event, which was elicited from subject matter experts in 2011 for the first iteration of the SNRA. Although these factors have a strong regularity across the accidental and natural hazards which enabled the provisional determination of factors for many of the new hazard events in the 2015 SNRA, this is not true of the adversarial events. For this reason, the 2015 SNRA does not report psychological distress estimates for the Physical Attack on the Power Grid event.

Environmental Impacts

The environmental impact estimate, which was assessed for the 23 original national-level events of the 2011 SNRA by subject matter experts from the U.S. Environmental Protection Agency (EPA), could not be assessed for the Physical Attack on the Power Grid threat event which was added to the SNRA in calendar year 2015.

To support the comparative analysis of the SNRA, the SNRA 2015 project team made a provisional assignment of environmental impact on the same scale as the 2011 events based upon the closely analogous Cyber Attack against Physical Infrastructure national-level event, which was assessed by the EPA experts in 2011.

For a power outage caused by a malevolent actor attacking the grid (with cyber as opposed to physical means), the 2011 experts identified the best estimate of environmental impact as *De Minimus* or none.

- Experts indicated, however, that this depends on the duration of the event. If the impacts of a power outage event occur for longer than a few days, then backup systems for sewage plants, chemical facilities, and other infrastructure could fail and result in more severe environmental impacts. The experts provided a Second Best estimate of Low for the environmental impacts of such a longer duration scenario.

The SNRA project team assigned a provisional Best estimate of *De Minimus* and a provisional Second Best estimate of Low for the environmental impacts of the Physical Attack on the Power Grid threat event. It must be stressed that this assignment has not been reviewed by the 2011 subject matter experts or by the EPA.

A future iteration of the SNRA will assess the environmental impacts of this event directly.

Potential Mitigating Factors

In March 2014, the Federal Energy Regulatory Commission (FERC)[72] determined that physical attacks "could adversely impact the reliable operation of the Bulk-Power System,[73] resulting in instability, uncontrolled separation, or cascading failures."[74] FERC's intent is to require owners and operators of the Bulk-Power System to improve their resiliency from physical attacks by doing the following:

[72] FERC is an independent agency within the U.S. Department of Energy, and it regulates the interstate transmission of electricity, natural gas and oil. Its responsibilities including protecting the reliability of the high voltage interstate transmission system through mandatory reliability standards and enforcing its requirements through imposition of civil penalties and other means.
[73] The Bulk-Power System and electric grid are synonyms for practical purposes.
[74] FERC Docket No. RM14-15-000; Order No. 802.

- Identify which of their facilities are the most critical to the bulk-power system
- Assess those facilities' risk to physical attacks
- Have those assessments be verified by an appropriate third-party
- Develop and implement a security plan based on those risks

The existence of reliability standards themselves may not be enough to mitigate risk if they are not properly followed and enforced.

At this time, the rule-making process has not yet been completed, and it will still take additional time to be fully implemented. In the meantime, another key form of mitigation is already taken place: voluntary actions by the industry. For example, California-based PG&E announced plans to spend $100 million[75] to improve the security of its critical facilities, and a subsequent robbery[76] at the Metcalf substation in the months following the attack further reinforced the need for these improvements. In the short-term, voluntary risk reduction methods will be a key mitigation strategy.

In addition, government-led research and development holds potential for mid-term mitigation strategies. For example, in partnership with the utility industry and the DHS Office of Infrastructure Protection, the DHS Science and Technology Directorate (S&T) developed a prototype extra high-voltage transformer. Called the Recovery Transformer (RecX) project,[77] this prototype drastically reduced the amount of time needed to repair an extra high voltage transformer in an emergency—from several months to less than one week. Working with its industry partners, S&T successfully demonstrated the RecX prototype for one year, and the pilot ended in March 2013. A final report is currently in development.

To specifically mitigate health and safety impacts, local communities could identify their most critical systems and vulnerable populations, and steps could then be taken to ensure adequate measures are in place in the event of a power outage. For example, backup power systems could be "mandated, not only for acute care facilities, but also for community-based patients dependent on electrically powered lifesaving devices."[78] This would greatly minimize the impact of shorter-term power outages on public health capacity during emergencies.

References

Anderson et al (2012): Anderson GB, Bell ML. Lights Out: Impact of the August 2003 Power Outage on Mortality in New York, NY. *Epidemiology* (Cambridge, Mass). 2012;23(2):189–193. doi:10.1097/EDE.0b013e318245c61c.

Baker (2014): Baker, David. "FBI: Attack on PG&E South Bay Substation Wasn't Terrorism." *San Francisco Chronicle*. 11 Sept. 2014.

Balducci et al (2003): Balducci, Patrick, Joseph M. Roop, Lawrence A. Schienbein, John G. DeSteese and Mark R. Weimar. Electric Power Interruption Cost Estimates for Individual Industries, Sectors and the U.S. Economy. Pacific Northwest National Laboratory. Proceedings from the Twenty-Fifth Industrial Energy Technology Conference, Houston, TX, May 13–16, 2003.

Census Bureau (2010): U.S. Census Bureau. *Population: Estimates and Projections--States, Metropolitan Areas, Cities*. http://www.census.gov/compendia/statab/cats/population/estimates_and_projections--states_metropolitan_areas_cities.html.

[75] Baker (2014).
[76] Smith (2014c).
[77] DHS Science & Technology Directorate (2014).
[78] Prezant et al (2005).

DHS Science & Technology Directorate (2014): DHS Science and Technology Directorate Recovery Transformer Fact Sheet available at www.dhs.gov/sites/default/files/publications/Recovery%20Transformer-RecX2-508.pdf.

FBI (1982): Federal Bureau of Investigation (1982). FBI Analysis of Claimed Terrorist Incidents in the U.S. 1981. Terrorist Research and Analytical Center, FBI: at https://www.ncjrs.gov/pdffiles1/Digitization/120256NCJRS.pdf (retrieved 25 August 2014).

FEMA (2011): FEMA Benefit-Cost Analysis Re-Engineering: Development of Standard Economic Values. Version 6. 2011

FERC (2009): FERC Approves Settlement, $25 Million Fine for FPL's 2008 Blackout. Federal Energy Regulatory Commission News Release. October 8, 2009.

Holmgren (2006): Holmgren, Ake. Using Graph Models to Analyze the Vulnerability of Electric Power Networks. *Risk Analysis*, Vol. 26, No. 4, 2006.

Holmgren et al (2007): Holmgren, Åke, Erik Jenelius and Jonas Westin. Evaluating Strategies for Defending Electric Power Networks Against Antagonistic Attacks. IEEE Transactions on Power Systems. Vol 22, No 1, February 2007.

LaCommare et al (2004): LaCommare, Kristina Hamachi; & Eto, Joseph H.(2004). Understanding the Cost of Power Interruptions to U.S. Electricity Consumers. Lawrence Berkeley National Laboratory. Lawrence Berkeley National Laboratory: Lawrence Berkeley National Laboratory. Retrieved from: https://escholarship.org/uc/item/1fv4c2fv

Lin et al (2011): Lin S, Fletcher BA, Luo M, Chinery R, Hwang S-A. Health Impact in New York City During the Northeastern Blackout of 2003. *Public Health Reports*. 2011; 126(3): 384–393.

Lineweber et al (2001): Lineweber, David and Shawn McNulty. The Cost of Power Disturbances to Industrial & Digital Economy Companies. EPRI's Consortium for Electric Infrastructure for a Digital Society. 29 June 2011.

Lloyd's (2013): Solar Storm Risk to the North American Electric Grid. Produced by Lloyd's and the Atmospheric and Environmental Research, Inc. 2013. Available at www.lloyds.com/~/media/lloyds/reports/emerging%20risk%20 reports/solar%20storm%20risk%20to%20the%20north%20american%20electric%20grid.pdf (accessed May 2013).

Los Angeles Times (2011a): Power Back for 694,000 Customers of San Diego Gas & Electric, More on the Way. *Los Angeles Times* 9 September 2011. Available at http://latimesblogs.latimes.com/lanow/2011/09/some-540000-of-the-14-million-customers-who-lost-power-have-now-had-power-restored-san-diego-gas-electric-co-reported-at.html.

Los Angeles Times (2011b): Normal Life Starts Resuming After Power Restored in San Diego. 9 September 2011. Available at http://latimesblogs.latimes.com/lanow/2011/09/power-restored-after-massive-blackout-normalcy-returns.html.

Marx et al (2006): Marx, Melissa A., et al. Diarrheal Illness Detected through Syndromic Surveillance After a Massive Power Outage: New York City, August 2003. *American Journal of Public Health* vol 96(3) (March 2006), pp 547–553; accessed at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1470517/.

McGillivary et al (2015): McGillivary, Brian. "$1 million transformers don't fit at TCL&P." *The Record-Eagle*. 10 March 2015. Available at www.record-eagle.com/news/local_news/million-transformers-don-t-fit-at-tcl-p/article_1e4074f3-5df8-59a7-a20a-718beaa2d052.html.

NERC (2012): North American Electric Reliability Corporation (NERC) (2012, July 25). NERC Interconnections. At http://www.nerc.com/AboutNERC/keyplayers/Documents/NERC_Interconnections_Color_072512.jpg (retrieved 16 April 2015).

Nye (2010): Nye, David E. When the Lights Went Out: A History of Blackouts in America. MIT Press, Cambridge MA, 2010.

Padgett (2008): Padgett, Tim. "Florida's Blackout: A Warning Sign?" *Time Magazine*. 27 February 2008. Available at http://content.time.com/time/nation/article/0,8599,1717878,00.html.

Parformak (2014): Parfomak, Paul. Physical Security of the U.S. Power Grid: High-Voltage Transformer Substations. Congressional Research Service. June 17, 2014.

Prezant et al (2005): Prezant, David J. et. al. "Effects of the August 2003 Blackout on the New York City Healthcare Delivery System: A Lesson for Disaster Preparedness." *Critical Care Medicine*: January 2005 - Volume 33 - Issue 1 - pp S96–S101.

Smith (2014a): Smith, Rebecca. "Assault on California Power Station Raises Alarm on Potential for Terrorism." *Wall Street Journal*. 2 February 2014.

Smith (2014b): Smith, Rebecca. "U.S. Risks National Blackout from Small-Scale Attack." *Wall Street Journal*. 12 March 2014.

Smith (2014c): Smith, Rebecca. "PG&E Silicon Valley Substation Is Breached Again." *Wall Street Journal*. 28 Aug 2014.

Thomas (1981): Thomas, Jo (1981, November 28). Puerto Rico Terrorist Group Takes Responsibility for Blackout. *New York Times* 29 November 1981: at http://www.nytimes.com/1981/11/29/us/puerto-rico-terrorist-group-takes-responsibility-for-blackout.html.

Thornton (2015): Thornton, Jack. Another Side of Energy Independence: North America Reduces its Need to Import a Key Link in its Electricity Grid. *Mechanical Engineering*. March 2015.

Tweed (2014): Tweed, K., "Bulletproofing the Grid [News]," *Spectrum, IEEE* , vol.51, no.5. May 2014 http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=6808445&isnumber=6808432.

U.S. Department of Energy (2012): U.S. Department of Energy, 2011 Year-in-Review: Energy Infrastructure Events and Expansions, April 2012.

U.S. Department of Energy (2014): "Large Power Transformers and the U.S. Electric Grid." Infrastructure Security and Energy Restoration. Office of Electricity Delivery and Energy Reliability. U.S. Department of Energy. April 2014. Available at http://energy.gov/oe/downloads/large-power-transformers-and-us-electric-grid-report-update-april-2014

U.S.-Canada (2004): U.S Canada Power System Outage Task Force, Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations, 2004. Available at http://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/BlackoutFinal-Web.pdf.

Wang et al (2014): Wang, Yezhou, and Ross Baldick. Interdiction Analysis of Electric Grids Combining Cascading Outage and Medium-Term Impacts. *IEEE Transactions on Power Systems*. Vol 29, No. 5. September 2014.

Zimmerman (2005): Zimmerman, R. Electricity Case: Economic Cost Estimation Factors for Economic Assessment of Terrorist Attacks. Center for Risk and Economic Analysis of Terrorism Events (CREATE). University of Southern California. 31 May 2005.