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TOPICAL REVIEW

Understanding the social impacts of power outages in North America: a systematic review

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Abstract

As demand for electricity increases on an already strained electrical supply due to urbanization, population growth, and climate change, the likelihood of power outages will also increase. While researchers understand that the number of electrical grid disturbances is increasing, we do not adequately understand how increased power outages will affect a society that has become increasingly dependent on a reliable electric supply. This systematic review aims to understand how power outages have affected society, primarily through health impacts, and identify populations most vulnerable to power outages based on the conclusions from prior studies. Based on search parameters, 762 articles were initially identified, of which only 50 discussed the social impacts of power outages in North America. According to this literature, racial and ethnic minorities, especially Blacks or African Americans, those of lower socioeconomic status, children, older adults, and those living in rural areas experienced more significant impacts from previous power outages. Additionally, criminal activity increased during prolonged power outages with both pro-social and anti-social behaviors observed. Providing financial assistance or resources to replace spoiled goods can reduce crime. Future research on this topic must consider the financial effects of power outages, how power outage impacts seasonally vary, and the different durations of power outage impacts.

1. Introduction

The most recent reports from the Intergovernmental Panel on Climate Change suggests that heat waves and deep freezes will increase demand for electricity which in turn will lead to brownouts—intentional or unintentional drops in voltage to conserve electricity during emergencies—and blackouts (Revi *et al* 2014, Dodman *et al* 2022). Similarly, the 2021 American Society for Civil Engineers (ASCE) infrastructure report card rated the current condition of electrical infrastructure in the United States as mediocre, a slight improvement from the 2017 report. The report card defines mediocre as infrastructure in fair or good condition, but that requires attention and elements of the system show significant deficiencies in condition and functionality, thus increasing its vulnerability to risk (ASCE 2021). The ASCE estimated that more than 2.5 trillion dollars would be required to restore the nation's infrastructure to acceptable conditions (ASCE 2021). This frail and failing infrastructure will be further stressed by the effects of the changing climate, including more frequent anomalous weather events, as well as increasing population and associated demand for reliable electricity (Anderson and Bell 2012, Matthewman and Byrd 2014, USGCRP 2018). The current infrastructure was not designed to withstand the capacity of a rapidly increasing and urbanizing global population and is vulnerable due to outdated design standards (Chester and Allenby 2018, 2019). The system, as designed, is highly interdependent with other critical systems, such as water

purification and communication networks; any failures within the electrical system can lead to failures in other systems that depend on continuous electricity (Rinaldi *et al* 2001). As a result, scholars anticipate that the likelihood of blackouts, and their consequences, will increase in the coming decades (Anderson and Bell 2012, Matthewman and Byrd 2014, Burillo *et al* 2017). Infrastructure that is adaptive and flexible to the effects anticipated in the future climate is essential to mitigate impacts from future shocks and stressors (Chester and Allenby 2018). In this context, we are defining adaptive as having the capacity to respond to shocks and stressors to the system while maintaining its fitness (Chester and Allenby 2018). Future infrastructure design must consider all potential scenarios of the future climate and adapt infrastructure accordingly (Burillo *et al* 2017).

Recent large-scale failures in the electrical grid have also highlighted the critical nature of urgent infrastructure repairs. In 2019, the state of California experienced rolling blackouts to address an increasing wildfire threat. New York also experienced a brownout in 2020 that caused a widespread, and unexpected power outage. Most recently, in 2021, Texas experienced a near collapse of its electrical grid, leaving electricity providers to implement rolling blackouts that lasted for days in extremely cold temperatures. Recently passed legislation allocates funding into America's infrastructure systems over the next 10 years (The White House 2021). This investment in infrastructure provides a foundation to restore the infrastructure systems to acceptable conditions, but additional investments are needed to ensure that systems can still operate under future stresses and strains (ASCE 2021). While electrical grid failures are technological in nature, the impacts to human health and safety add a societal component to these technical failures.

People are affected adversely by power outages. Physical health impacts are a large concern during power outages, especially for those that rely on an electricity-dependent medical device (Miles *et al* 2014, Miles and Jagielo 2014, Esmalian *et al* 2019). Mental health issues also become a concern during power outages, as those affected are living in temporary uncertainty about how long the event will last and how it may affect them (Rubin and Rogers 2019). As these examples make clear, the effects of power outages are not uniform across society. Given the growing risks, it is important to understand how power outages may differentially impact various populations because of their unique social and household characteristics.

The purpose of this review is to understand how people are affected during power outages by utilizing 42 years (1978–2019) of academic literature. To the best of our knowledge, this is the first review that explores all social impacts of outages from literature published over a long time span. Klinger *et al* (2014), Rubin and Rogers (2019), and Casey *et al* (2020) conducted similar reviews. Klinger *et al* (2014) only focused on two years of peer-reviewed literature (2011–2012) and identified 20 relevant articles on the health impacts of power outages. They also utilized media pieces to further augment their analysis of power outages outside of North America (Klinger *et al* 2014). Casey *et al* (2020) also examined power outage impacts through a community health perspective. Rubin and Rogers (2019) focused on the psychological and behavioral impacts of power outages and argued that these concerns needed to be addressed by public leaders. Rubin & Rogers identified 47 articles in their review on how the public reacted to a major loss of electricity, did not have a geographic boundary, and included hypothetical, or what they call, "threatened" events. Our aim is to assess common themes in the literature on how different people are impacted by power outages. In short, this review advances knowledge by examining a broader range of social impacts.

These methodologies are similar to our review; however, we did not limit the scope to only health impacts, did not consider media pieces, and only used Scopus for our review and did not include Google Scholar or Web of Science. While we recognize Google Scholar and Web of Science are two common academic citation databases, each have their strengths and weaknesses over Scopus. Harzing and Alakangas (2016) found that Scopus yielded more results and the largest growth in the number of papers compared to Google Scholar and Web of Science. Google Scholar's interface does not allow for bibliometric analyses to be done and does not provide the same filtering options that Scopus provides (Harzing and Alakangas 2016). Google Scholar and Scopus have become as reliable, if not more than, Web of Science. We ultimately decided on Scopus to increase the probability of finding articles related to the topic of interest while also filtering out articles that would not be as relevant from Google Scholar (Harzing and Alakangas 2016).

When discussing the social impacts of power outages, we are considering the impacts to people and households that could occur during a power outage, regardless of how the outage occurred. We are defining social impacts as the direct and indirect effects on people's well-being or their physical or mental health. Some examples of direct impacts include being unable to use an electronic medical device and increased feelings of anxiety because of not knowing when power would be restored. Examples of indirect impacts are having thrown spoiled food away and re-locating temporarily to a location that has not lost power.

In the next section we detail the systematic review methodology, inclusion and exclusion criteria, and literature selected for this review. In section 3, we

present the findings from the literature categorized into common themes, accompanied by a discussion. Finally, in section 4, we summarize these insights and propose future directions for power outage research.

2. Review methodology

2.1. Literature search

Roughly 20 preliminary searches were conducted to iteratively identify a set of search terms that would return articles relevant to the research objective (see table 1 for the searches used to create the list of results for this review). At first, we focused on using search terms that were relevant to identifying research related to power outages that occurred after a natural hazard. While reading through abstracts of previous searches, it was apparent that we were missing outages that occurred independently, or those that were initiated due to failures within the electric grid system itself. We revised our terms to include papers related to these events within our review. Ultimately, we used two separate keyword lists to build a set of candidate articles for inclusion, and evaluated articles on each list based on inclusion criteria. We searched for articles using Scopus, limiting the search to peer-reviewed literature articles published in English with the search terms present in the title, abstract, or keywords (Andresen 2020). We understand that papers may be missing from the Scopus database and our search criteria may not capture all relevant papers. There also might be relevant non-peer-reviewed work that is relevant to this topic but not included in our criteria. We acknowledge and recognize these aspects of the methodology as potential limitations (Harzing and Alakangas 2016). The first set of search terms, applied in December 2019, used 'power outage*' AND 'impact*'. This search yielded 513 candidate articles.

The second set of search terms was applied in February 2020 to broaden the scope of articles on the social impacts of power outages that were included. The terms used in the searches, specifically power outage, blackout, and power failure, were used as they are similar in meaning and could most effectively capture research related to electricity disruptions. Excluding terms like alcohol and drink were necessary because in preliminary searches, there were instances where blackout would return results related to either medical conditions or over-consumption of alcohol, which is not the purpose of this review. Other terms, like electricity, were not included but should be considered when conducting future reviews on this topic; we recognize there are search terms that could yield additional articles to include in our review and acknowledge that omitting certain search terms as a limitation to our review. When examining the results from the first search, it appeared we were missing papers from the health perspective of power outages. The second search used a set of terms aimed at expanding the scope of the research further, by attempting to find relevant research from the health perspective, like that of Klinger *et al* (2014). The second search produced 560 articles.

We did not specifically examine research on modeling power outage patterns, both spatially and temporally, nor did we intend to review the findings of papers that explore the potential impacts that are modeled through simulations of future power outages, providing access to electricity, or maintaining a reliable electric supply. We also recognize that the infrastructure management in North America differs from other countries and that papers focused outside of North America were less likely to be written in English, and thus would have to be excluded per our filtering criteria. We also acknowledge that other languages are common within the United States, however the authors did not have the knowledge or resources available to accurately translate papers written in another language to include them in the review, and recognize this language barrier as a limitation to this review.

We bounded our review to only studies that focused on events within North America. We limited the geographic scope of papers in this review to North America due to aspects of the United States' electric grid existing in Canada and Mexico (Andresen 2020). Therefore, when failures occurr in the United States, the effects can, sometimes, cascade throughout portions of the system beyond the United States border. We did not limit the geographic scope to only the United States given this overlap with the two countries at certain points within the system (Learn More About Interconnections, n.d.).

2.2. Coding

The aforementioned search terms returned 762 results in Scopus. We read each abstract to determine if the paper possibly examined the social impacts of power outages. After reading through the abstracts the first time, four inductive and inclusive themes emerged: modeling ($n = 173$), technical ($n = 393$), social ($n = 70$), and other ($n = 333$). Abstracts were read a second time to classify each abstract into these themes. Papers classified as modeling used a simulation or modeling technique to simulate power outage occurrences. Those classified as technical papers explore the impacts of power outages on physical infrastructure. Social research examined impacts on individuals, households, or demonstrated how power outages impacted critical social services. The other category served as a classification for papers that do not fall under the three previously listed categories. Only those classified as social, either exclusively or in combination with other categories, were subject to additional criteria to determine if they examined the social impacts of power outages and were eligible for inclusion in the full review. This

Table 1. Search terms used to return the final list used for this systematic review (Andresen 2020). Reproduced from Andresen (2020) CC BY 4.0.

Search number	Terms used	Number of results
1	'power outage*' AND 'impact*'	513
2	'power outage*' OR 'blackout*' OR 'power failure*' AND 'social' OR 'health' AND NOT 'alcohol*' OR 'drink*' OR 'micro*' AND DOCTYPE (ar or re)	560
3	#1 OR #2 AND DOCTYPE (ar or re)	762

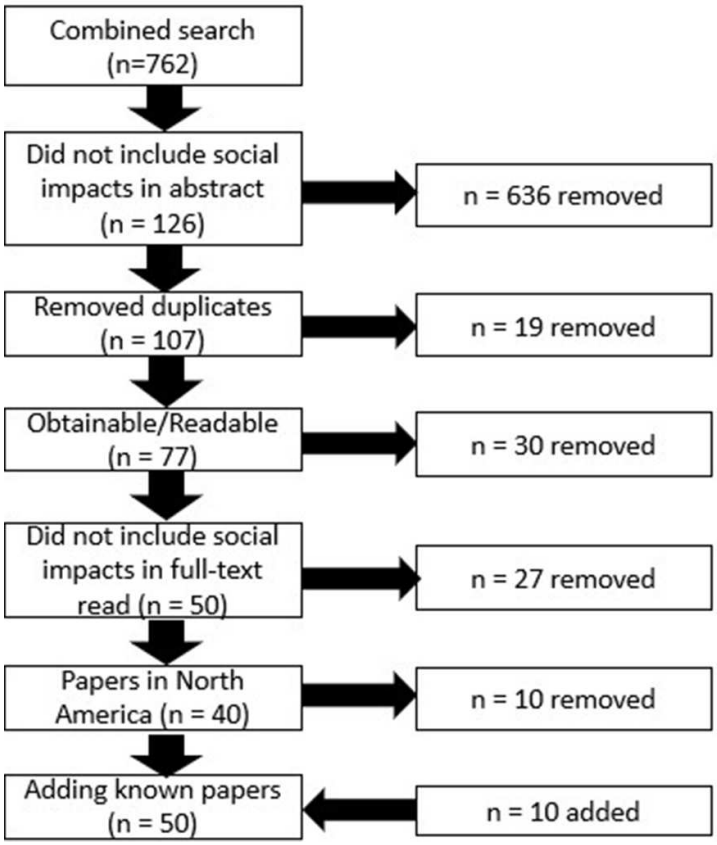

Figure 1. A visualization of the filtering process to obtain the list of literature used for this review. Adapted from Andresen (2020) CC BY 4.0.

step eliminated 636 papers. As part of this screening, we excluded 125 papers that examined a significant weather event but did not detail the impacts of the ensuing power outage. We eliminated 391 papers that observed the impacts past power outages had, or future outages may have, on the electric grid or other aspects of the electrical grid system, classified as only a technical paper. We excluded studies that examined willingness-to-pay or discrete choice experiments and classified these studies as other. While these studies estimated the number of money people would consider paying to avoid outages, no connection to impacts was made (Carlsson and Martinsson 2008, Abdullah and Mariel 2010). Additional studies excluded consisted of a biographical account of living in a situation with unreliable electricity outside of North America or deploying a model or simulation to show the potential impacts that could affect people (Hiete *et al* 2011, Kesselring 2017). We also removed 19 duplicate entries and 30 papers that were inaccessible, not written in English, or had insufficient data in the Scopus search returns. We then read the full text of the remaining 77 articles. After the full-text read of each paper, 27 more papers were removed as they did not examine the social impacts of power outages, despite making it through the previous criteria; 50 papers remained. Finally, we removed ten papers focused on areas outside of North America resulting in a final dataset of 40 papers. The authors were aware of ten additional papers from previous work and papers that were not included in the search results, bringing the final total to 50 papers for this review. A visual depiction of this process is displayed in figure 1. More details about the literature used can be found in the supplemental material.

We further analyzed the papers based on their research design and the methods used to conduct the research (see table 2). The research design and method themes emerged from the included papers based on the authors' descriptions and explanations. After categorizing the research designs for each paper included in the review, we classified the papers further to examine the common methodologies used to study the social impacts of power outages. The themes developed using an inductive approach to allow themes to emerge. This review did not use software to analyze the literature.

3. Results and discussion

3.1. Descriptive and thematic analysis

One of the most striking findings from our review is that only five percent of the original sample of 762 papers identified in Scopus focused on the social impacts of power outages. Of the 50 papers included in this review, six also included a statistical modeling component and were categorized as modeling. Four papers also discussed components of the hard infrastructure or the technical aspects of power outages and were also labeled technical. Finally, four papers also were classified as other as their methods or overall objective did not fit within the scope of a modeling or technical paper. Of the 50 papers analyzed, 40 solely focused on the social effects of power failures without addressing one or more of the other categories (see figure 2).

Significant events, like large-scale blackouts, provide an opportunity to research the social impacts of power outages; however, these are not planned events and can be difficult to anticipate for researchers. The primary focus of the literature we examined was the impact of power outages during the aftermath of significant weather or geological events. Most of the literature here focused on power outages lasting for more than one day (see table 2). From the 50 papers used in this review, 46 examined the power outage impacts of 26 distinct events. The most frequently examined events were the 2003 blackout that occurred across the northeastern United States and parts of Canada and Superstorm Sandy (2012), which were the subject of ten articles and seven articles, respectively. The 1977 blackout in New York City, Hurricane Irma (2017), and Hurricane Isaac (2012) were also each the subject of more than one article we reviewed; other events mentioned were examined in the literature only once. The remainder of the research did not emerge from a significant event ($n = 4$).

We found that articles related to the social impacts of power failures appeared in 40 different journals (see table 3), suggesting that this research is highly interdisciplinary. Only five journals published more than one article included in this review. These journals included Prehospital and Disaster Medicine (five publications), Disaster Medicine and Public Health Preparedness (three publications), the Journal of Environmental Health, Natural Hazards, the American Journal of Preventive Medicine, and the Journal of Infrastructure Systems (each with two publications). Journal titles reflected a wide range of disciplines addressing the social impacts of power failure, including public health, geography, sustainability, and energy.

There has also been a rise in scholarship in this field over recent decades (figure 3). Before the 21st century, we found only four articles on the social impacts of power outages, with the earliest article in our review published in 1978, ten from 2000–2009, and 35 from 2010–2019. However, it should be noted that this increase may correspond to the overall increase in published research within the past decade, as well as opportunities for research presented by hazards such as Hurricane Isaac and Superstorm Sandy (2012), and Hurricanes Irma and Maria (2017). The possibility does exist that some events received more research attention in general and could therefore have more papers written about them, including those related to power outage impacts. However, examining which events have been studied most frequently in greater detail is outside the scope of this review.

We further classified the papers we reviewed based on their design and methodological approach. Each paper was classified as either a case study or systematic literature review. If the paper was classified as a case study, we further classified the paper based on the method(s) used. The most common methods in the articles we reviewed were interviews ($n = 12$), followed by surveys ($n = 7$), reports or summaries of events ($n = 3$), models ($n = 2$), and other ($n = 1$). To clarify, any research classified as a case study examined a variety of impacts because of an event but maintained a focus on the ensuing power outage that occurred after the event (see table 4).

As of June 2020, when we collected citation information, the papers found through this review were only modestly cited in the literature, with an average citation count of 10.84 citations per paper (standard deviation = 11.85). Forty-four of the 50 papers in this review were within one standard deviation of the average citation count. Forty-seven of the papers were within two standard deviations of the average. The most cited had, at the time of this review, 56 citations (Anderson and Bell 2012), with the next highest being 45 citations (Marx *et al* 2006), and then 40 citations (Greenwald *et al* 2004). Most of the papers published before 2000 have a relatively small number of citations, except for Wrenn and Conners (1997) with 30 citations.

3.2. Themes within the literature

This section encompasses the relevant findings from the literature across three inductive themes: populations of concern ($n = 29$), health impacts ($n = 24$),

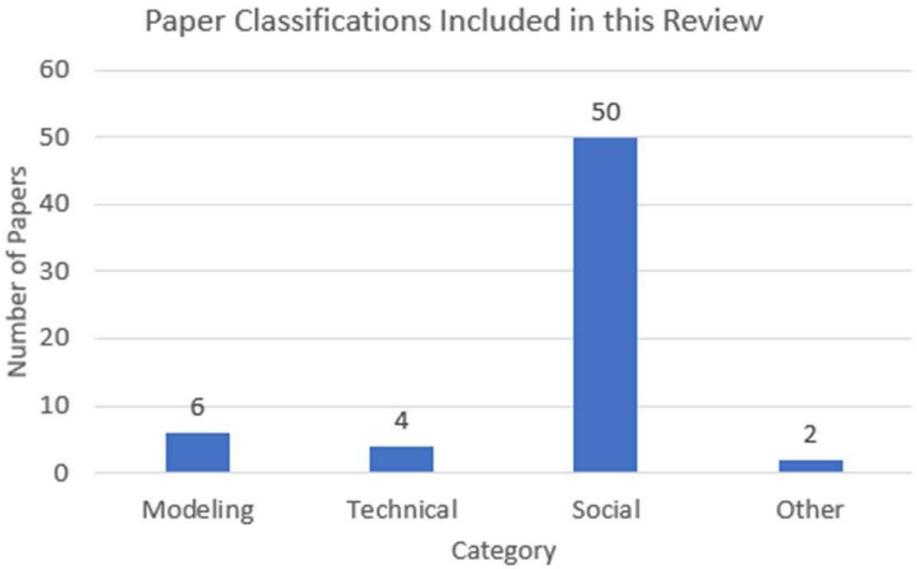

Figure 2. A visual breakdown showing how many papers included in the review fell under each category. Adapted from Andresen (2020) CC BY 4.0.

and criminal activity ($n = 6$) (see also Andresen (2020) for more information about these results).

3.2.1. Health impacts

This section examines the 24 studies that observed the health impacts of previous power outages and how these events impacted healthcare systems. This section also highlights the physical and mental impacts to human health that were caused by power outages.

3.2.1.1. Physical health impacts

Health impacts were a common theme in the literature. One of the main concerns from the health sector when a major power outage occurs is the increase in the emergency department (ED) visits due to carbon monoxide (CO) poisoning. CO poisoning primarily resulted from improper and unsafe usage of generators during a power outage, as noted by Riddex and Dellgar (2001), Van Sickle *et al* (2007), Fife *et al* (2009), Call (2010) and Wrenn and Conners (1997). An increase in the number of hospital and ED admissions due to carbon monoxide was reported by Baer *et al* (2011) after a significant windstorm in the state of Washington in December 2006. A similar pattern was observed after a Colorado snowstorm in 2006, when 264 people, presented with CO poisoning symptoms (Musciatello *et al* 2006). Similarly, Schnall *et al* (2017) noted 566 cases of carbon monoxide poisoning post-Superstorm Sandy. Anderson and Bell (2012) also found that deaths from CO poisoning were accidental and more likely to occur in older age groups. Hospitals and emergency departments should expect an increase in ED visits because of incidents that occur after the hazard (Greenwald *et al* 2004, Muscatiello *et al* 2010, Johnson-Arbor *et al* 2014, Schnall *et al* 2017).

3.2.1.2. Mental health impacts

Another concern related to health was the impacts on mental health during power outages. The longer duration that services, like electricity, were lost, the more likely signs of anxiety, depression, stress, and, in some cases, Post Traumatic Stress Disorder were to develop (Gros *et al* 2012, Paradis 2012, Apenteng *et al* 2018, Moreno and Shaw 2019). However, if the outage lasted a short time, significantly less severe psychological symptoms were observed, primarily due to preparedness factors before the outage occurred (Gros *et al* 2012). ED visits for mental health reasons also increased during power outages (Lin *et al* 2016, Rubin and Rogers 2019).

Other potential physical injuries may occur during a power outage from mental health impacts. During power outages, some people may resort to abusing substances to cope with the unusual times, like alcohol and drugs, adding to the danger of power outages (Jani *et al* 2006, Lemieux 2014, Lin *et al* 2016). Jani *et al* (2006) noted that of the 32 deaths examined from Hurricane Isabel, alcohol appeared to be involved in eight deaths and marijuana in one. All deaths occurred while completing tasks that require coordination and good judgment, for instance, driving in dangerous weather conditions (Jani *et al* 2006). Communication and messaging about the dangers of using these substances during and after extreme weather events are critical to limit the number of indirect deaths (Jani *et al* 2006).

3.2.1.3. Food-related impacts

Food-related illnesses also increase during and after power outages due to the consumption of spoiled food. Marx *et al* (2006) noticed an increase in ED visits in New York City after the 2003 Northeast blackout for symptoms of diarrheal illness. The authors could

Table 2. A list of events and their frequency in the literature reviewed. Adapted from Andresen (2020) CC BY 4.0.

Event	Number of papers	In-text citations
1977 NYC Blackout	4	Imperato (2016), Muhlin *et al* (1981), Sugarman (1978), Wohlenberg (1982)
1991 Ice storm	1	Wrenn and Conners (1997)
1994 Ice storm	1	Wrenn and Conners (1997)
1998 Blackout	1	Lemiuex (2014)
1998 Ice storm	1	Riddex and Dellgar (2001)
1999 Power outages	1	Dominianni *et al* (2018b)
2003 Blackout	11	Eachempti *et al* (2004), Greenwald *et al* (2004), Kile *et al* (2005), Rand *et al* (2005), Freese *et al* (2006), Marx *et al* (2006), Klein *et al* (2007), Lin *et al* (2011), Paradis (2012), Anderson and Bell (2012), Dominianni *et al* (2018b),
2003 Hurricane Isabel	1	Jani *et al* (2006)
2003 SARS	1	Paradis (2012)
2004 Hurricanes	1	Van Sickle *et al* (2007)
2005 Florida hurricanes	1	Becker *et al* (2012)
2006 Power outages	1	Dominianni *et al* (2018b)
2006 Snowstorm	1	Muscatiello *et al* (2010)
2006 Windstorm	1	Baer *et al* (2011)
2008 Hurricane Ike	2	Fife *et al* (2009), Gros *et al* (2012)
2011 Snowstorm	1	Johnson-Arbor *et al* (2014)
2011 Outage	1	Miles *et al* (2014)
2012 Derecho	1	Abir *et al* (2013)
2012 Hurricane Isaac	2	Miles and Jagielo (2014), Miles *et al* (2016)
2012 Superstorm Sandy	7	Burget *et al* (2013), Burger and Gochfeld (2014), Burger and Gochfeld (2015), Gotanda *et al* (2015), Arya *et al* (2016), Lin *et al* (2016), Schnall *et al* (2017)
2013 Snowstorm	1	Johnson-Arbor *et al* (2014)
2016 Hurricane Hermine	1	Ulak *et al* (2018)
2017 Hurricane Harvey	1	Esmalian *et al* (2019)
2017 Hurricane Irma	3	Mistova *et al* (2018), Chakalian *et al* (2019), Mitsova *et al* (2019)
2017 Hurricane Maria	1	Román *et al* (2019)
Ice Storms from 1886–2000	1	Call (2010)
N/A	6	Palmieri and Greenhalgh (2002), Kosa *et al* (2011), Kosa *et al* (2012), Matthewman and Byrd (2014), Dominianni *et al* (2018a), Rubin and Rogers (2019)

not establish a relationship between power outage and consuming spoiled food, as additional samples and data would be needed to further support their findings. However, the authors stated that spoiled food after the blackout may have caused an increase in ED visits (Marx *et al* 2006). Kosa *et al* (2011) highlighted through their study that many Americans are not prepared enough for a prolonged outage. Of those that experienced a power outage, only 37% discarded food that thawed in the freezer, and 31% discarded refrigerated perishable food that remained in the refrigerator for at least 4 h without power (Kosa *et al* 2011). From the sample, 33% of the sample knew to discard perishable foods, like meat, eggs, and dairy, after 4 h without power (Kosa *et al* 2011).

3.2.1.4. Medical devices

In addition to those that require hospitalization or care at a medical facility, people that require at-home care or are dependent on medical equipment outside of a medical facility, are vulnerable during power outages. Those that are dependent on medical devices, other than home oxygen therapy (HOT) equipment, are also more likely to call for emergency services during an outage (Rand *et al* 2005). During the 1977 New York City blackout, over 70 000 emergency calls were received in the 48 h blackout, as opposed to an average of 18 500 calls in 48 h under normal conditions (Imperato 2016). Those that require regular medical treatments (e.g. dialysis and other specialized medical practices) are vulnerable during power outages because of the possibility of missing treatments and not having a facility with reliable electricity to receive that treatment (Abir *et al* 2013). Device failure, from HOTs and ventilators, also led to an increase in ED visits, which requires significant ED and hospital resources (Greenwald *et al* 2004). The findings here indicate that patients who require HOT

Table 3. A list of journals, and frequencies, where articles for the review were published. Reproduced from Andresen (2020) CC BY 4.0.

Journal	Number of papers
Academic Emergency Medicine	1
American Journal of Disaster Medicine	1
American Journal of Preventive Medicine	2
American Journal of Preventive Medicine	1
American Journal of Public Health	1
American Society of Civil Engineers	1
Archives of Surgery	1
Clinical Toxicology	1
Computing in Civil Engineering 2019: Smart Cities, Sustainability, and Resilience—Selected Papers from the ASCE International Conference on Computing in Civil Engineering 2019	1
Disaster Medicine and Public Health Preparedness	3
Disasters	1
Economic Geography	1
Educational Gerontology	1
Environmental Health Perspectives	1
Epidemiology	1
Evaluation and Program Planning	1
Food Protection Trends	1
IEEE Spectrum	1
International Journal of Disaster Risk Reduction	1
Journal of Community Health	1
Journal of Emergency Medicine	1
Journal of Environmental Health	2
Journal of Infrastructure Systems	2
Journal of Psychopathology and Behavioral Assessment	1
Journal of Public Health and Management	1
Journal of Risk Research	1
Journal of Toxicology and Environmental Health—Part A: Current Issues	1
Journal of Trauma—Injury, Infection and Critical Care	1
Journal of Urban Health	1
Natural Hazards	2
Pediatrics	1
PLoS ONE	1
Prehospital and Disaster Medicine	5
Prehospital Emergency Care	1
Public Health Reports	1
Science of the Total Environment	1
Social Space	1
Sustainability (Switzerland)	1
Vulnerability, Uncertainty, and Risk: Quantification, Mitigation, and Management—Proceedings of the 2nd International Conference on Vulnerability and Risk Analysis and Management, ICVRAM 2014 and the 6th International Symposium on Uncertainty Modeling	1
Weather, Climate, and Society	1

treatments need assistance before the storm so they can prepare for the post-event period without power (Esmalian *et al* 2019). Thus, planning for large-scale events, and more specifically planning where those who rely on electronic medical equipment need to be transported to receive the proper treatment, is a vital component of power outage preparedness, response, and recovery (Miles *et al* 2014, Miles and Jagielo 2014).

3.2.2. Populations of concern

A common theme within the literature was the recognition that certain populations are more at risk for negative outcomes during a power outage. We found 29 studies that identified one or more populations of concern. Populations of concern identified through this research included children, non-English speakers, racial/ethnic minorities, older adults, and those that live in rural areas. While we identify these groups as populations of concern, we recognized most articles view this phrase in a vulnerability context. In using language that aligns with vulnerability, the definitions of what make a vulnerable population can vary. In this review, we attempted to synthesize the commonly identified populations of concern in the literature.

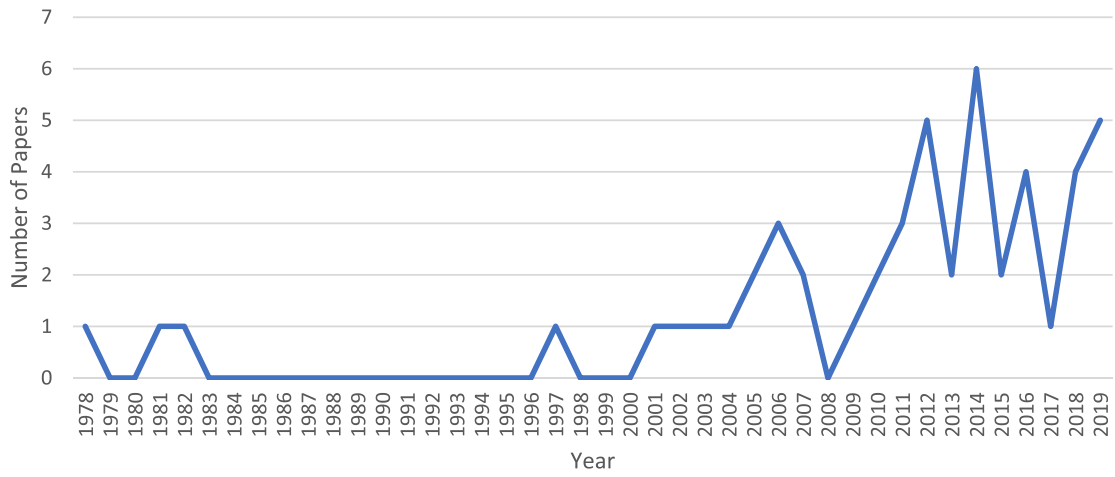

Figure 3. A line graph showing the frequency of papers published each year from 1978–2019. Adapted from Andresen (2020) CC BY 4.0.

Table 4. A list of the designs and methods used throughout the review. Adapted from Andresen (2020) CC BY 4.0.

Design	Number of papers
Case Study	44
Lit review	1
Other	2
Report	3
Method	**Number of papers**
Interviews	11
Lit Review	1
Mixed methods	3
Model	6
Other	10
Report/summary	3
Retrospective review	6
Statistical analysis	3
Survey	7

3.2.2.1. Children

Children, specifically under the age of 17, are a population of concern during power outages because of the greater risk of exposure to Carbon Monoxide (CO) poisoning because of improper generator use (Schnall *et al* 2017). This group was less aware of the dangers associated with power outages after Superstorm Sandy (Schnall *et al* 2017). Fife *et al* (2009) also found the number of children affected by CO poisoning was higher than other populations because they relied on technology for entertainment. This activity becomes a danger because children will use their devices near an operating generator while they are charging, leading to a greater risk of CO poisoning because of their proximity to the generator (Fife *et al* 2009).

3.2.2.2. English as a second language speakers

Those who do not speak English as their first language may not understand safety messaging provided only in English. Safety messaging emerged as a sub-theme in several studies that examined the intersection of language and power outage communication and messaging. The three studies that investigated the role of language consistently found that individuals with limited English proficiency were at higher risk of improper generator use or could not access or understand relevant safety information (Wrenn and Conners 1997, Burger *et al* 2013, Schnall *et al* 2017). Information that is available in multiple languages will assist this population most during power outages.

3.2.2.3. Racial and ethnic minorities

Racial and ethnic minority populations, more specifically African Americans, were reported to be at greater risk of adverse effects during power outages. Muhlin *et al* (1981) indicated that areas with greater minority populations were at greater risk to experience increased crime during a power outage. Lin *et al* (2016) also noted that those of low socioeconomic status experienced greater mental health problems, for example, anxiety, mood disorders, and substance abuse, because of a power outage. These impacts were present after Hurricane Sandy and highlighted the Bronx area, where roughly 44% of the population is Black according to a 2019 U.S. Census estimate, as a significant place of concern in the aftermath of Hurricane Sandy (Lin *et al* 2016).

3.2.2.4. Older adults

Older populations may also be at greater risk during power outages, as they are more likely to be

dependent on medical equipment for chronic illness and increased mental health impacts (Anderson and Bell 2012, Paradis 2012, Lin *et al* 2016). Like those of lower socioeconomic status, Lin *et al* (2016) also found that older adult populations experience greater psychological symptoms during a power outage, such as increased stress, anxiety, depression, and the overall need for greater support—and should be prioritized. Similar findings were noted by Eachempati *et al* (2004), Gotanda *et al* (2015), and Rubin and Rogers (2019). However, Chakalian *et al* (2019) found the opposite after Hurricane Irma, noting that households with individuals over the age of 64 were less likely to experience stress or discomfort because of a hurricane or a blackout. This group was more self-reliant in mitigating impacts on their overall well-being and was more independent during these times than initially hypothesized (Chakalian *et al* 2019).

3.2.2.5. Rural populations

Rural populations are more likely to experience longer outages than those living in urbanized areas (Call 2010, Gros *et al* 2012). In urban settings, the concentration of power lines that are considered high priority is centralized and located within proximity, leading to faster response and restoration times compared to surrounding rural areas (Call 2010, Gros *et al* 2012, Román *et al* 2019). Thus, providing rural areas with greater assistance after a significant event or during a prolonged power outage is necessary as electrical infrastructure in these areas is not as clustered as urbanized areas (Román *et al* 2019). However, due to previous experiences, this group may also be more prepared for longer outages, and better anticipate longer restoration times for future events (Román *et al* 2019).

3.2.2.6. Healthcare workers

Healthcare system workers are more likely to be overstressed and overworked during a power outage. The blackout that occurred in 2003 across the northeastern United States demonstrated that Specialists-in-Poison Information, workers in the Poison Control Center, were greatly overworked and had trouble finding time to rest during and after the blackout (Klein *et al* 2007). Workers experienced a significant increase in call volume both during the blackout and after power was restored (Eachempati *et al* 2004, Freese *et al* 2006, Klein *et al* 2007, Paradis 2012). Freese *et al* (2006) found a statistically significant increase in the number of emergency calls made compared to a normal 24 h period. The increased call volume has the potential to impact healthcare workers mentally as they respond to a larger than normal number of emergency calls. This population needs attention to help avoid burnout and fatigue both during them outage and after power is restored.

3.2.2.7. Other populations

Lin *et al* (2011) indicated those of higher socioeconomic status should also be considered if a power outage occurred during the summer season as they are more likely to experience heat-related symptoms. Lin *et al* argued this group may have less experience dealing with uncertainty, for instance, a power outage, and less knowledge about how to keep cool in their homes during the summer months without air conditioning. This population can also afford healthcare and therefore receive treatment. Those of higher income are more likely to own resources that are necessary to stay cool in warmer temperatures, like air-conditioning. However, when these resources become unavailable during a power outage, those of higher income could have a lower capacity in dealing with warmer temperatures, both indoor and outdoor, and may be less aware of cooling strategies.

In the event of a power outage, the list of populations identified in this review serves as a starting point for practitioners to assess preparedness. Those that rely on medical equipment or suffer from chronic conditions are dependent on hospitals having reliable backup generators and running generators until power is restored. Should supplies run low, medical providers must be able to connect their customers with additional resources that can provide services until power is restored (Arya *et al* 2016). Therefore, both those that need medical equipment and those that provide medical services and care, including pharmacies, must be prepared for a prolonged power outage.

3.2.3. Criminal activity

A third theme that we identified in the literature centered on whether criminal activity increased because of power outages. While this theme was less of a focus than health impacts and populations of concern, we did find six articles that discussed the issue. Interestingly, while the literature discusses that criminal activity is theorized to occur post-hazard, this impact may be overstated; no articles in our review demonstrated that criminal activity increased post-natural hazard. When power outages occur independently of a hazard, crime and various criminal acts were more likely to occur due to an increase in motivation to commit crimes (Lemieux 2014, Matthewman and Byrd 2014). Power outages and blackouts provide an opportunity for fraud, theft, and exploitation (Matthewman and Byrd 2014). Businesses located in poorer areas were more likely to be looted than businesses located in areas with greater economic prosperity (Sugarman 1978, Wohlenberg 1982). Wohlenberg (1982) found that business owners in poorer areas that were harder hit by anti-social acts during a power outage intentionally burned their businesses. Other crimes not planned for may increase, such as generator theft and breaking into properties with an alternate power supply (Riddex

and Dellgar 2001). If a blackout disrupts public services, authorities must expect pro- and anti-social activities to occur (Wohlenberg 1982).

However, this finding from Wohlenberg is contested both in findings from the literature for this review and in the disaster literature. Freese *et al* (2006) found that the crime rate did not change in comparison with the same dates in the previous year. The findings from Freese *et al* (2006) align with findings from the disaster literature, which indicates that an increase in criminal activity rarely occurs, despite heavy media attention directed towards isolated incidents (Quarantelli 2007, Call 2010, Lemieux 2014). But as Moreno and Shaw (2019) indicate, when looting did occur, instances of pro-social and anti-social looting occurred. People looted supermarkets for food and water (pro-social looting) and department stores for non-essential items like televisions and jewelry (anti-social looting). Looting affects perceptions of safety and trust within communities and can impact restoration times due to concerns over worker safety (Moreno and Shaw 2019).

Despite the potential for crime to occur, crimes can be mitigated with financial support and from local officials (Lemieux 2014). Financial assistance and food can be provided to reduce the crime rate during a power outage, but this solution is only temporary as the crime rate would increase once the initial relief has expired but power has not been restored (Rubin and Rogers 2019). This increase in crime could occur because of people requiring further assistance when additional assistance cannot be provided, which could lead to distress and unhappiness for persons needing resources.

3.3. Gaps within the literature

This review identifies a number of critical knowledge gaps in our understanding of power outage impacts. First and foremost, more research needs to consider the social impacts of power outages, which may increase in the future. Future research should put more effort into understanding how people are affected by more frequent power outages of shorter duration compared to longer and less frequently occurring power outages. While shorter outages may seem like only a nuisance to some, others may see more frequent outages as a significant concern, especially if they rely on a breathing machine or struggle to consistently afford essentials. For those that rely on dialysis treatments, for example, losing power while receiving treatments can be deadly if patients are not immediately taken off the machine. Knowing what impacts are anticipated with outages at certain lengths of time can help local organizations respond more effectively by providing sufficient resources that can aid those affected, especially those of lower income, that can last until power is restored.

The financial impacts of power outages have been under-investigated and would serve those of lower socioeconomic status, as they tend to struggle to afford essentials and may be disproportionately impacted by the loss of food or inability to work. While there have been studies that examined willingness-to-pay and how much people would be willing to pay to have consistent power to their residence, there have not been many that examined how people are financially affected by prolonged power outages (Carlsson and Martinsson 2008, Abdullah and Mariel 2010). By examining how people are impacted financially can also help identify potential groups that may have difficulty recovering in the aftermath of a prolonged power outage, and greater assistance can be directed towards these areas to reduce the financial burden a prolonged power outage may cause, especially to those of lower income.

Considering these impacts from an environmental justice perspective can further highlight inequalities that exist within hazards and disasters. Previous research has indicated that there could be a relationship between demographic variables, like race and ethnicity, and power outage impacts highlighted from this review. While the findings were not statistically significant, further investigation is needed with stronger statistical samples to determine if power outage impacts align with previous research on the inequities that emerge from hazard- and disaster-related impacts.

The published research has focused more on how power outages are seen as an impact, rather than a separate hazard that occurs post-disaster. During the aftermath of a disaster, news and media coverage typically talk about people's experiences and how they are recovering from the event. There is not much discussion of power outages as a technological hazard and the societal consequences that may emerge from these events. Further research on this topic will be needed as the climate continues to evolve and will create weather scenarios that infrastructure was not designed for, whether it be extreme cold or heat. As these events become more frequent, and therefore placing infrastructure in a position to experience these scenarios more frequently, more people will be impacted by power outages, regardless of how the outage was initiated. Events like the Texas blackout the occurred in February 2021 would be of interest to study as Texans experienced anomalously cold temperatures and rolling outages over multiple days and before the recent infrastructure bill was signed into law.

Lastly, research should address how power outage impacts vary by season, particularly how summer and winter outages may present different hazards and require different responses. How someone prepares for a power outage in the winter will look differently than one that would occur in the summer; different resources would be required, but populations of concern would likely be similar.

4. Conclusion

In this review, we identified 50 articles that explored the social impacts of power outages. We identified many more articles focused on the technical impacts of power outages on electrical infrastructure. This emphasis on the technical impacts points to a need for more examination of these social impacts as the likelihood of outages increases. Some populations were disproportionately affected. Many populations of concern were identified including children, older adults, racial and ethnic minorities and those that live in rural areas. The greatest health concern that emerged during power outages was CO poisoning because of unsafe generator use during power outages. Hospitals should expect an increase in ED visits as more people will present with CO poisoning-related symptoms or require an operating medical device since patients' devices cannot work without electricity. Criminal acts increase during power outages, but crime rates can be reduced temporarily during prolonged power outages by providing aid and consistent updates on where to receive assistance and when power is expected to be restored. Looting most likely occurs in areas with lower socioeconomic advantage; authorities should expect prosocial and anti-social resource appropriation during prolonged outages to occur as people see power outages as an opportunity to commit criminal acts (Barsky *et al* 2006). As power outages are expected to occur more frequently, understanding the differential effects across populations is critical to mitigating their impacts.

Future work can expand on this review by addressing the gaps identified in the literature. Studies of short duration but high frequency outages were not observed in this review but are increasingly salient with more frequent disturbances in grid reliability. More frequent outages may leave those that rely on medical devices more anxious because of uncertainty about when next power outage will occur. Increased power outages may lead to an increased likelihood of more food being spoiled and thrown away, which can represent a significant financial burden to lower-income households. Exploring power outages' effects may vary based on seasonality and temperature can provide context into how extreme cold and heat can influence household experiences and the different adaptation strategies deployed to reduce the potential impacts. Future work should also investigate power outage impacts from an environmental justice perspective to understand if power outage impacts align with other research that has highlighted racial disparities that occur with disasters.

This review highlights to the need to address the growing impact of a changing climate on the United States' already-deteriorating electrical infrastructure. Because of the increasing trend of reported electrical grid disturbances, research on the social impacts of power outages is vital in the context of a changing climate (Andresen 2020). While there has been an effort by the Biden Administration to address the deteriorating infrastructure, the ASCE (2021) Report Card has indicated that more money in addition to what has already been allocated by the recently signed legislation is needed to restore infrastructure to acceptable conditions. The effects of the increased investment in infrastructure will not be clear for some time. In the short term, the current infrastructure systems will remain fragile and weather events that bring anomalous weather conditions will stress electrical infrastructure systems that will cause an increase in power outages to occur and an increase in the number of people who are impacted.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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