<u>Comentario Público Modelo para la Participación Ciudadana en la evaluación de las métricas de desempeño de LUMA</u>

Ponencia de vistas públicas, 16 de febrero de 2023

A la atención de: **Lcdo. Edison Avilés Deliz, Presidente**
Negociado de Energía de Puerto Rico

Asunto: Comentarios Públicos en el Caso No. NEPR-AP-2020-0025

Saludos Presidente Lcdo. Edison Avilés Deliz y comisionados/as del Negociado de Energía,

Mi nombre es Carissa Cabán Alemán. Soy residente de Naguabo, Puerto Rico y vivo con mi esposo. Soy psiquiatra comunitaria, profesora universitaria y vivo con mi esposo. Pertenezco a las organizaciones American Psychiatric Association, Climate Psychiatry Alliance, VAMOS PR, entre otras. Regresé a Puerto Rico en septiembre 2022 luego de casi 14 años en la diáspora. Acababa de pasar Fiona y, aunque el área de la finca que compramos no sufrió ningún daño, tuvimos que esperar hasta octubre 31 para que atendieran nuestras querellas y volviera el servicio eléctrico, que no servía por un "breaker" dañado. Imagínense si fueramos personas de edad avanzada y/o con condiciones médicas. Imagínense si fuera otro huracán Maria que de verdad afectara nuestra comunidad. La luz se ha ido varias veces después del reparo en el sector.

Conozco varias historias de personas a los que no les han resuelto querellas de varios meses, como la querella de mi padre, que reportó un cable vivo al lado de su casa, y le dijeron que no lo podían remover. Una persona podría sufrir heridas y hasta morir si tocara un cable vivo. Entiendo que el sistema ya estaba deteriorado antes de que lo manejara LUMA, pero ahora es peor y más caro.

Hoy también me dirigo a ustedes representando al PR Clinicians for Climate Action. Nuestra misión es crear conciencia acerca de los efectos del cambio climático en la salud humana y ecológica, y abogar por soluciones equitativas y justas. Queremos enfatizar la importancia de tener como centro la preservación de la salud de todos los seres vivos y la importancia del acceso a servicios de energía renovable para la salud del pueblo, sobre todo de los más vulnerables, como los pacientes que necesitan refigeración para sus medicamentes y máquinas de oxígeno para poder respirar. Se ha demostrado en estudios que los apagones constantes y otros fenómenos del cambio climático que se ven afectados por apagones, como el calor extremo, pueden causar una incidencia más alta de síntomas de ansiedad, depresión y otros diagnósticas psiquiátricos. Hay evidencia que fenómenos del cambio climático como temperaturas mas altas y contaminación del aire, pueden causar mayor riesgo de suicidio, problemas cognitivos, demencia, etc.

Pedimos que se establezcan métricas de desempeño que estén de acuerdo con lo que es un sistema energético del siglo 21. Es decir, que haya un compromiso con proveer un servicio mejor al pueblo con costos razonables y que la políica pública del país incluya sistemas funcionales de fiscalización para que esta compañía no abuse de su poder y provea asistencia de una forma responsable a toda la clientela sin prejucios ni favoritismos. Entendemos que el proceso de evaluación no ha sido lo suficientemente abierto, transparente y no ha tenido una participación ciudadana efectiva.

Las métricas de desempeño propuestas por LUMA no sirven el propósito de modernizar y aumentar la resiliencia del Sistema de Transmisión y Distribución. Si por el contrario, el negociado adoptara unas métricas de desempeño cónsonas con un sistema energético asequible y sostenible, LUMA se vería incentivado a reestablecer el servicio eléctrico en menor cantidad de tiempo y obligado a evitar apagones y fluctuaciones de voltaje ya que conllevarían la imposición de penalidades monetarias.

Unas métricas adecuadas redundarían entre otras cosas, en: un sistema eléctrico más estable y resiliente, recuperaciones ligeras y efectivas luego de eventos atmosféricos, menos enseres eléctricos dañados, menos compras dañadas, mejores sistemas de comunicación, mejor servicio al cliente, así como menos contaminación aérea y sonora debido a la constante necesidad de encender generadores de electricidad que queman diésel o gasolina.

Recomendaciones para la evaluación y adopción de las Métricas de Desempeño

Adopto las recomendaciones que me compartió una abogada de la organización Earthjustice, hechas por el Ing. Agustín Irizarry y el economista Dr. José Alameda:

Recomendación #1 – Considerar métricas adicionales para incentivar la transformación hacia un “sistema moderno, sostenible, confiable, eficiente, costo-efectivo y resiliente” como lo exigen la Ley 17, la Ley 120 y el Acuerdo de Operación y Mantenimiento del Sistema de Transmisión y Distribución, para así lograr una red eléctrica del siglo 21.

Recomendación #2 – Hacer este proceso más participativo al publicar todos los documentos del caso en español, para la mejor evaluación de las métricas y para proveer una perspectiva ciudadana sobre el progreso de los objetivos trazados

Recomendación #3 – Las métricas de desempeño deben ser monitoreadas y verificadas de manera independiente. El monitoreo debe ser publicado de manera amplia en una página web para que la ciudadanía conozca sobre las causas, ubicaciones y tendencias de las interrupciones en el servicio eléctrico.

Recomendación #4 – Imponer penalidades a LUMA, en caso de que no cumpla con cierto nivel de estabilidad en el sistema y que no cumpla con las metas de energía renovable propuesta por la Ley 17-2019.

Recomendación #5 – No se le deben otorgar incentivos a LUMA por cumplir con el presupuesto propuesto. Al contrario, si LUMA no logra mantenerse dentro de su presupuesto, se deben reducir los incentivos en las distintas categorías.

Recomendación #6 – Los protocolos de seguridad para las y los trabajadores deben estar en cumplimiento con las regulaciones de la Administración de Seguridad y Salud Ocupacional (OSHA, por sus siglas en inglés). En el caso que LUMA no cumpla, deben imponerse penalidades por arriesgar la vida de sus empleados(as).

Recomendación #7 –Adoptar métricas análogas a las que se encuentran en el contrato de la Long Island Power Authority con la empresa PSEG. En específico, las (“Gating Performance Metrics”) métricas que, de no lograrse, reducirían la capacidad de recibir compensación mediante incentivos y las (“Default Performance Metrics”) métricas que, de incumplirse, otorgan el derecho a terminar el contrato.

Recomendación #8 – Debe haber sanciones económicas si LUMA muestra un bajo desempeño durante varios períodos de evaluación en métricas clave como seguridad pública y laboral, sostenibilidad, confiabilidad, resiliencia y servicio al cliente de tal forma que el servicio eléctrico de Puerto Rico continúe deteriorándose. Si LUMA no corrige estas deficiencias, se debe terminar el contrato.

Recomendación #9 – Que las métricas de desempeño que sean adoptadas por el negociado estén completamente definidas para así tener claridad en cuáles son las recompensas y penalidades que les aplica. Esto debe adoptarse independientemente de la estructura de cargo fijo más cargo adicional, del contrato existente entre LUMA y la AEE. La estructura de compensación fija (en la cual LUMA cobra una cantidad de dinero fija sin importar su desempeño) es contradictoria al propósito de un sistema de recompensas y penalidades, ya que esta estructura promueve el bajo rendimiento.

Recomendación #10 –Desarrollar un Programa de Recompensas y Penalidades, como también un Mecanismo de Compensación por Apagones para cubrir los daños ocasionados por LUMA mediante apagones, fluctuaciones de voltaje, etc.

CONCLUSIÓN

Para concluir, quiero reiterar mi apoyo a que se establezcan unas métricas de desempeño justas por parte del NEPR, y que sean con estas métricas revisadas que se mida el desempeño operacional de LUMA. A diferencia de las métricas de desempeño en otras jurisdicciones, las métricas actualmente propuestas no incluyen penalidades por bajo rendimiento, algo que es especialmente problemático dado el evidente deterioro del servicio. En lo que respecta a algunas métricas, LUMA propone que se le recompense por cumplir con unas funciones y expectativas de carácter básico. Rechazamos las métricas de desempeño actualmente propuestas por LUMA, ya que nos mantendría con un sistema de energía eléctrica propio del siglo 20. Sin embargo, el pueblo de Puerto Rico se ha expresado y exige un sistema energético del Siglo 21, que sea resiliente y sostenible; a ello tiene derecho.

Gracias por su tiempo y consideración,

Carissa Cabán Alemán

Sonia Seda

From: Car C. <carissacaban1@gmail.com>
Sent: Friday, February 17, 2023 10:50 AM
To: Secretaria
Cc: Comentarios
Subject: Public Comments on LUMA's Revised Request — Case No. NEPR-AP-2020-0025
Attachments: Article comm health impacts power outages.pdf; Climate change and risk of completed suicide, 3-20.pdf; Carissa Caban Ponencia Feb. 16, 2023.pdf

Hola,

Como me solicitaron, adjunto está el artículo que utilizé para la ponencia de ayer ("Article comm..."). También le incluyo una copia escrita de la ponencia y un artículo científico de suicidio y cambio climático.
Aquí les comparto enlaces a otros artículos sobre los impactos a la salud mental y física que mencioné ayer:
1. https://www.centerforhealthsecurity.org/our-work/Center-projects/completed-projects/extended-power-interruptions.html
2. https://a816-dohbesp.nyc.gov/IndicatorPublic/beta/data-stories/poweroutages/
3. https://time.com/4968766/puerto-rico-hurricane-maria-power-outage/
4. https://gh.bmj.com/content/4/3/e001372

Gracias por su interés.

Atentamente,

Carissa Cabán Alemán, MD, FAPA

How power outages affect health

Imagine your child has asthma. One summer night, a powerful storm rolls in and knocks the power out.

Your child starts to have trouble breathing. Usually, you'd use a home nebulizer, an electric machine that turns liquid medicine into a mist that your child breathes in through a face mask.

But the power is out. Without the nebulizer, your child's breathing gets worse - and you wonder, is it time to go to the hospital again?

This scenario - or something like it - is a reality for many New Yorkers.

Asthma and many other medical conditions are treated at-home with electrical medical equipment. Citywide, 7.6% of households include someone who uses electric medical equipment, with some neighborhoods at nearly 17%.

Neighborhood	Households using electric medical equipment ▼	Poverty
New York City	**7.6%**	**19.6%**
Williamsbridge/Baychester	16.9%	18.5%
East Harlem	16.0%	
Highbridge/South Concourse	14.8%	
Morrisania/East Tremont	14.5%	
Brownsville/Ocean Hill	14.2%	
Mott Haven/Hunts Point	13.5%	
South Shore	12.3%	7.0%
Throgs Neck/Co-op City	12.1%	11.4%
Riverdale/Kingsbridge	12.0%	18.2%
Rockaways	11.9%	19.5%
Howard Beach/South Ozone Park	11.8%	12.7%
Kingsbridge Heights/Mosholu	11.2%	
East New York/Starret City	10.9%	28.1
Pelham Parkway	10.4%	20.2%

Households reporting someone who uses electric medical equipment (2017) and neighborhood poverty (2013-17).

As the chart above shows, neighborhoods with more households that rely on electrical medical equipment also have higher rates of poverty.

> *Poverty is created by current and historical racist practices, like redlining, that deprive people and communities of resources and harm people's health. The Health Department has declared racism a public health crisis.*

Power outages threaten health.

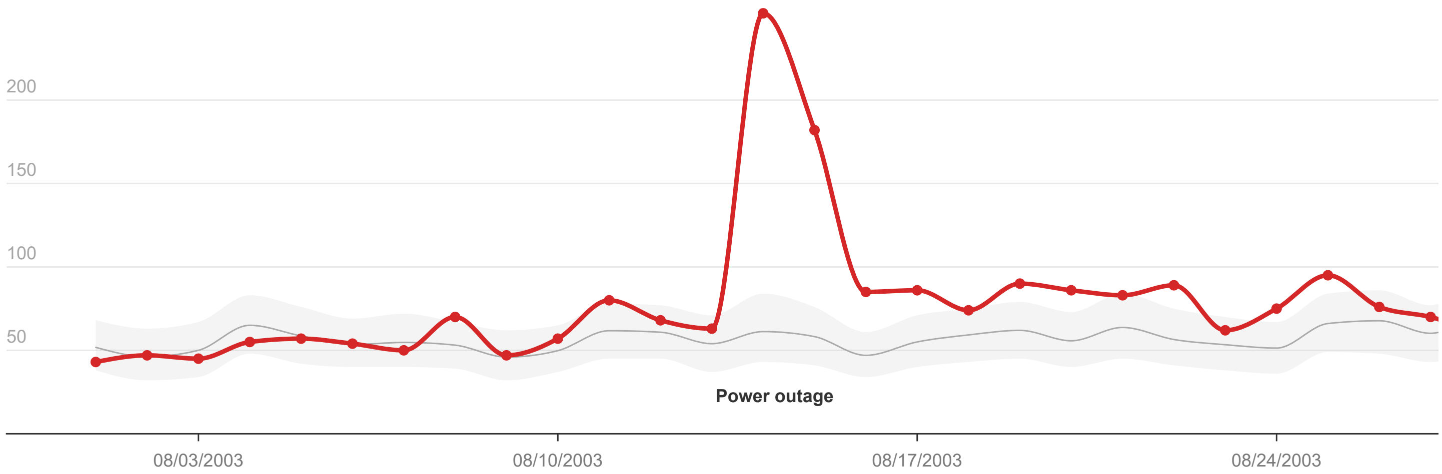
On Thursday, August 14, 2003, a widespread power outage stretched from NYC to Ontario, Canada, affecting 55 million people. Many areas, including here in New York City, were without power for days.

In New York City, the power outage started around 4:10pm on the 14th, a day when temperatures were in the 90s. While the power was restored in some neighborhoods by early morning on the 15th, full power for the entire city did not return until that evening.

That blackout was dangerous for NYC residents, and we can see the effects in health data. Hospitalizations for respiratory problems spiked above predicted levels.

The 2003 Blackout caused a spike in respiratory hospitalizations...

Respiratory hospitalizations: **Predicted** and **Observed**.



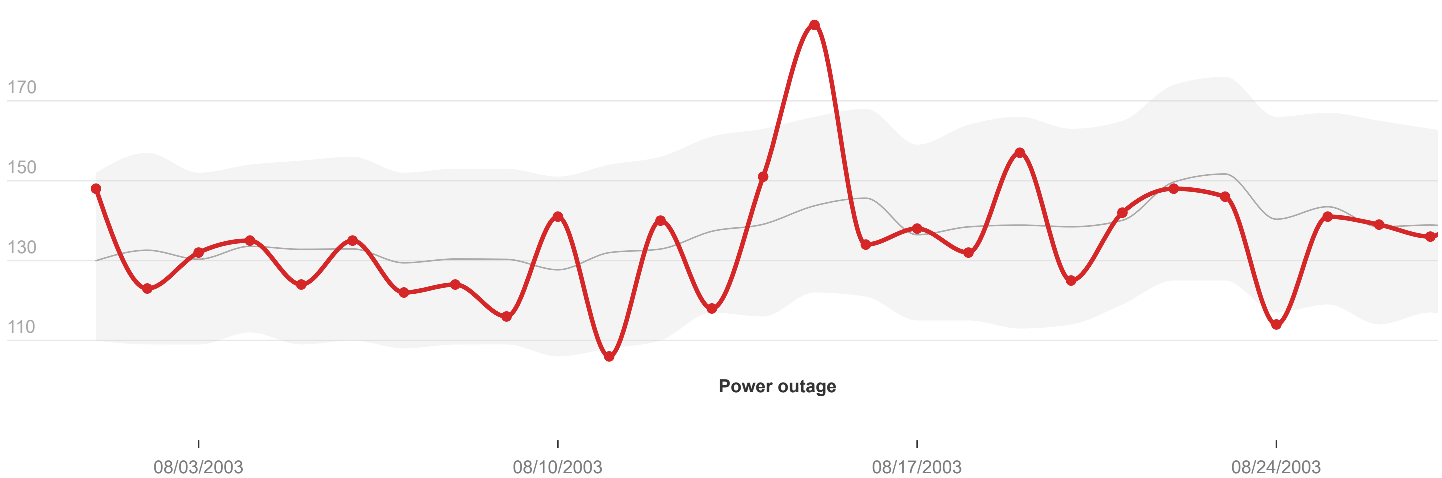
The health impacts were not limited to just hospitalizations. In fact, the power outage was deadly.

In the chart below, you can clearly see that **observed deaths** generally bounce around the level of **predicted deaths**, staying within the prediction range . But on and after the power outage, observed deaths spiked: more people died during and immediately after the power outage.

In the chart below, you can clearly see that observed deaths generally bounce around the level of predicted deaths, staying within the prediction range. But on and after the power outage, observed deaths spiked: more people died during and immediately after the power outage.

...and a spike in deaths in NYC.

Predicted deaths and **Observed deaths**.



The deaths could have been caused by many dangers of power outages: people not being able to charge medical equipment, not being able to use air conditioning on hot days, or experiencing increased physical and mental stress and isolation of living without elevators or subways.

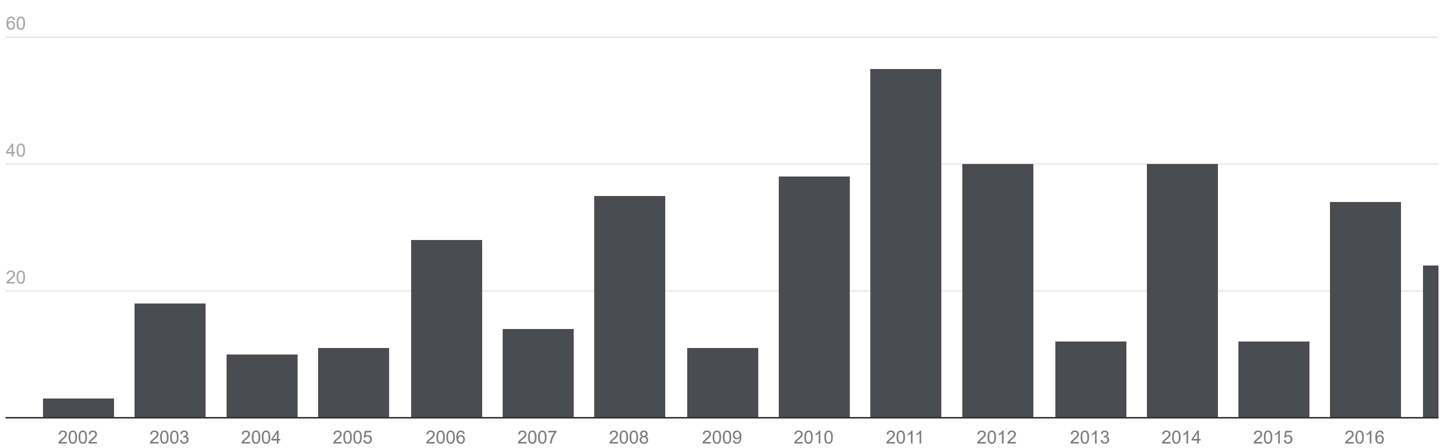
And, when we studied hospitalization and mortality data around NYC's smaller blackouts in July 1999 and July 2006, we saw that localized power outages also threaten health. We found an increase in hospitalizations for respiratory disease, renal (kidney) disease, and an increase in all-cause mortality (deaths).

Climate change is likely to bring more power outages...

Weather-related power outages are increasing, as climate change brings more frequent, more powerful storms that threaten our power grid and other physical infrastructure.

The chart below from www.climatecentral.org shows the increasing frequency of weather-related power outages over the last 20 years. While there are year-to-year differences, the overall increasing trend is clear.

Increasing weather-related power outages in the Northeast U.S.



Source: Climate Central

...but not all NYC residents are prepared.

Our survey found that 58% of NYC residents have basic preparation for power outages: a working flashlight and a 3-day supply of water and food.

People with household members who depend on electrical medical equipment are more likely to be prepared for power outages (70% vs. 56% of respondents without electric-dependent household members). However, even though they are more prepared, they report not *feeling* more prepared as they face the challenge of ensuring that their medical equipment runs during power outages: when you need electricity to stay healthy, it's hard to feel completely prepared for a blackout.

Stay prepared.

It's important for our City to build a power grid that is resilient, since we expect more extreme weather as our climate continues to change. As we experience this changing climate, a reliable supply of electricity is crucial to support life-saving equipment. And it's vital that this resiliency be equitable, so that people in high-poverty neighborhoods that have been deprived of resources aren't made additionally vulnerable by climate change and power outages.

But we can also expect some power outages, so it's important for residents to be prepared, especially if you or somebody in your household uses medical equipment that requires electricity - including nebulizers, dialysis machines, apnea monitors, or portable oxygen.

Tell your utility provider if you use electric-powered medical equipment. They can let you know if power problems are expected in your area. If utilities are included in your rent, you can still register for this service from your building's utility provider:

- Con Ed
- For PSEG Long Island, click here and search "Critical Care Program".

Be ready for any emergency. Make sure you have backup batteries and/or oxygen tanks, and create an emergency contact list and a written emergency plan. For more information, call 311 or visit on.nyc.gov/power.

Even if you don't have electrical medical equipment, it's good to stay prepared. Here's how:

- Create an emergency plan and contact list.
- Keep copies of important documents and cash in a waterproof bag.
- Prepare a first aid kit.
- Have a written record of your medications and a seven-day supply.
- Stock up on flashlights, extra batteries, bottled water and non-perishable food.
- Charge all communications devices and have a battery-operated radio.
- Sign up at nyc.gov/notifynyc to receive information about emergency events.

More information on emergency preparedness, and how to plan for utility disruptions (power outages).

Banner image: Benjamin Kanter/Mayoral Photo Office

Questions about this data story? Ideas for another one? Email us.

Keywords:
asthma | weather | mortality | death | cooling | air conditioning | built environment |

Banner image:
Benjamin Kanter/Mayoral Photography Office

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January 10, 2022

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Public Health Impacts of Extended Power Interruptions: Scenario scoping, public health responses, and health priorities

Focus area:
Medical and Public Health Preparedness and Response

The electrical power grid is an integral part of 21st century life, with nearly all facets of everyday activities depending on electricity. Yet, the energy grid is at risk: It has become a prime target for cyberattacks and is vulnerable to naturally occurring outages due to weather events and disasters. The health consequences of crippled electrical power infrastructure could potentially be significant. The health system, many water utilities, communication systems, and others are dependent on the functioning of the electrical grid, which, if threatened, could cause cascading health impacts. Health impacts are likely to increase in frequency and severity as outages increase in length. Research is needed to identify the particular pathways by which power outages directly or indirectly (eg, via disruption of other services that require power to operate) affect public health, and the actions that can be taken to reduce vulnerability and hasten recovery.

Although optimal restoration of electric power service following an event has been an active area of research, maximization of restoration of service is often measured by number of customers or amount of electric load served. However, consideration of public health consequences and, in particular, supply chains for essential services and products that depend on electricity could result in very different sequences of actions, in terms of which distribution circuits are energized and which power plants restarted.

This research project is a joint research project with faculty members in the Johns Hopkins University Department of Environmental Health and Engineering, with a particular emphasis on encouraging multidisciplinary collaboration between engineering and public health faculty. The project seeks to determine the health-focused priorities for power recovery and public health response actions to manage long-term power outages in order to reduce morbidity and mortality from electrical power grid failure. Findings and recommendations from this work could be used to improve emergency response planning by utilities and public agencies across the nation to be used in small and more frequent outages as well as large-scale potentially catastrophic events. This work will provide an important foundation for future inquiry into the relationship between electrical power grid resiliency and public health.

Project team lead: Tara Kirk Sell, PhD

Project team: Amanda Kobokovich, MPH; Elena Martin, MPH; Thomas Inglesby, MD

Engineering project team: Benjamin Hobbs, PhD; Puneet Chitkara, PhD; Umesh Korde, PhD; Kenming Xu

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TIME

How Power Outages Can Affect Mental Health

Heydee Perez, age 29, and her son, Yenel Calera, age 4 have not received any aid one week after Hurricane Maria. The roof of their home is gone and they have very little to eat. Carolyn Cole—LA Times/Getty Images

BY **ALEXANDRA SIFFERLIN** AND **KARL VICK**

OCTOBER 4, 2017 3:27 PM EDT

It's been two weeks since Hurricane Maria swept through Puerto Rico, plunging it into darkness. Today, around 95% of Puerto Rico's electric grid remains down, and that outage could last for months.

Being without power comes with obvious physical health risks, especially for hospitals and nursing homes, which rely on power for dialysis and oxygen machines, refrigerated insulin medication and more. Being in the dark impairs safety and security, too. But blackouts also take a lasting toll on people's mental health, experts say. This often-ignored issue is slowly gaining more recognition in disaster response.

Dr. Shao Lin, a professor in the department of environmental health sciences at the University at Albany and her research team are studying how power outages impact community health, including mental health. Her 2016 study on the impact of Hurricane Sandy found that impacted areas of New York experienced extended blackouts and disruptions to public transportation and health care. The impact on mental health was substantial, she concluded; there was a significant increase in emergency room visits for substance abuse problems, psychosis, mood disorders and suicides throughout the city.

MORE: 'We Deserve More Help.' Puerto Ricans Rely on Each Other While Waiting for Aid

The longer the power outage continued—Manhattan largely recovered in five days and Nassau County was without power for about two weeks—the greater the increase in emergency room visits. Communities with lower socioeconomic status felt the greatest toll. Bronx county—where 30% of residents live in poverty—experienced a 782% increase in risk for mental health emergency room visits during the blackout after Hurricane Sandy.

"New York City prepared well for Sandy," says Lin, who expects to see "severe problems" in the mental health of people in Puerto Rico throughout the power outages.

MORE: How the U.S. Turned Its Back on Puerto Rico

There are many reasons why mental health events increase during power outages, including stress from the shutdown of necessities like food storage, transportation, life support devices and more. It can also increase loneliness and cut people off from one other. "A power outage cuts out communication and can cause social isolation," says Yi Lu, a graduate research assistant in environmental health sciences at the University at Albany who works with Lin. "Especially for groups like the elderly, isolation can cause mental stress."

Hyun Kim, an assistant professor in the division of environmental health sciences at the University of Minnesota who has studied the long-term impacts of Hurricane Sandy and the World Trade Center attacks, says the stress of the chaos—like living in the dark—can deteriorate mental health. "Such extreme living conditions lead to fear and anxiety, which are often contagious among the affected communities, and this phenomenon disproportionately impacts those who are exposed to more severe living conditions," he says.

Even after power eventually returns, the risk for residual effects like post-traumatic stress disorder (PTSD) will remain high, Kim says. "Experiencing or witnessing first-hand serious injuries or death caused directly or indirectly caused by power outage, can lead to PTSD, which has life-threatening consequences of its own," he says.

After Hurricane Katrina in 2005, studies found that 30-50% of people who survived suffered from PTSD. After Hurricane Sandy, more than 20% of residents reported PTSD, 33% reported depression and 46% reported anxiety, Kim wrote in a recent article for Fortune Magazine.

When it comes to the response in Puerto Rico, Kim says first responders should be cognizant of the mental health risks for communities, adding that there's a "pressing need" to raise public awareness about how mental health may be affected after a disaster.

"Given the seriousness of the situation in Puerto Rico, the first responders should be periodically monitored for their mental health," he says. "Once an affected person is made aware of the possible risks, mental disorders can be detected and treated. Unfortunately, however, mental health stigma and prejudices are often the biggest barriers to this problem."

In the meantime, responders are doing what they can to ease the shock of the blackout for people in Puerto Rico.

“We take light for granted,” says David Darg, vice president of international operations for Operation Blessing International, which is helping distribute thousands of collapsible lamps that are charged by sunlight and provide up to 12 hours of light throughout Puerto Rico. The lamps are meant to provide portable light to families and help improve neighborhood security. “We go into these dark places at night, and after you distribute about a hundred, the whole place lights up.”

Yentil Ramirez, a 26-year-old living in the La Perla neighborhood of Puerto Rico, has been living in her five-person home without light since the storm hit, and has been using one of Operation Blessing’s solar lights. “It’s a pretty simple design, but it actually works” she says.

The mayor of San Juan, Carmen Yulin Cruz, helped distribute the lamps, and held one aloft as a symbol of hope at a news conference the following day. “You should have seen La Perla last night,” she said during the Sept. 29 press conference. “Not only did you see hope—they took charge of the streets again.”

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Power outages and community health: a narrative review

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Abstract

Purpose of review: Power outages, a common and underappreciated consequence of natural disasters, are increasing in number and severity due to climate change and aging electricity grids. This narrative review synthesizes the literature on power outages and health in communities.

Recent findings: We searched Google Scholar and PubMed for English-language studies with titles or abstracts containing “power outage” or “blackout.” We limited papers to those that explicitly mentioned power outages or blackouts as the exposure of interest for health outcomes among individuals living in the community. We also used the reference list of these studies to identify additional studies. The final sample included 50 articles published between 2004–2020, with 17 (34%) appearing between 2016–2020. Exposure assessment remains basic and inconsistent, with 43 (86%) of studies evaluating single, large-scale power outages. Few studies used spatial and temporal control groups to assess changes in health outcomes attributable to power outages. Recent research linked data from electricity providers on power outages in space and time and included factors such as number of customers affected and duration to estimate exposure.

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Conflict of interest: Joan A. Casey, Mihoka Fukurai, Diana Hernández, Satchit Balsari, and Mathew Kiang declare that they have no conflict of interest.

Human and Animal Rights: All reported studies/experiments with human or animal subjects performed by the authors have been previously published and complied with all applicable ethical standards (including the Helsinki declaration and its amendments, institutional/national research committee standards, and international/national/institutional guidelines).

Summary: The existing literature suggests that power outages have important health consequences ranging from carbon monoxide poisoning, temperature-related illness, gastrointestinal illness, and mortality to all-cause, cardiovascular, respiratory, and renal disease hospitalizations, especially for individuals relying on electricity-dependent medical equipment. Nonetheless the studies are limited and more work is needed to better define and capture the relevant exposures and outcomes. Studies should consider modifying factors such as socioeconomic and other vulnerabilities as well as how community resiliency can minimize the adverse impacts of widespread major power outages.

Keywords

Power outage; blackout; natural disasters; energy insecurity; carbon monoxide poisoning; durable medical equipment

INTRODUCTION

In August 2003, over 50 million Americans and Canadians lost power for up to four days due to a surge of electricity along faulty transmission lines (1). In China, ice-coated transmission lines and towers collapsed during a severe winter storm in 2008, interrupting electric service to 200 million people (2). Meanwhile, hot weather and related air conditioner use triggered a blackout affecting 8 million people in Baku, Azerbaijan in July 2018 (1). The largest blackout in history affected at least 600 million people across India in July 2012 (3). The frequency and severity of these events will increase with population growth and climate change, as infrastructure damage from intense storms and floods, hydropower shortage from droughts, and increased demand as temperatures rise and strain an aging electricity grid (4-6).

Power outages worldwide

Today, South Asia has the highest system average interruption frequency index (SAIFI). The average business there experienced 26 outages per month in 2019 (7). However, even businesses in Organisation for Economic Co-operation and Development (OECD) countries experienced one power outage every other month in 2019. Outages last longest, on average, in Latin America and the Caribbean (8 hours) and Sub-Saharan Africa (7.5 hours), compared to just 2.5 hours in East Asia (8). The United States (U.S.) Energy Information Administration predicts that global electricity production will increase by 75%, from 20 trillion kilowatt-hours (kWh) in 2018 to 45 trillion kWh in 2050, driven in large part by demand in non-OECD countries (9). This increased demand will result in more power outages, with unique economic, social, and health consequences, of which we review that latter.

Causes and costs of U.S. power outages

In the U.S., major power outages increased 10-fold between 1984–2012 with the average household experiencing 470 minutes without power in 2017 (11, 12). Large blackouts, disturbances that interrupt more than 300MW (enough power for ~50,000 homes) or 50,000 customers and require reporting to the U.S. Department of Energy (13), occur more commonly in the winter and summer and year-round during the mid-afternoon (14).

Electromagnetic events and intentional cyber-physical attacks caused >25% of total U.S. power outages between 2000-2016 (Figure 1A) (10, 15). Such attacks present substantial risk to the electricity grid and could result in an outage that stretches for months across wide geographies, especially if timed after a natural disaster (16). Most widespread power outages were caused by severe weather (Figure 1B) and Florida, California, New York, and Michigan were hit hardest with 25.3 million, 22.2 million, 18.3 million, and 12.4 million affected customers, respectively (15).

Outages, particularly those related to weather, are almost always accompanied by intersecting and related phenomena that result in economic, social, and health damages (Figure 2). Economically, they interrupt business, cripple the internet, and halt many forms of transportation (8). The 2003 Northeast Blackout in Canada and the U.S. cost between $4-10 billion (17), and electricity infrastructure repairs alone cost $3.5 billion after Hurricane Sandy (18). Social costs include increased crime, motor vehicle crashes, psychosocial stress, and interrupted communication between emergency services, delivery of clean water, and waste removal (3, 12, 19, 20). Although, altruistic acts, including providing assistance to others, donating money, assisting with traffic, may also increase (19-22). Several factors influence the severity of economic, social, and health costs of power outages including outage frequency, duration, timing, and geographic range, as well as mitigation measures, population preparedness, and prior experience (19, 23).

Medically high-risk groups during power outages

Certain subgroups have higher risk of adverse health outcomes during power outages. These include older adults, those reliant on electricity-dependent durable medical equipment (DME, e.g., oxygen concentrators), those unable to evacuate, including nursing home patients, those reliant on others to complete activities of daily living, the heat/cold susceptible, and those with underlying conditions exacerbated by the inciting events, such as respiratory, cardiovascular, and renal disease (23-25). The number of electricity-dependent individuals is anticipated to grow in the coming years (23, 25); numbers already trend upward and rate of DME use appears higher among lower socioeconomic status individuals (26).

Documented disparities in power outage preparedness and exposure

Evidence from the U.S. suggests older adults, poorer families, and individuals of non-Hispanic Black and Hispanic race/ethnicity are least likely to have a three-day supply of food, drinking water, and medication, a preparedness measure for power outages (27-29). In New York City, only 58% of 887 people surveyed were prepared for a disaster; preparedness dipped to 45% among households with income <$30,000 and to 28% among primary Spanish-speakers (29). Generator cost ($2-5,000) may price out lower socioeconomic status families and those living in public housing or apartment buildings that prohibit generators (21, 29). Finally, power outages may last longer in lower socioeconomic status or communities of color (30-34), where impacts may already be greater. For example, in Florida after Hurricane Irma, higher income individuals evacuated farther and to destinations with lower power outage rates compared to their lower income counterparts (33). After Hurricane Maria, satellite imagery of Puerto Rico suggested that households with power restored in Stage 1 earned almost double the income of households with power restored in Stages 2-3 (32). After Hurricane Sandy in New Jersey, non-Hispanic White individuals had the longest duration outages (11.2 days compared to 8.2 days for African Americans) (34). Such disparities put these already-vulnerable groups at increased risk of adverse power outage-related health outcomes.

Goal of this review

This review focuses on blackouts—the unavailability of electric power in an area—and does not address issues of energy poverty, a separate and important predictor of health (35, 36). In addition, we do not cover challenges faced by healthcare facilities during power outages. In this narrative review, we highlight themes in the current scholarship on power outages and community health and identify future avenues for research.

METHODS

We conducted searches via Google Scholar and PubMed in spring 2020 for studies written in English with titles or abstracts containing "power outage" or "blackout." We limited papers to those that explicitly mentioned power outages or blackouts as the exposure of interest for health outcomes among individuals living in the community. The reference lists of the identified studies were also examined to identify additional relevant articles. We screened the articles to include only original primary research published between January 2004 and June 2020 that explicitly mentioned power outage or blackout as an exposure of interest. The final sample included 50 articles spanning power outage events from 1977 to 2019 (Figure 3). The majority (72%) of the studies evaluated health outcomes in the US, but we collected literature from across the globe (Appendix Figure 1). Non-US articles tended to focus on interrupted healthcare (37, 38), which was outside the scope of this review.

Exposure assessment

Single, large-scale power outages.—Nearly all studies evaluated single, large-scale power outages. While the definition of large-scale varied from study to study, many met the U.S. Department of Energy criteria: 50,000+ customers affected or an unplanned loss of 300 MW (13). Researchers assumed individuals experienced the outage if they lived or attended a healthcare facility in the region where the outage occurred. Most studies relied on pre-post outage temporal comparisons to draw inference (20, 28, 39-53) or only described health outcomes after the outage (54-71) (Figure 4A). Eight studies of single outages also incorporated geographic variability in outage distribution in the study design, in addition to using pre-post outage health measures (72-79).

Multiple power outages.—Seven studies evaluated multiple power outages (30, 80-85), with three using outage frequency to characterize long-term exposure (82, 84, 85). Others conducted longitudinal analyses. In South Africa, Gehringer and colleagues used a combination of government data, Facebook, and the local electric utility's Twitter handle to track daily load shedding events (halted electricity distribution due to demand exceeding supply), including outage duration (30). Koroglu used standard electricity reliability data from the Maharashtra State Electricity Distribution Company in India to characterize monthly SAIFI and system average interruption duration indices (SAIDI) values statewide (83). Zhang and colleagues linked power outage records, including total number of customers affected, from the New York State Department of Public Service (NYSPS) between 2001-2013 to the power-operating division-level (~1,700 divisions exist in New York with an average population of ~11,000 people each). They created daily exposure metrics based on proportion of customers affected and duration (in days) of power outages. Likewise, Dominianni et al. used half-hourly NYSPS data to identify outages within each of New York City's (NYC) 66 electricity grid networks (80). They defined the entire grid network area as exposed on a given day if >1,000 people were without power during the warm-season and if >75 people were without power during the cold-season. Different cutpoints were used because fewer people experienced outages during the cold season.

Outcomes

Carbon monoxide poisoning.—Twenty-three (48%) of studies included evaluated carbon monoxide (CO) poisoning (44, 45, 50, 51, 54, 55, 57-62, 64-66, 69-72, 76, 77, 85, 86), a topic previously reviewed (87-89). CO is a colorless, odorless, and tasteless gas, formed by incomplete combustion of carbon compounds. Because hemoglobin binds 250x more readily with CO than with oxygen, prolonged exposure leads to cellular hypoxia, ischemia, and death (90).

In the 23 reviewed articles, indoor use of charcoal and gasoline-powered generators caused the majority of CO poisonings. The most common symptoms of CO poisoning were headache, nausea, vomiting, dizziness, loss of consciousness, and death. The majority of studies identified CO poisoning using medical chart reviews including emergency department (ED) visits (50, 54, 55, 57, 60, 64-66, 69-72, 77), hospitalizations (58, 69-71, 76), and emergency medical service (EMS) and poison control calls (28, 44, 45, 58, 59, 65, 69, 72) coded as CO poisoning-related; several studies used laboratory confirmation or reported serum carboxyhemoglobin (COHb) levels (44, 54, 55, 59-61, 64, 70, 91). Many studies reported fatalities, particularly in the several days following storms (54, 55, 57, 59-62, 65, 69-71, 85). Over 50% of CO poisoning studies reported the use of hyperbaric oxygen therapy (44, 54, 55, 58, 59, 61, 64, 65, 69-72, 91), and higher COHb levels may be related to persistent cognitive and psychiatric changes after CO poisoning (91). In many cases, children (54, 55, 59, 72), older adults (61, 62, 65), immigrants (60, 65), and people of color (55, 60, 64, 65, 70) were disproportionately affected. Qualitative methods can provide key insights not otherwise captured. For example, Styles and colleagues also found that 62% of non-Hispanic White generator/charcoal grill/heater operators reported hearing warnings about CO poisoning in the year prior compared to just 30% of those in other racial/ethnic groups (70) and Van Sickle et al. determined fear of theft was the most common reason to place a generator indoors (71).

While most studies only catalogued CO poisoning events following power outages, a few employed a comparison time period (28, 45, 50, 72, 76, 77), allowing authors to determine if more CO poisoning occurred than expected following power outages. After the Great East Japan Earthquake of 2011, Nakajima and colleagues found 13.5x the odds of CO poisoning among patients in the disaster area (including power outage exposure) from March 11 to

April 9, 2011 compared to the same dates in 2012 (76). A spatial control also revealed higher counts of CO poisoning in the disaster area versus an unexposed region. Johnson-Arbor compared two major storms in Connecticut in 2011 and 2013, where the 2011 storm resulted in 11x the number of individuals losing power and 5x the number of CO poisonings (44).

All-cause, cardiovascular, respiratory, and renal disease healthcare visits.—In general, hospitals see fewer patients in the days leading up to storms (42), whereas more patients arrive during and after outages, often with respiratory, cardiovascular, or renal disease exacerbations (30, 40, 42, 46, 47, 53, 68, 80, 81). In a comprehensive study, Dominianni et al. evaluated three major NYC outages (1999, 2003, 2006) and localized warm- and cold-weather outages within NYC (80). In models accounting for temperature, day of week, and seasonal and long-term trends, they confirmed prior findings of increased cardiovascular and respiratory disease hospitalizations during the 2003 outage and found new evidence of elevated risk of renal disease hospitalizations during warm-season power outages and cardiovascular disease hospitalizations during cold-season power outages. Zhang and colleagues also illustrated the utility of using daily sub-city level power outage data in their study of chronic obstructive pulmonary disease (COPD) hospitalizations statewide. They used power-operating division-level (~11,000 residents per division) between 2001-2013 in New York and found the largest increases in COPD hospitalizations during the first three days after power outages, where 23% of COPD hospitalizations on power outages days could be attributed to the outage itself (81). Compared to non-power outage periods, COPD patients arriving for care during power outages had a higher number of comorbidities and healthcare costs. Interrupted use of nebulizers, and oxygen and bilevel positive airway pressure machines, as well as sensitivity of COPD patients to changing indoor conditions (e.g., lack of air conditioning or dehumidifiers) likely explained the large increase in hospitalizations.

Many acute care visits related to cardiovascular and respiratory disease exacerbation during blackouts appear to result from failure of *electricity-dependent medical devices* (41, 42, 46, 50, 51, 63, 67, 68, 80, 81, 92). For example, after the 2011 Great East Japan Earthquake, 75% of 24 new pediatric inpatients at Tohoku University Hospital relied on DME, including 13 children using ventilators (76). After Hurricane Sandy, ED visits at Beth Israel Medical Center related to respiratory device failure and “power outage” increased in all age groups and peaked the day following the disaster (41).

Older adults and children may be at particular risk during power outages. Unlike many other NYC hospitals in downtown Manhattan, Beth Israel Medical Center remained open after Hurricane Sandy and their electronic health record (EHR) data revealed a 114% increase in ED use among patients aged 80+ and a 11% decline among those aged 18-64 compared to the six-months prior (41). In addition to power outage-related care, this increase reflects spillover from other closed hospitals. In South Africa, Gehringer and colleagues evaluated repeated, daily, temporary outages on pediatric hospital admissions, finding an average treatment effect of 6 additional admissions per day due to any power outage in the two days prior (30). They found the largest effect sizes for respiratory outcomes, burns, and ear, eye, and gastrointestinal system outcomes in models that controlled for important factors like weather and seasonal and long-term trends.

Gastrointestinal illness.—Power outages can affect food refrigeration and water system supply and disinfection, potentially precipitating gastrointestinal illness as measured via poison control calls, prescription orders, and hospital admissions (30, 45, 48, 78). However, evidence is mixed, with several studies finding no increase in gastrointestinal illness after power outages (72, 78, 86). Marx et al. employed methods from digital epidemiology to evaluate diarrheal illness after the 2003 Northeast Blackout finding that diarrheal syndrome ED visits, antidiarrheal medication sales, electrolyte sales, and worker absenteeism due to gastrointestinal illness all increased above expected in the days following the blackout (48).

Temperature-related illness.—Power outages reduce individuals' ability to control the indoor environment and may coincide with temperature extremes (both heatwaves and winter storms) resulting in illness (40, 42, 51, 53, 55, 68, 77, 80) and disturbed sleep (49) related to heat and cold exposure. Racial, socioeconomic, and age disparities exist in response to extreme temperature exposures, owing to differences including baseline health, access to generators, the urban heat island effect, and occupation (93, 94).

Maternal and neonatal health.—Four studies assessed the relationship between power outages and maternal healthcare utilization, measures of fertility, and birthweight (73, 74, 79, 83). Using monthly power outage data from 2010–2015 in India's Maharashtra state, Koroglu and colleagues evaluated the relationship between SAIFI (system average interruption frequency index) and SAIDI (duration) metrics and use of maternal health services (83). Increased monthly SAIFI but not SAIDI was associated with reduced odds of delivering in a healthcare institution (versus at home), both indices were associated with reduced odds of attendance of birth by skilled professional, and neither were related to caesarean section delivery. Outages may affect a woman's ability to travel to a healthcare facility or reduce her perception of the quality of care she will receive there, encouraging her to stay at home.

Burlando exploited a month-long 2008 blackout that occurred on the island of Zanzibar, Tanzania to study both measures of fertility (counts of live births) and birth weight (73, 74). The outage caused both a transitory negative income shock, with those who used electricity at work reporting a decrease in earnings and hours worked, and individuals to spend more time at home. With data from the island's main maternity hospital (500-900 births per month), Burlando used a difference-in-differences strategy to estimate the effect of the power outage on fertility and birthweight by comparing outcomes among mothers living in shehias (communities) with and without any electrification exposed and unexposed to the blackout at different times during pregnancy. They found that the blackout was associated with a 17% increase in live births (253 additional births) 8-10 months later (73). The outage also appeared to reduce birthweights 7-10 months later, with the strongest associations among the lowest-percentile weights (e.g., 8th-percentile weight was reduced by 2kg) (74).

Mental health and wellbeing.—Qualitative studies identified worry, anxiety, stress, and reduced wellbeing among individuals exposed to power outages, generally tied to concerns about disrupted heating, food, water supplies, and healthcare (75, 82). In the acute setting, healthcare-seeking for mental health problems may actually decline, as was seen immediately after the 2003 Northeast Blackout in NYC (40). Therefore, alternative data, such as Twitter, may supply valuable information about population health during an outage (20). Li et al. found a sharp drop in Twitter sentiment (i.e., more negative tweets) in the first hour of a NYC power outage in 2019. Other studies have evaluated longer-term effects of power outages (56, 79, 84) In Ghana, University students who experienced power outages ≥4 times per week had significantly higher levels of anxiety as measured by the generalized anxiety disorder 7-item scale (84). After Hurricane Sandy, ED visits for mental health problems among pregnant women in New York increased gradually and peaked eight months later at a level 33% higher than expected based on data from prior and subsequent years (79).

Mortality.—Three studies identified increased mortality after the 2003 Northeast Blackout in New York City (NYC), which affected 8 million NYC residents (39, 47, 80). Anderson and Bell found increased accidental (+122%) and non-accidental (+25%) mortality controlling for important environmental confounding variables such as temperature, air pollutants, day-of-week, and seasonal and long-term trends (39). Dominianni and colleagues extended Anderson and Bell's study to span major NYC blackouts in 1999, 2003, and 2006, as well as localized outages in 66 NYC electric-grid networks (80), finding significant associations between localized cold-weather, but not warm-weather, outages and all-cause and non-external mortality. Conversely, Imperato could not identify an effect of the 1977 NYC power outage on all-cause mortality as it coincided with and could not be disentangled from a heatwave (43). Other studies have tied power outage-related mortality to CO poisoning (see prior section), falls (55, 62), fire (55, 62), heat (85), and cold exposure (55).

Other outcomes.—Several studies reported increases in healthcare visits for burns, lacerations, or other injuries (40, 42, 50, 68, 77), but attributing these events to power outages, rather than co-occurring exposures such as housing damage or motor vehicle crashes has been difficult. Further, two studies reported reduced prescription refills during power outages (42, 52) and one found no change (50). After Hurricane Maria power outages lasted months in Puerto Rico and prescription refills did not revert to normal levels even one-year later (52).

REVIEW SUMMARY AND RECOMMENDATIONS

Recent studies point to a relationship between power outages and adverse health outcomes among community residents. Most have assessed single, large-scale power outages without linking events directly to patient residential addresses. New work has used data from electric utilities (80, 81, 83) and social media (30) to more accurately capture the temporal and spatial extent of outages. Consistent evidence from >20 studies across a range of power outages from hurricanes to ice storms to earthquakes finds increased rates of CO poisoning during outages as individuals use alternative fuel sources, such a generators and charcoal. We also observed moderate evidence for an association between power outages and all-cause, cardiovascular, respiratory, and renal disease hospitalizations, except for the sub-group of individuals relying on electricity-dependent medical equipment where associations consistently pointed to elevated risk. In times and places where power outages corresponded to hot or cold ambient temperatures, we found moderate evidence of a relationship between power outage and temperature-related illness, gastrointestinal illness, and mortality. Recent studies have broadened their scope to consider additional outcomes such as mental health (19), maternal and child health (73, 74, 83), prescription refills (42, 52), and injuries (40, 42, 50, 68, 77); future work should continue to explore these and other potentially important outcomes.

Future areas for exposure assessment.

To date, most studies have focused on single power outages, which can allow better characterization of co-exposures but misses the larger burden of repeated outages and under-estimates individual-level effects. Studies should consider factors such as duration (e.g., longer outages are likely much worse for health) and location (e.g., outages in San Diego likely have fewer impacts than outages in Maine in the winter). The lack of resolved spatial and temporal exposure data has also limited research. Attribution of adverse health outcomes directly to power outages will require exploiting variability in power outage locations, times, duration, and severity among populations. Zhang et al. successfully did this using NYSPS data (81). Such data are difficult to acquire and do not exist for many regions of the U.S. and world. Therefore, borrowing from digital epidemiology (95), alternative strategies may be used, including remote sensing, internet connected devices, and social media, to characterize spatiotemporal variability in power outages.

Remote sensing.—Researchers can use satellite or aircraft to measure reflected and emitted radiation of the earth. In particular, remote sensing of artificial lights at night (96) can be used to measure power outages (97). In India, Min et al. created a Power Supply Irregularity (PSI) index using nighttime satellite imagery to compute the outage index in all 600,000 villages in India from 1993-2013 (97). Likewise, Román et al. used globally-available, daily nighttime light data from NASA’s Black Marble product to track electricity grid restoration in Puerto Rico after Hurricane Maria (32). These data were used to create three metrics down to 902 barrios: (1) percent recovery; (2) number of days without electricity; and (3) number of customer-hours of interruption.

Internet connected and other consumer devices.—Meier et al. used the power status of internet-connected thermostats, of which 6 million exist in the U.S., to track outages at 15-minute intervals during Hurricane Irma and severe windstorm (98). Others have proposed using smartphones (99) or a host of internet connected devices (e.g., alarm systems, ATM networks) to track power outages (100).

Social media.—Several researchers have used Twitter feeds to track power outages (20, 101-104). One option is to use geotagged tweets (101), but these make up <1% of tweets as most users turn this function off (105). Instead, researchers can search for location-specific terms within tweets, for example, “New York City” or obtain information from registered locations from the users’ accounts (20, 104). Khan et al. also attempted to extract power outage cause in four groups: manmade, natural (e.g., “storm”), wildlife, and faulty equipment (104). This type of data may have increased utility in the future.

Co-exposures/complex disasters: One key and complicating feature of power outages is that they often occur alongside other disasters. Disentangling the impact of power outages from other physical destruction of infrastructure, such as landslides in Puerto Rico following Hurricane Maria (106, 107), fuel crises in Nepal after the 2015 earthquake (108), or windstorms in Ohio following Hurricane Ike (109) may not be possible. Bromet et al. noted a synergistic effect of multiple Sandy-related exposures, where participants experiencing 3-5 exposures (i.e., loss of power, extreme concern about finding gasoline, filing a FEMA claim, extensive home damage, and extensive possession damage) had >6x the odds of PTSD and major depressive disorder compared to those experiencing 0 exposures (56). Many studies implicitly include power outage as an exposure, but the researchers do not explicitly cite power outage as the main exposure of interest. Future work should consider the long-tail, ancillary impact of power outage-related health effects. Sustained power outages result in delayed or interrupted access to healthcare from infrastructure damage, access limitations, inability to pay (from disaster-related impoverishment), and loss of personnel (34, 83, 110). Such deferred care, from delayed treatments, unfilled prescriptions, or failure of DMEs impacts morbidity and mortality–as was in the case after Hurricane Maria in Puerto Rico, where nearly 4000 excess deaths occurred (111).

Future areas for outcome assessment.

Outcome assessment should increase in depth and breadth. Most studies only evaluated immediate effects of power outages. Future studies should expand the timescale to assess outcomes in the short-term and long-term. For example, Xiao et al. defined immediate impacts of Hurricane Sandy as the 30-days after and long-term impacts over the following year (79). They found immediate and long-term increases in ED visits for overall pregnancy complications among women in eight Sandy-exposed New York counties that exceeded increases in 54 less-exposed counties, highlighting the need to extend the relevant follow-up period. While studies have begun to assess perinatal health, future work should also consider children, another susceptible group. Additionally, studies must continue to evaluate the health of older adults, who rely more heavily on electricity-dependent medical equipment (26) and may have cognitive impairment or functional limitations (112), increasing their vulnerability to power outages.

The use of large insurance claims databases or EHRs (113), combined with better exposure assessment, will allow for investigating the impact of power outages on health in at least three important ways. First, it will allow for assessing a larger variety of health outcomes over a longer period of time. Many outcomes, such as maternal and child health or mental health, are known to be sensitive to power outages, yet remained understudied. In addition to these outcomes, exploratory analyses of large claims databases may identify currently unknown outcomes impacted by power outages. Second, it will allow for identifying and studying particularly susceptible subpopulations, such as patients with temperature-sensitive co-morbidities like multiple sclerosis or heart failure. Lastly, it will allow for a more complete description of the racial/ethnic, socioeconomic, and spatially patterned disparities in health response to power outages. Very few studies to date employ spatial and temporal control groups, rigorous statistical methods, and assess for effect modification by import socioeconomic and racial/ethnic sub-groups. This work can assist in identifying crucial points of intervention to allow for equitable allocation of preparedness, response and recovery activities, and resources to reduce disparities.

Building resilience and supporting response.

Resiliency spans from the individual to regional and global levels and encompasses individual skills, community health, and societal resources (114).

Preparedness.—Individual and community preparedness, including access to alternative power sources, can influence the scope of effect of outages on population health. While baseline levels of individual preparedness appear low, a silver lining of repeated outages is that households become more prepared, buying additional supplies or equipment, over time (19). In Florida, CO poisoning counts increased after the first, but not the second or third consecutive hurricanes, suggesting increased awareness, preparedness, or public health warnings during subsequent hurricanes of the season (50). Personal preparedness can reduce the effect of power outages on health, but low socioeconomic status individuals have limited capacity to store food and water or own a generator (29) and marginalized groups may receive fewer disaster-related warnings (70). Instead, emergency planners should focus on bolstering community resilience–physical, economic, and social–which can take many forms, from strengthening infrastructure to reducing baseline environmental exposure levels and socioeconomic inequities to expanding social capacities (21, 75). Resilient communities deploy collective strategies such as community kitchens, checking on older adults, and providing each other with warmth, food, and shelter during outages (19, 115). Government officials and utilities can further support health and safety by providing advanced warning of power outages as well as estimated duration once the outage has begun.

Electricity infrastructure.—Several steps can be taken to improve electricity grid resiliency and response. These might include better protection against cyber-attacks and tree maintenance (1, 16, 116), improved weather forecasting that allows utilities to prepare, decentralized power generation such as solar and battery storage (117, 118), smart grid technologies like advanced metering infrastructure and isolation and service restoration to update and enhance grid reliability (1, 15). Rather than increase access to generators, modest system upgrades could also allow for low-amperage service (e.g., 20A, which would keep lights or air conditioning on) during outages, possibly paid for via monthly backup insurance payments of <$1 per customer (119).

Supporting health during outages.—In addition to primary prevention and building resilience, some specific actions can directly support power outage-related health maintenance. For example, notifying patients pre-disaster to refill prescriptions. Prior to a mid-Atlantic blizzard CVS pharmacy randomly notified 2.2 million patients to check their medication supply and found that they had a 9% increased odds of a refill within 48 hours compared to the comparison group (120). Pre-dialysis and other forms of pre-care at healthcare facilities can allow individuals to go safely without power for longer (121). We also must further identify locations and co-morbidities among those reliant on electricity-dependent medical equipment via patient registration with utility companies and information from EHRs or publicly-available data sources like the emPOWER mapping tool (25, 26, 122), and provide community-based charging stations for medical equipment. In North Carolina, >95% of severe CO poisoning after an ice storm occurred in households without CO detectors (123). The benefit-to-cost ratio of installing a CO monitor may be as high as 7.2 to 1 (124). Low-tech interventions, like paired CO monitor and generator purchases, or engineering controls like automatic generator shutoffs, low CO generators, or simply longer generator cords could reduce CO poisoning (125). Finally, in low-resource settings where outages can limit ability to travel to hospitals or results in blackouts at hospitals themselves, mobile clinics can offer distributed access to care (126) and novel technologies, like solar and storage or oxygen reservoir systems, can support further continuity of care (127, 128).

CONCLUSION

As power outages increase in frequency and duration, researchers must expand efforts to understand their impact on individual and population health, refining methods of exposure assessment with attention to varied and disparate outcomes. There is urgent need for these data to inform disaster mitigation, preparedness and response policies (and budgets) in an increasingly energy-reliant world.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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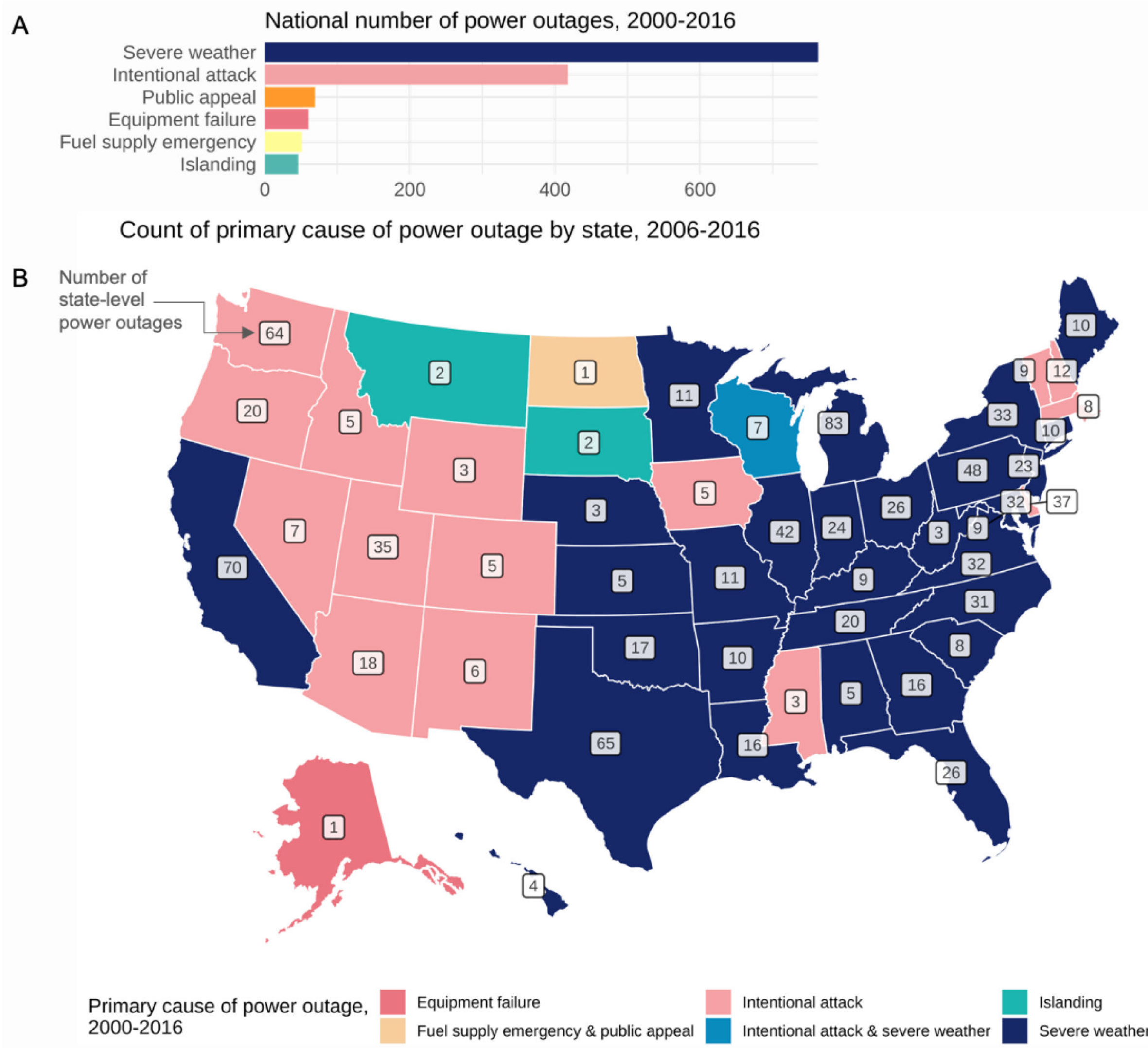

Figure 1: Summary of large power outages in the United States from 2000-2016.

A) Number of large power outages by cause between 2000-2016. B) Count of outages by primary cause type by state between 2000-2016. For example, Texas had 65 power outages caused by severe weather between 2000-2016. Data from Mukherjee et al. 2018 (10), which they assembled from publicly-available datasets. A large power outage is defined by the U.S. Department of Energy as: 50,000+ customers affected or an unplanned loss of 300 MW.

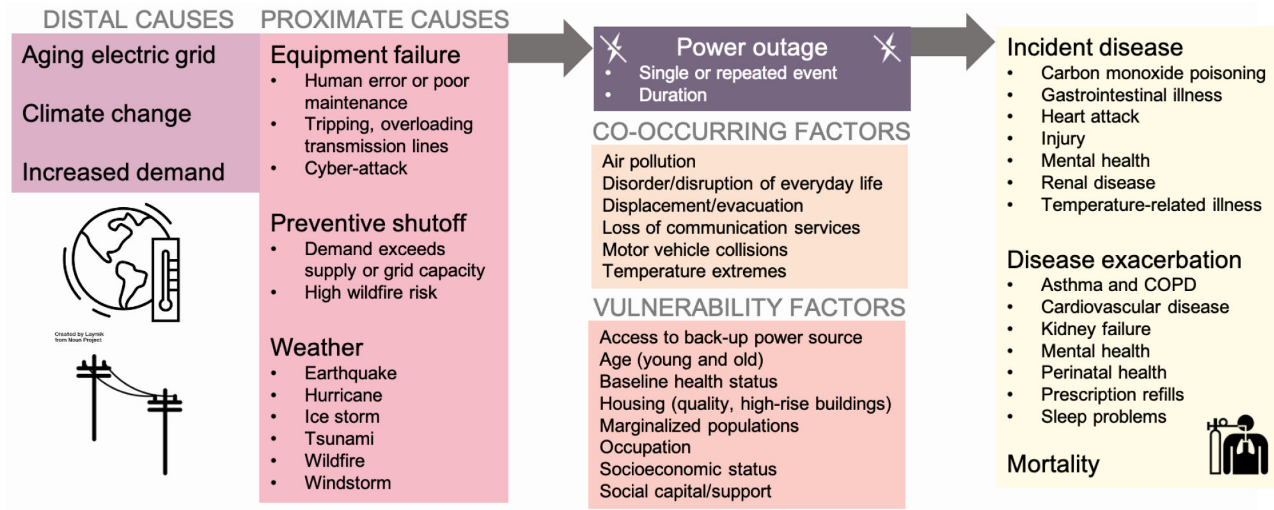

Figure 2: Schematic showing hypothesized pathways between power outages and disease exacerbation.

We illustrate co-occurring factors such as displacement, extreme temperatures, and air pollution, as well as vulnerability factors that might increase the risk of adverse health outcomes during power outages, including baseline health status, socioeconomic status, and social support.

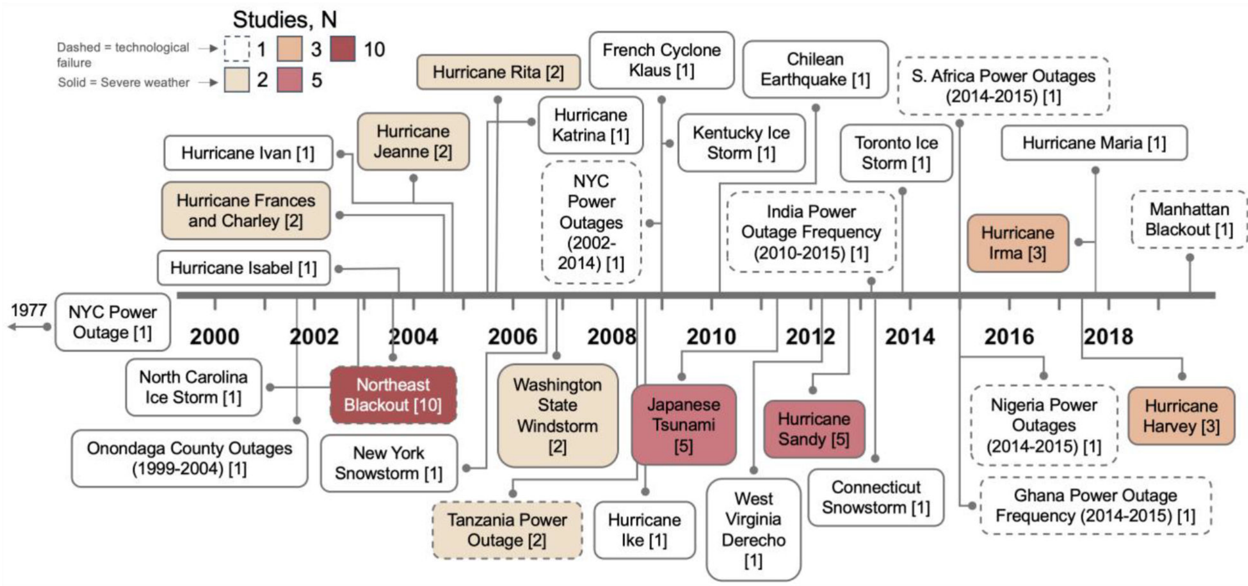

Figure 3: Timeline of the power outages evaluated by the epidemiologic literature between 2004-2020.

Dashed outlines represent outages caused by technological failure and solid outlines those caused by severe weather. Numbers in square brackets denote the number of studies evaluating the specific outage and fill colors get closer to red with more studies evaluating the outage.

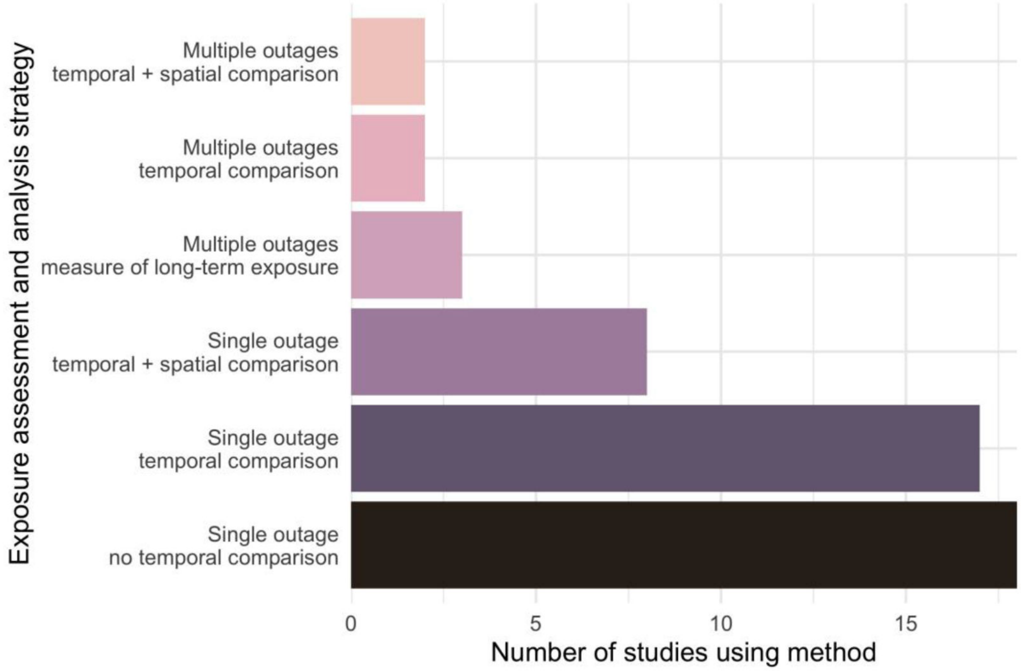

Figure 4: Exposure definition and analytic comparison groups used in 50 reviewed epidemiologic studies, 2004-2020.

Most studies evaluated a single outage by describing outcomes after the event among the exposed population (single outage, no temporal comparison). Eight studies evaluated a single outage but used both spatial and temporal comparison groups to make inference (single outage, temporal + spatial comparison). Three studies used measures of long-term exposure from multiple outages to assign levels of power outage exposure to the study population (multiple outages, measure of long-term exposure).

Table:

Recommendations for future exposure measurement and outcome assessment

Exposure assessment	Outcome assessment
• Consider duration of outage as a risk factor • Incorporate location of power outage (e.g., temperate versus cold climate) • Link outage and health data in space and time • Use tools from digital epidemiology: remote sensing, internet-connected devices, social media to characterize power outages • Account for co-exposures: physical hazards, psychosocial hazards, loss of property, etc.	• Include both short- and long-term effects • Expand studies to include perinatal health, mental health, and outcomes among those with chronic illness • Consider susceptible populations including people of color, children, older adults, and those of lower socioeconomic status or with co-morbidities • Use large insurance databases or electronic health records to study large populations

Climate Change and Risk of Completed Suicide

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Abstract: Climate change is increasingly recognized as having multiple adverse mental health effects, many of which are just beginning to be understood. The elevated rates of suicides observed in some communities affected by climate change and rising rates of suicide in the United States as climate change intensifies have suggested the two may be associated. We searched PubMed and PsycInfo using the terms climate change and suicide, and provide here a review of the current literature on climate change and suicide that explores possible associations and methodological issues and challenges in this research.

Key Words: Climate, suicide, mental health, psychiatry, environment, disasters

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Each year and throughout the world, more than 900,000 people die by suicide. In the United States alone, 14 of every 100,000 people died by suicide in 2017, making suicide the 10th leading cause of death in the United States (Murphy et al., 2018). This rate has increased by 33% since 1999 (Curtin and Hedegaard, 2019), and significantly increased from 2016 to 2017 (Murphy et al., 2018). It has increased for both males and females and for all ages 10 through 74 (Curtin and Hedegaard, 2017). Particular groups of concern include adolescents and young adults (Miron et al., 2019).

Although a myriad of psychiatric, psychological, and cultural factors may be involved in the increasing rates of suicide, one less appreciated factor is the role of climate change. Climate change is increasingly recognized as having a profound impact on mental health. Populations especially vulnerable to climate change include the poor and homeless, children, the elderly, and the mentally ill (Berry et al., 2018; Bourque and Cunsolo Willox, 2014; Coverdale et al., 2018; Masson-Delmotte et al., 2018). Elevated rates of suicide have been observed in some communities affected by climate change (Hanigan et al., 2012). We searched PubMed and PsycInfo using the terms climate change and suicide, and found no overview of the different contributing factors that have linked climate change to suicide to date.

In this article, therefore, we aim to explore the potential role of climate change in suicide rates and to describe the methodological issues and challenges in this research. There is significant value in correlating suicide rates with climate change, as it may be one indicator of psychic distress among those struggling at the front lines of a changing planet. As the quality of suicide data being reported improves globally (Bachmann, 2018), the outcomes of suicide prevention measures and climate adaptation efforts can be more accurately assessed. We advocate for an increased focus of attention and research on this important public health concern, because the prioritization of action on climate change by the psychiatric field requires good science and evidence.

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This review addresses four aspects of anthropogenic climate change and associated findings on suicide rates: 1) air pollution from the burning of fossil fuels, fire smoke, and ozone production; 2) higher temperatures, including ambient temperature and increased frequency of heat waves; 3) habitat changes linked to rising global temperature, including changes in landscape, food source, plant and animal life, and drought; and 4) impacts of ocean warming, including more frequent natural disasters, sea level rise, and associated predicted mass migration. We also include suicide that appears to have arisen directly from a psychological reaction to these climate realities. For the purposes of this review, we do not include changes in suicide associated with the changing epidemiology of infectious diseases and soil-based changes in nutrition. Although changes in the geographical distribution and prevalence of nutritional and infectious disorders will likely influence the rates of suicidal behavior associated with these illnesses, these novel habitat-illness interactions have not yet been studied. Our description here of the literature is not exhaustive but highlights a range of studies with both positive and negative findings to demonstrate the state of the field and suggest areas for further research.

ASSOCIATION OF SUICIDE RATES WITH AIR POLLUTION

Air pollution is defined by the EPA in terms of six criteria pollutants: lead, ozone, carbon monoxide, nitrogen oxide, particulate matter, and sulfur dioxide. The burning of fossil fuels is considered to be the source of 81% (Philip et al., 2014) of these pollutants. Particulate matter air pollution, defined based on particle sizes of 2.5 μm (PM2.5), 10 μm (PM10), and ultrafine particles (UFPs), now has a robust literature of association with adverse health and mental health effects. Particulate air pollution has been shown to translocate to the brain via olfactory and pulmonary nerves as well as the vascular system, where it causes multiple pathological changes in neurons and glia (Wright and Ding, 2016).

As with any climate variable, studying the effects of a particular element of air pollution on the brain is complex, and scientists must delineate each from other types of air pollution and from other air factors, such as seasonal variations in wind flow, fires, dust, pollen, temperature, moisture, and sunshine.

Particulate matter and the criteria pollutants ozone, sulfur dioxide, and nitrogen oxide have been the most studied for their mental health impacts. All have been associated either with a direct increase in suicide risk or with neuropsychiatric conditions known to increase suicidality: autism (Volk et al., 2013), dementia (Cacciottolo et al., 2017), depression (Gu et al., 2019; Kioumourtzoglou et al., 2017), and bipolar disorder (Khan et al., 2019). Increased suicide risk and increased rates of neuropsychiatric disorders associated with suicide have also been found under a variety of spatial and temporal conditions, including proximity to coal plants, traffic, and freeways, and chronic and acute air pollution events (Cacciottolo et al., 2017; Gu et al., 2019; Khan et al., 2019; Perera, 2017; Volk et al., 2013).

Overall, studies have revealed increased suicide rates of 1% to 2% per day of poor-quality air. It is important, however, for psychiatrists to feel secure with the depth and breadth of the science supporting a link of air pollution to mental disorders (reviewed in Buoli et al., 2018), as it is frequently a target for critique and has significant import for our patients. Therefore, we present this literature in greater detail.

One of the most comprehensive studies (Kim et al., 2018) examined 10 cities in Asia, each with a population of over 2 million, for time spans of 10 to 30 years. This study controlled for sunshine, temperature, barometric pressure, and precipitation, and used a time-controlled case-crossover design to control for trends in air pollution and suicide over time. All criteria pollutants were studied individually and in association with each other. The study assessed relationships between 9-day average pollution and suicide rates 0 to 5 days later. An association was found for relative risks of suicide per worse quartile air quality following these 9 days ranging from 1.016 (PM1) to 1.019 (nitrogen oxide, PM10–2.5), to 1.02 (sulfur dioxide). No association was found for PM2.5.

Similar designs have been used to study cardiovascular patients in South Korea (Kim et al., 2015), the city of Guangzhou, China (Lin et al., 2016), Tokyo (Ng et al., 2016), and Salt Lake City, Utah (Bakian et al., 2015). Each study spanned 10 years. In these studies, associations of air pollution and suicide were found for PM2.5 (10% increase) and PM10 (9% increase) (Kim et al., 2015), for NO2 (7% increase) and PM2.5 and SO2 (11% increase) (Lin et al., 2016), and PM2.5 (odds ratio, 1.05) and NO2 (odds ratio, 1.20) (Bakian et al., 2015). Taken together, these studies demonstrate an increase in the rate of suicide that ranges from 2% to 20% depending on the pollutant studied, time frame, and other factors.

The pathophysiology of air pollution associated suicide risk is hypothesized to be neuroinflammatory, with air particulates acting as irritants that generate systemic and local inflammatory responses (Costa et al., 2014). The hypothesis that pollution triggers a neuroinflammatory response is supported by findings of increased rates of inflammatory vascular and pulmonary disorders, including asthma, strokes, and heart attacks, in association with poor quality air (Wright and Ding, 2016).

This hypothesis is also supported by Min et al. (2018) whose results stratified the risk of suicide with worse air pollution by using a national health survey sample that identified the presence or absence of a physical or mental disorder. Min found a large increase in suicide risk associated with PM10 (hazards ratio [HR], 3.09), NO2 (HR, 1.33), and SO2 (HR, 1.15). Illness further increased this suicide risk. In the top quartile of air pollution, PM10 and NO2 pollutants were associated with an HR of 4.35, particularly in metropolitan areas (HR, 4.93 for PM10, 1.89 for NO2). Although unfortunately this study could not isolate those with mental disorders from other illnesses, it demonstrates the profound impact of air pollution on suicide rates in those already vulnerable to air pollution health impacts because of preexisting medical illnesses, including those associated with inflammatory responses.

ASSOCIATION OF SUICIDE RATES WITH RISING TEMPERATURES

Global temperatures are projected to increase between 2.6°C and 8.5°C by the end of this century, depending on the total greenhouse gases emitted under either stringent or high emissions scenarios (Masson-Delmotte et al., 2018). Present estimates, with implementation of currently endorsed unconditional policies around the world, project a two-thirds probability of temperatures rising approximately 2.9°C to 3.2°C (Climate Action Tracker: Warming Projections Global Update, 2019). The overall increase in heat-related suicides that would be predicted by such a 3°C increase is in the range of 2.1% to 6.3% (Burke et al., 2018).

Since before the 19th century, a seasonal pattern to suicide rates has been observed, with rates tending to increase in late spring and early summer compared with the fall and winter. Although the etiology of these fluctuations has been difficult to elucidate, these seasonal patterns of suicide have been reported in the literature from an array of countries and geographic areas (Galvão et al., 2018; Likhvar et al., 2011), and likely represent a heterogeneous phenomenon related to variations in temperature, daylight exposure, chronobiological aspects of mood disorders, and socioeconomic factors (Ajdacic-Gross et al., 2010; Kevan, 1980). Historical data suggest a decreasing trend in seasonal variability of suicide rates, particularly in Western countries, which may be due in part to change in access to violent suicide methods (Ajdacic-Gross et al., 2010). This will be important to keep in mind and to elucidate further when analyzing suicide data alongside rising global temperatures. Since climate change is defined over longer periods, researching climate-related suicides over large populations and longer periods is more likely to capture trends and minimize confounding factors, such as seasonal variation. Recent studies taking this approach have indeed found suicide rates increase with hotter temperatures (Bando et al., 2017; Burke et al., 2018; Carleton, 2017; Fountoulakis et al., 2016; Luan et al., 2019). This association holds true for both of the main impacts of climate change on ambient temperature: a greater total number of hotter days and more frequent acute heat waves.

A significant study (Burke et al., 2018) examined the effect of local ambient temperature in the United States and Mexico on suicide by using vital statistics over large geographic areas, larger populations than other studies (United States N = 851,000; Mexico N = 611,366), and longer periods (decades). They found that, between 1990 and 2010, suicide rates increased 0.7% in United States and 2.1% in Mexico for every 1°C increase in monthly average temperature. They concluded that if climate change proceeds unmitigated under the "business as usual" scenario that the IPCC technically refers to as "Representation Concentration Pathway (RPC) 8.5," it will add an estimated 9,000 to 40,000 additional suicide deaths by 2050. Their data indicate a relatively linear response of suicide rates to monthly average temperatures. Unlike the effect of temperature on other all-cause mortality, there was no increased risk as the temperature grew colder, and the effects did not diminish in those with higher incomes and more prevalent air conditioning. Furthermore, they did not find evidence of decreased sensitivity to temperature in populations more frequently exposed to high temperatures.

Linkages between suicide rates and elevated temperatures have also been observed in large urban populations. In China, the relative risk for suicide deaths, measured from 2009 to 2013 in 31 capital cities amounting to a population of 300 million, was 1.37 (95% confidence interval) for high temperatures, defined as the 95th percentile of ambient temperature (Luan et al., 2019). A time-stratified case-crossover study of multiple cities in three East Asian countries found a positive association between temperature and suicide rates, ranging from 3.9% to 7.8% for approximately a 4°C increase in temperature (Kim et al., 2016). A noted limitation was that air pollution was not accounted for in the data analysis. A time-series study in San Paolo, Brazil, revealed a 2.28% increase in suicides with each 1°C increase in weekly averages of minimum temperature. These findings were significant for men only (Bando et al., 2017). Studying annual rates of suicide attempts and suicides per 100,000 inhabitants in Thessaloniki, Greece, between 2000 and 2012 (Fountoulakis et al., 2016), it was found that male suicide rates correlate significantly with high mean annual temperature and accounted for 51% of the variance of male suicide rates.

Carleton (2017) explored the effects of exposure to temperature and rainfall in India, a developing country that accounts for over one quarter of suicides worldwide, and where suicides rates have doubled since 1980. The causes of the increased rates have been a source of debate, as factors such as lower crop yields from higher temperatures causing economic strain could also lead to higher rates of suicide. This study found that fluctuations in climate, in particular, high temperatures during the growing season, correlate positively with suicide rates. On days above 20°C, a day's increase of 1°C during the growing season added 0.008 suicides per 100,000 persons annually, amounting to a total of 59,300 additional deaths by suicide since 1980. There was no association between temperature and suicide rates in the nongrowing season. These findings are significant given the extent to which rising global temperatures will impact agricultural communities in developing countries.

ASSOCIATION OF DROUGHT AND SUICIDE

As the study by Carleton highlights, increased temperatures contribute to drought, resulting in lower crop yields. The likelihood that anthropogenic climate change is increasing drought is very high across all continents (Masson-Delmotte et al., 2018). It is therefore important to consider whether drought is a separate risk factor for climate change suicide, and how temperature, drought, and social factors such as agricultural incomes together may increase suicide rates.

Drought is defined as a period of abnormally dry weather that depletes water resources, including lake, reservoir, and groundwater. The resultant lower soil moisture and stream flow lead to erosion, habitat degradation, more wildfires, and water quality decline (Yusa et al., 2015). Droughts have a slow, vague onset, indirect manifestations, certain but unpredictable recurrence, and a severity of impact determined partly by the behaviors of people nearby. All of these parameters both increase the total mental stress of a drought and make it more difficult to isolate the elements of this complex drought-associated psychology that impact mental well-being.

Most studies of the impact of drought on mental health have been conducted in Australia, a country with the world's widest climatic fluctuation and a large rural and indigenous population. Studies have generally shown an increase in psychic distress overall (OBrien et al., 2014) and suicide specifically, although only under specific drought conditions and among rural farmers.

Anecdotal reports of completed suicide in association with drought exist at least before 1915 (Alpino et al., 2016). One early study of suicide in Australia that spanned 1901 to 1998 showed that drought was a general risk factor for suicide over these 100 years at the population level, with RR of 1.07 (Page et al., 2002).

A more recent study of drought-related suicides in New South Wales, Australia, found that suicide rates from 1970 to 2007 rose in rural males aged 30 to 49 by 15% when the drought index increased from the first to third quartile (Hanigan et al., 2012). This study also demonstrated an additional separate suicide rate increase of 3% in the general population with each 1.6°C increase over average annual temperature during this drought period. This increase in suicide with temperature is similar to the other temperature-related suicide studies cited. Female suicides did not increase in association with drought. Another study by this group looked at the same region from 1964 to 2001, both during and not during long droughts. They demonstrated an 8% increased risk of suicide for every 300-mm decrease in rainfall, a measure similar to that of water resource strain (Nicholls et al., 2006), but different in that there is both drought and an awareness of changes in weather. Both of these studies controlled for overall trends in suicide rates during the years in question. Another study (Guiney, 2012) did not demonstrate an increase in frequency of suicide over the drought years of 2001 to 2007 in Victoria, Australia. However, it did not adjust for downward trends in suicide rates in Australia over the years in question, and included employment groups less likely to have suffered drought-related economic losses.

ASSOCIATION OF INDIGENOUS POPULATIONS AND SUICIDE

Proportionally higher rates of suicide have long been recognized in indigenous populations compared with nonindigenous populations (Cunsolo Willox et al., 2014; Qi et al., 2009). A recent meta-analysis affirms this finding, although noting high variability between different indigenous groups independent of climate conditions. This variability, along with extremes in the climate conditions that will be experienced by indigenous groups around the world, will make conclusions about general climate effects difficult (Pollock et al., 2018).

A qualitative study (Cunsolo Willox et al., 2014) of an Inuit population found that changes in the environment and climate, when combined with other stressors, were implicated in increased suicidal ideation, as did a study of suicidal thoughts in Swedish group of reindeer herders (Omma et al., 2013). Furthermore, preservation of community institutions and practices was found to be roughly inversely associated with suicide rates and group distress in a study of Canada's indigenous groups (Chandler and Lalonde, 1998). However, there is not yet more direct evidence of climate change impacts on completed suicide itself within indigenous populations.

ASSOCIATION OF NATURAL DISASTERS AND SUICIDE

Although hurricanes and other disasters can have severe health consequences (Beaglehole et al., 2018; Lane et al., 2013), a direct relationship between a disaster and its impact on mental health is difficult to establish, as many other factors also contribute to the severity of its impact on an individual or group (Hammer, 2018). There is also not a consensus that climate change has influenced hurricane frequency (Landsea et al., 2006; Patricola and Wehner, 2018). It has, however, been amply demonstrated that climate change has increased the average and extreme rainfall of hurricanes, and will, in the future, increase wind speed (Patricola and Wehner, 2018).

One systematically conducted review identified 14 articles of varying designs that assessed the relationship between hurricanes and other forms of disasters on suicidal behaviors (Kõlves et al., 2013). This review found variability in outcomes across all studies, in part because of the varying methodologies employed and lengths of follow-up. Only two of the articles concerning the impact of hurricanes addressed suicide mortality (Castellanos et al., 2003; Lew and Wetli, 1996) but sample sizes were small. These findings included an insignificant increase in youth suicide rates and a small increase in homicide-suicides after hurricane Andrew.

In another study prehurricane and posthurricane, annual average suicide rates in 24 counties affected by a single severe hurricane in the United States increased, but not significantly so (Krug et al., 2002). We found no studies concerning suicide rates after wildfires.

SUICIDALITY AMONG REFUGEES AND IMMIGRANTS

The 1951 United Nations Convention on the Status of Refugees defines a “refugee” as a displaced person who must have “a well-founded fear of persecution because of their race, religion, nationality, membership of a social group or political opinion; and be unable or unwilling to return to the country for fear of persecution” (McColl et al., 2008). Some countries also designate a category of “asylum-seeker” to someone who has applied for refugee status. Those who leave their home because it has become uninhabitable due to global warming do not fit easily under this definition. For this reason, and because there are relatively few studies on suicide in refugees and asylum seekers, we include “immigrants” in our literature search, to better assess suicide rates associated with moving from one home country to another or leaving one's home under diverse situations of threat.

According to a 2017 United Nation Development Programme report, projected estimates of climate-related displaced persons by 2050 range from 25 million to 1 billion people per year. In comparison, there are currently an estimated 70.8 million displaced persons from all causes worldwide (Opitz et al., 2017). Reasons for displacement from one's home country due to climate change will include both direct climate impacts such as flooding and indirect climate impacts such as political or economic instability, violence, or disease.

The earliest studies on immigrant suicide by (Sainsbury and Barraclough, 1968) established a statistically robust correlation between suicide in country of origin and country of emigration across multiple nations, establishing both that one's cultural predisposition to suicide holds true regardless of location and that methods of recording suicide are sufficiently consistent across national boundaries to study this topic. These were uncontrolled studies that showed widely variable differences in rates of suicide with immigration.

Stack (1981) assessed the population rate of suicide compared with the rate of immigration in 34 countries in the year 1970 and found a 0.13% increase in national suicides for every 1% increase in immigration. Stack controlled for age older than 65 years and percentage of women in the work force, which he took to be confounding variables for population isolation and role conflict that might influence suicide rates in a similar way to immigration stress.

More recent studies on suicidality among refugees and immigrants come mostly from Northern Europe. A study of immigrant suicides in Sweden from 1987 to 1991 (Ferrada-Noli, 1997) found that immigrants from 60% of origin countries were, on average, 50% more likely to complete suicide than native Swedish residents. Immigrants from 90% of those origin countries were more likely to complete suicide than those from their home country. A study of asylum-seekers in the Netherlands from 2002 to 2007 (Goosen et al., 2011) found that men in this group were twice as likely to complete suicide and had a relative risk of 1.42 for hospital-treated suicidal behavior compared with Dutch natives. In a negative study based on data from the Danish Immigration Service from 1993 to 1999, refugees had a lower suicide rate than native-born Danes, but this result was low-powered (29 completed suicides) (Norredam et al., 2013). Neither Goosen nor Norredam controlled for suicide rate in country of origin.

Two much larger studies of suicides in immigrants, however, show similarly contrasting results. The first was conducted using WHO data from 1989 to 2003 for all of Europe. It revealed that suicide attempt rates were significantly higher in immigrants than in their host country counterparts for 27 of 56 countries of origin. Suicide attempt rates in the new country correlated positively with suicide completion rates in the country of origin for 14 of 19 countries. Four immigrant groups—those from Chile, Iran, Morocco, and Turkey—had a high suicide attempt rate despite relatively low home country suicide completion rate (Lipsicas et al., 2012).

The second study (Ikram et al., 2016) uses data from the Migrant and Ethnic Health Observatory Project, a database of countries in the European Union, and controlled for suicide risks in country of origin with a measure weighted for length of emigration. This study showed lower risk of suicide (mortality rate ratio, 0.36–0.60) in all groups studied with the exception of those from North Africa (mortality rate ratio, 1.42).

Taken together, the consistency of the findings that suicide attempts and completions correlate with those in country of origin as well as the fact that certain immigrant groups surpass their expected suicide and suicide attempt rate suggest that cultural norms in country of origin and risks embedded in the immigration experience all contribute to variability in suicide risk.

Uncovering these risk factors with so many potential variables and a relatively small number of completed suicides is challenging. One attempt (Hagaman et al., 2016) involved performing psychological autopsies of 14 completed suicides between 2009 and 2012 among Bhutanese refugees to the United States. The suicide rate among these refugees is roughly twice that of the US population overall. Most of the 14 examined were married men without a regular income, some with poor health. Most had not previously attempted suicide, and about half seemed to have symptoms of a mood disorder or PTSD. Focus groups in a subsequent analysis (Brown et al., 2019) involving 83 Bhutanese refugees, including children, revealed common themes of loss and isolation, as well as a taboo against communicating suicidal thoughts to each other.

Many populations displaced by climate change can be expected to flee from one developing country to another, with little access to infrastructure and mental health support when they arrive and throughout the immigration experience. This already occurs throughout the world, among populations fleeing violence and political instability. Thirty-six percent of 297 mothers interviewed at an Afghan refugee camp in nearby Pakistan screened positive for a mental disorder in 2002, and 91% of that group endorsed suicidal thoughts in the previous month (Rahman and Hafeez, 2003). In a Nigerian refugee camp composed mostly of Liberians studied in 2012, 27% of residents endorsed at least passive suicidal ideation in the previous month, compared with 17% of the host population. Suicidal thoughts correlated most strongly with a poor quality of life and being unskilled or unemployed (Akinyemi et al., 2015).

Much remains unanswered. It is reasonable to suspect, however, that populations displaced by climate change will face an even higher burden of mental distress and suicidality than other migrant groups, given the predicted increase in their numbers and lack of resources available.

CLIMATE CHANGE AS AN EXISTENTIAL THREAT

It has been recognized that climate change negatively influences mental health through an array of interwoven pathways (Berry et al., 2010) and that distress over climate change can contribute to nonsuicidal, self-destructive behavior (Bodnar, 2008). Bodnar details psychoanalytic cases of self-destructive behavior by young adults related to environmental distress, arguing that the natural world is an attachment figure in development and speculating that such behavior expresses in vulnerable individuals our changed relationship with the natural world. The high-profile suicide in 2018 of environmental advocate and attorney David Buckel via immolation (Conroy, 2019; Mays, 2018) is the only report of existential concern over climate change as a contribution to completed suicide. He emailed the New York Times of his intent, "Most humans on the planet now breathe air made unhealthy by fossil fuels, and many die early deaths as a result—my early death by fossil fuel reflects what we are doing to ourselves." His statement, "[My] privilege" is "feeling heavier than responsibility met," is suggestive of the "ecological debt" experience described in psychoanalytic literature (Randall, 2013). There was not a formal psychological autopsy in this case. Although there is a growing literature about climate anxiety, there is not yet evidence beyond the incomplete knowledge of the Buckel case of a climate change contribution to completed suicide via guilt or distress over climate change itself.

DISCUSSION

There is convincing evidence that the impacts of the greenhouse gases, air pollution, and higher global temperatures directly increase suicide risk, making this an issue of global concern for psychiatry.

Existing studies suggest a population-wide increased risk of suicide of up to 3% 2 to 3 days after episodes of significantly worsened air quality. The data so far also show that the risk of suicide is significantly worse when the air is particularly polluted, as, for example, in the three studies that show a threefold to fourfold increase in suicides for the worst quartile air compared with acceptable averages (Kim et al., 2015; Lin et al., 2016; Ng et al., 2016). Of further concern, these studies may have underestimated the risks of polluted air. It has only recently been possible to measure UFPs at air quality stations and in the brain, yet they are the most common particle type. UFPs may therefore play an important role that has yet to be measured (Donaldson et al., 2005) in the neuroinflammatory changes that are hypothesized to contribute to risk of suicide.

The consistency of the association between temperatures above 37°C and suicide across both middle-income and developed countries and across different climate types suggests a similar possible unifying neurobiology (Burke et al., 2018; Dixon et al., 2014). The use of depressive language on United States in social media posts, which also increases with rising temperatures, suggests a direct effect of temperature on mental wellbeing. Linkages between temperature and violent conflict have been observed for decades, where heat increases rates of interpersonal as well as intergroup conflict (Hsiang et al., 2013). More violent methods of suicide form a larger proportion of suicides methods connected to rising temperatures, compared with suicides not stratified by temperature (Bando et al., 2017; Lin et al., 2008). These findings suggest that heat-driven biological pathways lead to increased human aggression, both against the self and against others, and underscore the need for ongoing research into the underlying causal pathways of temperature-linked suicides. Burke et al. (2018) note that their predicted increase in suicide due to heat in this century will neutralize the gains of all current suicide-reduction programs in the United States, highlighting the significance of this impact for psychiatry.

Although no population subgroup is immune from global climate impacts, climate change disproportionately increases the psychosocial stressors that contribute to suicide in vulnerable populations: indigenous people, whose way of life is tied to natural resources; refugees fleeing countries impacted by sea-level rise, resource depletion, and climate-related conflict; socioeconomically disadvantaged populations less able to adapt to heat, food, and water shortages; as well as children, women, the elderly, and the mentally ill will be particularly vulnerable to mental health issues. The interplay of factors linking drought to suicide in Australian studies is a good example of complexity of these climate stresses (Bhise and Behere, 2016; Ellis and Albrecht, 2017; Kunde et al., 2017). These psychological autopsy studies support the hypothesis that ecoterratic distress, such as solastalgia, loss of cherished land and animals, socioeconomic stress from drought-related debt and bankruptcy, and feelings of personal failure increase the likelihood of suicide. These vulnerable groups deserve imminent attention to their mental health needs.

Much of the risk of climate suicide, however, is likely to transcend social class, and has yet to be explored. Intense emotional reactions including hopelessness about the future, shame, guilt, and grief, as well as panic about personal survival amidst interpersonal hostility and geopolitical conflicts, will increasingly contribute to suicide risk, as they do elsewhere. Existential anxiety as Western lifestyles come under threat, and a sense of betrayal by older generations may further contribute to suicide risk. Given the unexplained rise in suicide rates in today's youth and the evidence that environmental factors may be the most important risk for suicide in some studies, it is incumbent on future suicide research to take climatic factors into account.

Although we focus mostly on suicide as a hard data point that is more easily measured at this global scale, the biological, intrapsychic, and psychosocial influences that contribute to climate suicide will also contribute to overall mental morbidity. Climate effects on the incidence and vulnerabilities associated with major psychiatric diseases such as schizophrenia, autism, and dementia will be of greater overall impact than completed suicide itself. It behooves psychiatrists to become familiar with the climate mental health literature and to implement preventative measures for all climate mental health risks in their lives and practices.

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DISCLOSURE

The authors declare no conflict of interest.

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Effect of power outages on the use of maternal health services: evidence from Maharashtra, India

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ABSTRACT

Introduction Electricity outages are common in low/middle-income countries and have been shown to adversely affect the operation of health facilities; however, little is known about the effect of outages on the utilisation of health services.

Methods Using data from the 2015–2016 India Demographic Health Survey, combined with information on electricity outages as reported by the state electricity provider, we explore the associations between outage duration and frequency and delivery in an institution, skilled birth attendance, and caesarean section delivery in Maharashtra State, India. We employ multivariable logistic regression, adjusting for individual and household-level covariates as well as month and district-level fixed effects.

Results Power outage frequency was associated with a significantly lower odds of delivering in an institution (OR 0.98; 95% CI 0.96 to 0.99), and the average number of 8.5 electricity interruptions per month was found to yield a 2.08% lower likelihood of delivering in a facility, which translates to an almost 18% increase in home births. Both power outage frequency and duration were associated with a significantly lower odds of skilled birth attendance (OR 0.97; 95% CI 0.95 to 0.99, and OR 0.99; 95% CI 0.992 to 0.999, respectively), while neither power outage frequency nor duration was a significant predictor of caesarean section delivery.

Conclusion Power outage frequency and duration are important determinants of maternal health service usage in Maharashtra State, India. Improving electricity services may lead to improved maternal and newborn health outcomes.

Key questions

What is already known?

- Electricity outages are frequent in many low/middle-income countries and have been shown to adversely affect the operation of health facilities.
- Increasing the proportion of births that occur in a healthcare facility and that are attended by a skilled health professional is considered important in improving maternal and newborn health outcomes.

What are the new findings?

- Our results demonstrate that the frequency of power outages is a significant predictor of both institutional deliveries and skilled birth attendance in Maharashtra State, India, while the duration of power outages is a significant predictor of skilled birth attendance.
- This translates to an almost 18% increase in home births in a typical month assuming the average number of electricity interruptions (8.5) occurs.

What do the new findings imply?

- The study findings suggest that improving electricity supply, specifically by reducing the frequency and duration of power outages, may result in increased rates of institutional deliveries and skilled birth attendance, which may lead to improved maternal and neonatal health outcomes in the long run.
- Until reliable 24 hour power for all has been achieved, interventions to mitigate the impact of power outages on maternal health service usage are needed.

INTRODUCTION

Access to electricity is necessary to promote economic development, and has been associated with a number of development outcomes, including increased rates of female labour participation,[1 2] higher school enrolment[3 4] and improved health. Indeed, electrification rates have been found to be correlated with lower infant and maternal mortality across Indian districts,[5] higher rates of immunisation and prenatal care in Pakistan[6] and improved nutritional status in children in rural Bangladesh.[7] Given its importance, expanding access to electricity, particularly in rural areas, is a global priority, and ensuring 'universal access to affordable, reliable, sustainable, and modern energy' has been selected as target 7 of the newly adopted Sustainable Development Goals. Despite this, approximately 15% of the world's population (almost 1.1 billion people) still did not have access to electricity as of 2016 (Energy Access Outlook, 2017), and almost one-quarter of these people live in India.

Unreliable electricity supply can severely impede health service provision, affecting both the operation of health facilities and

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the quality of care received at these facilities. Power outages can cause interruptions in the use of essential medical and diagnostic devices, for instance, and may limit communication, both within healthcare organisations and between patients and healthcare providers.[8] Furthermore, unreliable electricity can make it difficult to provide lighting or to refrigerate vaccines and medications properly in healthcare centres, hindering even the most basic maternal delivery and emergency procedures.[9 10] Only a few studies have investigated the role of electricity in the demand and supply of health services. One study in Ghana, for instance, found that the risk of mortality increased by 43% on days in which facilities experienced a power outage for 2 or more hours[11]; however, it is unclear how generalisable these findings are to other contexts.

A country of approximately 1.3 billion people, the demand for power in India exceeds the current supply and electricity outages are common events.[12] In one notable event in July 2012, over 620 million Indians lost power in the largest grid failure in human history. Although the Prime Minister of India pledged over 160 billion rupees (US$2.5 billion) in 2017 to electrify every household in India by the end of 2018, and to give 24 hour power to all by March 2019,[13] access to reliable electricity remains an important issue in Indian healthcare facilities, and power outages have been blamed for a number of high mortality incidents across the country, the majority of which were caused by the failure of life-sustaining equipment such as ventilators and incubators.[14–16]

In addition to direct harm caused to patients, there is also concern that the frequent power outages occurring across India may affect care-seeking behaviours, particularly among expectant mothers. Although India has shown substantial progress in improving maternal health outcomes over the past few decades, the country continues to see high numbers of maternal deaths each year, and the Indian government has thus made increasing the proportion of births that take place in health facilities a key priority.[17] A number of determinants of institutional deliveries have been identified, both in India and internationally, and, in addition to factors such as mother's age and education, urbanicity, socioeconomic status and birth order, include distance and travel time to a facility, and quality of care,[18–20] all of which may be affected by power outages. Healthcare facilities experiencing electricity outages may provide lower quality services, for example, due to a lack of lighting or an inability to operate certain medical equipment, or may be less able to accommodate new patients, increasing a woman's odds of being turned away. Power outages may also impact transportation networks, limiting a woman's ability to get to a healthcare facility, or may cause a woman to stay home in anticipation of reduced quality of services. Conversely, facilities that do have a generator may become a popular destination during electricity outages, resulting in an increase in the number of people seeking care and thus staff shortages and heightened wait times, or may lead to a woman travelling farther than usual in order to reach these facilities.

Despite these potential mechanisms, there has been little investigation in any international context into the association between electricity outages and the use of maternal health services. Given this gap, this study aims to quantify this effect using a population of women from Maharashtra, India; a state of 112 million people, in which power outages are common. Specifically, we assess the association between the frequency and duration of power outages in any given month and a woman's likelihood of giving birth in a healthcare facility, as well as the likelihood that the birth is attended by a skilled healthcare practitioner, and the likelihood that the delivery is via caesarean section. The results of this paper will provide greater insight into the role of electricity in maternal health service usage and may inform future strategies to improve maternal and neonatal health outcomes.

METHODS

Data source

The data analysed in this study come from the 2015–2016 India Demographic Health Survey (DHS); a large, nationally representative household survey of women of reproductive age (15–49 years). Our sample was restricted to women residing in the state of Maharashtra, due to the availability of high-quality data on electricity outages within this state. The sample was trimmed to eliminate months at the beginning and end of the survey period, in which there were only a small number of live births (<100) per month. The final sample thus spans the time period August 2010 to May 2015.

Patient and public involvement

No patients were directly involved in this study.

Measures

Institutional delivery rates were measured using self-reported data on the location of delivery of all live births within 5 years of the date of the survey. Response options included at home, at another person's home, in a government hospital or facility, in another public facility, in a private hospital or clinic, or in another private sector facility. For analyses, location of birth was considered a binary variable and was coded as a non-institutional delivery if the birth occurred at home or at another person's home, and an institutional delivery if it occurred in a government hospital or another public facility, or in a private hospital or another private sector facility. Information on whether or not the delivery was assisted by a skilled health professional, defined as a doctor, auxiliary nurse, or midwife (binary variable with response options yes and no), and whether or not a caesarean section was performed (binary variable with response options yes and no) was also collected and was used as outcome variables in secondary analyses.

Power outages were measured using electricity reliability data from the Maharashtra State Electricity Distribution

Company (MahaDiscom), India's largest power distribution utility, based on System Average Interruption Frequency Index (SAIFI) and System Average Duration Index (SADI) values, which describe the average number of and duration in minutes of sustained power interruptions per consumer in a given time period, respectively. For analyses, both SAIFI and SADI indices were treated as continuous variables.

Additional data on both the mothers and the households included in the sample were extracted from the DHS. For mothers, this included age in years (continuous), birth order of the child, which was considered a proxy for parity (continuous), and educational attainment (ordinal categorical variable with categories uneducated, at least some primary, at least some secondary and at least some tertiary). For households, this included urbanicity (binary categorical variable with categories urban and rural) and primary religion of the household (Hindu, Muslim, or other), which was included based on the findings of previous studies that suggest religious differences in the use of maternal health services. DHS calculated wealth indices for each household were also used to generate wealth quintiles for the state of Maharashtra (ordinal categorical variable).

Data analysis

Statistical analyses were conducted using R V.3.4.3. Descriptive statistics including means for continuous variables and percentages for categorical variables were calculated to describe the characteristics of the sample, as well as variations in the SAIFI and SAIDI power outage indices and in locations of delivery in Maharashtra over the survey period.

Multivariable binary logistic regression models were used to assess the relationship between the frequency and duration of power outages in any given month and delivery in a healthcare facility, controlling for individual and household-level covariates, and to determine which factors were most predictive of delivery in a facility. Secondary analyses using birth attendance by a skilled health professional and caesarean section delivery as the outcomes of interest were also performed. Subgroup analyses were used to further assess each relationship, in order to determine if power outages have different effects on maternal healthcare service use among different groups of the population. Specifically, each analysis was stratified by urbanicity, household electrification and socioeconomic status.

Additional analyses including multinomial logistic regression to determine whether power outage indices predict the odds of births occurring in public hospitals, private hospitals, or at home, logistic regression using extreme power outage frequency and duration, classified as a monthly power outage frequency or duration greater than the mean for the entire time period, as the predictor variables, logistic regression using whether or not the minimum recommended antenatal care visits were made as the outcome variable, and logistic regression using a restricted sample of each woman's most recent birth only, were also conducted.

All models were adjusted for month and district-level fixed effects. Fixed effects for month were included to account for differences in both power outages and facility deliveries which may be due to events that are more common during certain months, such as extreme heat or other weather events, festivals and holidays. District-level dummy variables were included to account for any unobserved, district-specific characteristics, such as the number of healthcare facilities in the district, the availability of skilled healthcare professionals, the physical quality of the healthcare facilities and the local road network. A monthly linear time trend was also used to capture time-varying unobservable factors, such as overall adoption of new technologies, that could be correlated with the number of facility deliveries and electricity outages over the sample period. Multivariable regression was used to assess the effect of the power outage indices on several maternal characteristics including age at time of birth, education, wealth and place of residence, in order to rule out possible selection bias (see online supplementary appendix table 1). Bayesian generalised model estimation was employed in order to overcome perfect separation among non-electrified households. Unadjusted and adjusted estimates are presented. Bootstrapped SEs were used to minimise the spatial correlation between the error terms and 95% bootstrapped CIs are presented.

RESULTS

Characteristics of the sample

Sample demographics and information on power outage frequency and duration are presented in table 1. In total, 9125 births were reported within 5 years of the survey date. Mothers were an average of 25.95 years old at the time of the survey, and the majority, approximately 67%, had at least some secondary education. About a third lived in an urban setting, and 93% had electricity at home. Just 37% of women reported that distance to a health facility was not a problem for them, while almost one-quarter perceived distance to be a major barrier to accessing healthcare. The sample was evenly distributed across the wealth quintiles (not shown). Hindu was the most common religion and made up three-quarters of the sample. The vast majority of deliveries, approximately 89%, took place in a public or private health facility, compared with just 11% at home. Online supplementary appendix figure 1 demonstrates that the proportion of births in each location remained relatively stable over the study period, although a slight increase in public facility deliveries and slight decrease in home deliveries were observed overall. Correspondingly, 90% of births were attended by a skilled healthcare professional. About one in five deliveries were via caesarean section, and fewer than three-quarters of women obtained the recommended four or more antenatal care visits for her most

Table 1 Characteristics of the sample

	Mean/Percent	Min	Max	Obs
Panel A. Electricity Distribution Data (Monthly)				
Frequency Index (Mean±SD)	8.52±5.65	1.13	20.33	58
Duration Index (Mean±SD)	91.66±26.83	41.98	156.94	58
Extreme Frequency (Mean±SD)	0.46±0.50	0	1	58
Extreme Duration (Mean±SD)	0.47±0.50	0	1	58
Panel B. Demographic Health Survey, India, 2015–16 (Individual level)				
Delivery Location (%)				
Public	51.0%	0.0%	100.0%	4615
Private	38.0%	0.0%	100.0%	3518
Home	11.0%	0.0%	100.0%	992
Skilled Birth Attendance (%)				
Yes	90.0%	0.0%	100.0%	8213
No	10.0%	0.0%	100.0%	912
Caesarean Section (%)				
Yes	18.0%	0.0%	100.0%	1643
No	82.0%	0.0%	100.0%	7482
Antenatal Visits (%)				
4+Visits	73.0%	0.0%	100.0%	5059
<4 Visits	27.0%	0.0%	100.0%	1871
Household Electricity (%)				
Yes	93.0%	0.0%	100.0%	7879
No	7.0%	0.0%	100.0%	593
Urbanicity (%)				
Urban	33.3%	0.0%	100.0%	3042
Rural	66.7%	0.0%	100.0%	6083
Mother's Age (Mean±SD)	25.95±4.46	15	47	9125
Parity (Mean±SD)	1.90±1.04	1	11	9125
Mother's Education (%)				
Uneducated	11.0%	0.0%	100.0%	971
Primary	11.0%	0.0%	100.0%	1053
Secondary	67.0%	0.0%	100.0%	6096
Tertiary	11.0%	0.0%	100.0%	1005
Religion (%)				
Hindu	75.0%	0.0%	100.0%	6823
Muslim	15.0%	0.0%	100.0%	1409
Other Religions	10.0%	0.0%	100.0%	893
Distance to Health Facility (%)				
No problem	37.0%	0.0%	100.0%	3336
Not a big problem	40.0%	0.0%	100.0%	3679
Big problem	23.0%	0.0%	100.0%	2110

Frequency index: average number of sustained electricity interruptions per consumer per month.
Duration index: average duration in minutes of sustained electricity interruptions per consumer per month.
Extreme frequency: proportion of consumers experiencing higher than the average number of sustained electricity interruptions per month.
Extreme duration: proportion of consumers experiencing longer than the average duration of sustained electricity interruptions per month.

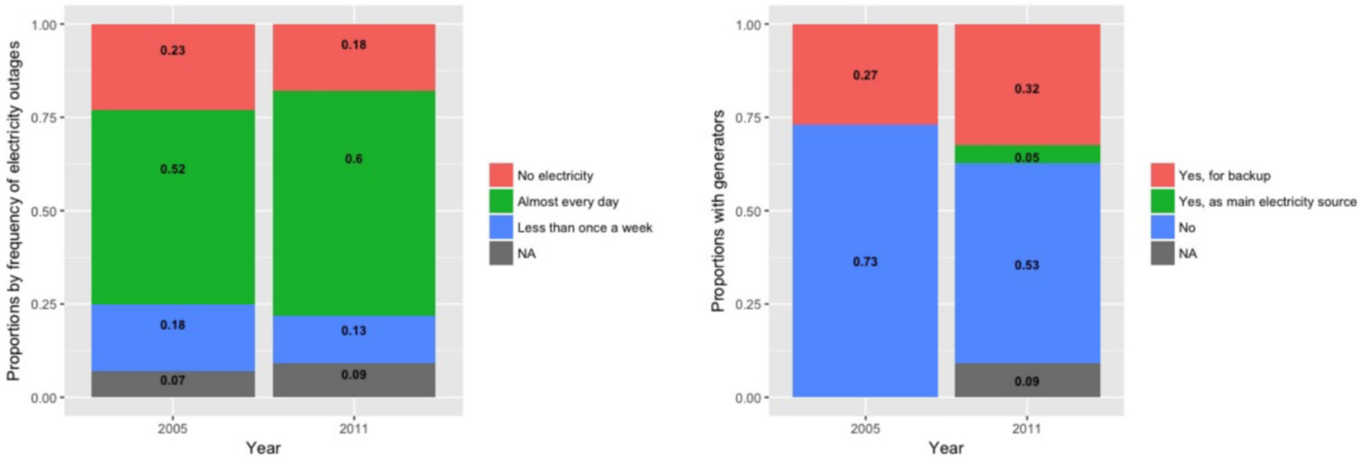

Figure 1 Electricity in Indian health facilities. NA, not applicable.

recent delivery. On average, households experienced power outages about 8.5 times in any given month and these outages totalled to around 92 min/month.

Electricity in Indian health facilities

Figure 1 presents data from the 2011–2012 India Human Development Survey, which collected information on health facilities, including generator ownership. Overall, the proportion of health facilities with no electricity decreased by 5% from 2005 to 2011, however 18% still did not have access to electricity in 2011 and the proportion experiencing an outage almost every day increased. Similarly, the proportion of facilities without a generator decreased from 2005 to 2011 and a new category of facilities which used a generator as their main electricity source emerged. We were also able to evaluate monthly variations in the duration and frequency of power outages in Maharashtra State over the study period, the results of which are presented graphically in online supplementary appendix figure 2. A general downward trend in the frequency of electricity outages was observed between 2010 and 2015, while the duration of outages appeared to increase overall, although seasonal variation was apparent for both indices, with the number of frequencies peaking from May to October and the duration from June to October.

Relationship between power outages and delivery in a healthcare facility

The relationship between a woman's likelihood of delivering in a healthcare facility and the frequency and duration of power outages is evaluated in table 2, with the marginal effects at the mean presented in online supplementary appendix table 2. Overall, an increase in the frequency of power outages was associated with a significantly lower odds of delivering in a healthcare facility, and this was true in both unadjusted (column 3) and adjusted (column 6) analyses. Specifically, each additional power outage instance was associated with a 2.08% (OR 0.98; 95% CI 0.96 to 0.99) lower odds of delivering in an institution, adjusting for individual-level covariates and month and district fixed effects; approximately a 17.68% lower odds if the mean of 8.5 monthly power outages occurs. In column 9, we also include household electrification status as a covariate in the model which leads to the outage frequency variable just failing to be a significant predictor of institutional delivery, though the effect size remains consistent. As electricity status is included in the calculation of the wealth index in the DHS, we suspect the inclusion of a potentially correlated variable may have affected our ability to find a significant effect, but we present these results to show that our effect size is consistent when this variable is included in the model.

In examining the effect of the duration of power outages on a woman's likelihood of delivering in a healthcare facility, the relationship was less consistent. In crude analyses, for example, a significant positive association was observed, however after adjusting for individual and household characteristics and month and district fixed effects, there was an insignificant negative relationship, with each increase in the duration of power outages of 1 min associated with a 0.20% (OR 0.99; 95% CI 0.99 to 1.00) lower odds of delivering in an institution.

Table 3 explores these relationships among key subgroups of the population, namely by urbanicity, household electrification status, socioeconomic status and perception of distance to a facility. Negative but non-significant associations between power outage frequency and delivering in a healthcare institution were observed for both urban and rural and low-wealth and high-wealth mothers, while among women who perceived distance to health facility as a major issue in accessing care, a statistically significant reduction in the odds of institutional delivery of 3.9% (OR 0.96; 95% CI 0.93 to 0.99) was observed, adjusting for individual and household-level covariates and month and district fixed effects.

In examining the effect of power outage frequency on delivering in a healthcare institution in electrified compared with non-electrified households, we found a statistically significant reduction in the odds of

Table 2 Effect of power outage indices on institutional delivery (log odds)

	Unadjusted Log-OR (Frequency)	Unadjusted Log-OR (Duration)	Unadjusted Log-OR (Frequency and Duration)	Adjusted Log-OR	Adjusted Log-OR (Month Fixed Effects)	Adjusted Log-OR (Month and District Fixed Effects)	Adjusted Log-OR (Month and District Fixed Effects and Interaction Term)	Adjusted Log-OR (Month and District Fixed Effects and Antenatal Visits)	Adjusted Log-OR (Month and District Fixed Effects and Electrified)	Adjusted Log-OR (Month and District Fixed Effects and Duration/Frequency)
Frequency Index	−0.035*		−0.034*	−0.012	−0.020	−0.021*	−0.011	−0.036*	−0.021	−0.010
	(-0.047,–0.024)		(-0.046,–0.023)	(−0.028, 0.006)	(−0.040, 0.001)	(-0.042,–0.0002)	(−0.052, 0.035)	(-0.06,–0.01)	(−0.044, 0.001)	(−0.054, 0.035)
Duration Index		0.003*	0.001	0.00	−0.002	−0.002	−0.001	−0.006*	−0.002	0.0007
		(0.0001, 0.0052)	(−0.002, 0.003)	(−0.003, 0.002)	(−0.006, 0.003)	(−0.006, 0.002)	(−0.006, 0.005)	(−0.011, 0)	(−0.006, 0.002)	(−0.006, 0.005)
Frequency Index x Duration Index							−0.0001			
							(-1.706,–0.268)			
Duration Index/ Frequency Index										−0.0001
										(−0.001, 0)
Urban				0.446*	0.456*	0.428*	0.429*	0.426*	0.438*	0.439*
				(0.232, 0.656)	(0.249, 0.678)	(0.200, 0.667)	(0.219, 0.668)	(0.146, 0.743)	(0.194, 0.7)	(0.243, 0.682)
Antenatal Visits								0.683*		
								(0.508, 0.88)		
Electrified: No electricity access									−0.236*	−0.238*
									(-0.441,–0.023)	(-0.487,–0.007)
Linear Monthly Time Trend				0.017*	0.016*	0.016*	0.016*	0.016*	0.016*	0.016*
				(0.0110, 0.024)	(0.009, 0.022)	(0.009, 0.023)	(0.008, 0.022)	(0.008, 0.025)	(0.01, 0.024)	(0.009, 0.023)
Month Fixed Effects	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
District Fixed Effects	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes
Observations	9125	9125	9125	9125	9125	9125	9125	9125	9125	9125

Bootstrapped 95% CIs are reported in parentheses.
Included in the models but not shown in the tables are wealth index, mother's education, mother's age, parity, and religion. The full results are available from the authors upon request.
*Denotes statistical significance at the 5% level.

Table 3 Effect of power outage indices on institutional delivery: subgroup analyses (log odds)

	Rural Households	Urban Households	Electrified Households	Non-electrified Households	Low-wealth Households	High-wealth Households	Perceived distance to health facility as a major barrier
Frequency Index	−0.021	−0.027	−0.026*	0.008	−0.025	−0.049	−0.039*
	(−0.045, 0.002)	(−0.085, 0.03)	(−0.05,−0.002)	(−0.051, 0.069)	(−0.055, 0.001)	(−0.11, 0.018)	(-0.076,−0.001)
Duration Index	−0.002	−0.002	−0.003	0.003	−0.001	−0.008	−0.002
	(−0.007, 0.003)	(−0.013, 0.01)	(−0.007, 0.001)	(−0.009, 0.017)	(−0.006, 0.004)	(−0.017, 0.006)	(−0.01, 0.005)
Urban			0.461*	0.329	0.541*	0.657*	0.76*
			(0.229, 0.708)	(−0.426, 1.214)	(0.187, 0.97)	(0.21, 1.196)	(0.28, 1.296)
Electrified: No electricity access	−0.210	−0.343			−0.368*	16.120*	0.040
	(−0.461, 0.034)	(−1.026, 0.404)			(-0.629,−0.12)	(15.32, 17.666)	(−0.355, 0.463)
Linear Monthly Time Trend	0.017*	0.014	0.015*	0.024*	0.015*	0.015	0.018*
	(0.01, 0.025)	(−0.001, 0.034)	(0.008, 0.022)	(0.004, 0.047)	(0.006, 0.024)	(−0.001, 0.034)	(0.007, 0.031)

Bootstrapped 95% CIs are reported in parentheses.
Included in most models but not shown in the tables are wealth index, mother's education, mother's age, parity, and religion. The full results are available from the authors upon request.
All columns include month and district-level dummy variables.
Columns 5 and 6 include a sample of respondents for the lowest and highest two wealth indices, respectively.
*Denotes statistical significance at the 5% level.

institutional delivery of 2.57% (OR 0.97; 95% CI 0.95 to 0.99) for women who resided in electrified households, adjusting for individual and household-level covariates and month and district fixed effects, but a small, non-significant positive association for women in non-electrified households. This discrepancy could also explain why adjusting for household electrification nullified the relationship between power outage frequency and institutional delivery in the full sample analysis. Similar trends emerged when assessing power outage duration as the independent variable, with small and non-significant negative effects observed for all subgroups, with the exception of women in non-electrified households, for whom there was again a small and non-significant positive relationship.

Relationship between power outages and birth attendance by a skilled professional

The relationship between the likelihood that a birth is attended by a skilled healthcare professional and the frequency and duration of power outages was also investigated and is presented in table 4. Both indices are significantly associated with a reduced odds of birth attendance by a skilled professional in full sample analyses, with a 2.76% (OR 0.97; 95% CI 0.95 to 0.99) lower odds observed for each additional power outage instance and a 0.40% (OR 0.996; 95% CI 0.992 to 0.999) lower odds observed for each additional minute of outage duration, adjusting for individual and household-level covariates and month and district fixed effects. In subgroup analyses, power outage frequency remained a statistically significant predictor of skilled birth attendance for urban women (OR 0.95; 95% CI 0.91 to 0.99), women residing in electrified households (OR 0.97; 95% CI 0.95 to 0.99) and women of high wealth (OR 0.96; 95% CI 0.91 to 0.99), while power outage duration was significantly associated with a reduced odds of skilled birth attendance for rural women (OR 0.995; 95% CI 0.990 to 0.999), and women residing in electrified households (OR 0.996; 95% CI 0.991 to 0.999), adjusting for individual and household-level covariates and month and district fixed effects.

Relationship between power outages and caesarean section delivery

The relationship between the likelihood of delivery via caesarean section and power outage frequency and duration is demonstrated in table 5. No statistically significant associations were observed between the power outage indices and caesarean section delivery in either the full sample or the subgroup analyses.

Additional analyses

The results of a series of additional analyses are presented in online supplementary appendix tables 3–6. Online supplementary appendix table 3 assesses the association

Table 4 Effect of power outage indices on skilled birth attendance (log odds)

	Full Sample	Rural households	Urban households	Electrified households	Non-electrified households	Low-wealth households	High-wealth households
Frequency Index	−0.028*	−0.018	−0.05*	−0.031*	0.001	−0.022	−0.045*
	(-0.05,−0.007)	(−0.042, 0.008)	(−0.095,−0.004)	(−0.054,−0.01)	(−0.059, 0.068)	(−0.054, 0.004)	(−0.089,−0.004)
Duration Index	−0.004*	−0.005*	−0.002	−0.004*	−0.003	−0.005	−0.005
	(−0.008, 0)	(−0.01, 0)	(−0.011, 0.006)	(−0.009, 0)	(−0.018, 0.009)	(−0.01, 0)	(−0.013, 0.004)
Urban	0.132			0.196	−0.577	0.435*	0.122
	(−0.065, 0.332)			(−0.021, 0.433)	(−1.442, 0.188)	(0.11, 0.819)	(−0.258, 0.51)
Electrified: No electricity access	−0.263*	−0.196	−0.911*			−0.394*	15.237*
	(-0.501,−0.019)	(−0.469, 0.123)	(-1.621,−0.242)			(−0.65,−0.127)	(14.661, 16.604)
Linear Monthly Time Trend	0.009*	0.013*	−0.002	0.009*	0.013	0.013*	−0.003
	(0.002, 0.015)	(0.005, 0.02)	(−0.016, 0.013)	(0.002, 0.015)	(−0.005, 0.039)	(0.005, 0.022)	(−0.016, 0.012)
Observations	9125	6088	3037	8472	653	3647	3652

Bootstrapped 95% CIs are reported in parentheses.
Included in most models but not shown in the tables are wealth index, mother's education, mother's age, parity, and religion. The full results are available from the authors upon request.
All columns include month and district-level dummy variables.
Dependent variable takes a value 1 if a mother received assistance from a doctor, auxiliary nurse, midwife, or other health professional, and 0 otherwise.
*Denotes statistical significance at the 5% level.

Table 5 Effect of power outage indices on caesarean section delivery (log odds)

	Full Sample	Rural houeholds	Urban households	Electrified households	Non-electrified households	Low-wealth households	High-wealth households
Frequency Index	−0.002	0.009	−0.022	−0.002	−0.001	0.014	−0.009
	(−0.018, 0.015)	(−0.013, 0.032)	(−0.046, 0.005)	(−0.018, 0.015)	(−0.123, 0.102)	(−0.02, 0.047)	(−0.033, 0.013)
Duration Index	0.0002	0.0004	−0.006	−0.0001	0.007	0.002	0.0001
	(−0.003, 0.003)	(−0.004, 0.006)	(−0.005, 0.004)	(−0.004, 0.003)	(−0.014, 0.025)	(−0.006, 0.009)	(−0.004, 0.004)
Urban	0.226*			0.238*	−0.831	0.186	0.354*
	(0.072, 0.364)			(0.106, 0.379)	(−2.327, 0.335)	(−0.241, 0.605)	(0.181, 0.542)
Electrified: No electricity access	−0.240	−0.141	−0.476			−0.392*	0.208
	(−0.6, 0.081)	(−0.57, 0.239)	(−1.479, 0.076)			(-0.838,−0.042)	(−0.928, 1.136)
Linear Monthly Time Trend	0.017*	0.018*	0.015*	0.017*	0.018	0.019*	0.016*
	(0.012, 0.022)	(0.012, 0.026)	(0.008, 0.024)	(0.012, 0.022)	(−0.018, 0.063)	(0.009, 0.031)	(0.01, 0.024)
Observations	9125	6088	3037	8472	653	3647	3652

Bootstrapped 95% CIs are reported in parentheses.
Included in most models but not shown in the tables are wealth index, mother's education, mother's age, parity, and religion. The full results are available from the authors upon request.
All columns include month and district-level dummy variables.
*Denotes statistical significance at the 5% level.

between power outage frequency and duration indices and whether a birth takes place in a public hospital, private hospital or at home. Using home delivery as the reference category, we found that a higher frequency of power outages was associated with a 2.27% lower odds of delivering in a private facility (OR 0.98; 95% CI 0.96 to 0.99) and a 2.08% lower odds of delivering in a public facility (OR 0.98; 95% CI 0.96 to 0.99), controlling for covariates. In subgroup analyses, power outage frequency was significantly associated with a reduced odds of delivering in a public facility for rural women and a reduced odds of delivering in a private facility for low-wealth women.

Online supplementary appendix table 4 evaluates the effect of extreme power outages, which take a value of 1 if the frequency and duration indices for a given month are greater than the average of each outage index, on institutional delivery. No significant associations were observed in full sample analyses, however subsample analyses reveal that extreme power outage frequency yields a 27.39% lower odds of delivering in a healthcare facility among low-wealth women (OR 0.73; 95% CI 0.53 to 0.95), suggesting that the poor may be the most vulnerable to extreme events.

Online supplementary appendix table 5 investigates the relationship between power outage frequency and duration indices and the likelihood of a woman attending four or more antenatal care visits. We found no statistically significant association in either full sample or subsample analyses.

Lastly, online supplementary appendix table 6 evaluates the effect of the power outage frequency and duration indices on the likelihood of institutional delivery in a restricted sample, consisting only of each woman's most recent birth. Overall, increased power outage frequency was associated with a 3.54% lower odds of delivering in a facility (OR 0.96; 95% CI 0.94 to 0.99), while increased power outage duration was associated with a 0.6% lower odds (OR 0.994; 95% CI 0.988 to 0.999). In subsample analyses, both power outage frequency and duration remained significant predictors of institutional delivery among women from electrified households, while in rural households, low-wealth households and high-wealth households, power outage frequency was significantly negatively associated with institutional delivery.

DISCUSSION

This study investigated the impact of power on rates of healthcare facility delivery in Maharashtra State, India, as well as on skilled birth attendance and caesarean section delivery. Using data from the 2015–2016 India DHS, we found that, controlling for other previously identified determinants, including urbanicity, household wealth, maternal education, age, parity and religion, electricity interruptions were associated with a statistically significant reduction in a woman's likelihood of giving birth in a healthcare institution. Specifically, each additional electricity interruption was found to yield a 2.08% lower likelihood of delivering in a facility, which translates to an almost 18% increase in home births per month if the average number of 8.5 power outages occurs. These findings are in line with the results of previous studies, such as that by Ghosh,[21] who identified a positive association between maternal health services use and an index of development indicators which included access to electricity. Interestingly, power outage duration was not a significant predictor of institutional delivery in either full or subsample analyses. We speculate that these findings may be consistent of evidence that power outages directly affect women's decision to seek care: a woman may decide to stay home if there is an outage but without any knowledge of how long the power outage will last.

Along with reduced odds of delivering in a facility, our results demonstrated a significant association between both more frequent and longer power outages and a reduced likelihood of a skilled health professional attending the birth in full sample analyses. In subsample analyses, the effect of power outage frequency was stronger in urban women, women from electrified households and women of higher wealth status, while the effect of power outage duration yielded greater reductions in the odds of skilled birth attendance in rural women, and women from electrified households. These discrepancies may indicate that, even among those who are better able to access healthcare, due either to physical proximity or increased financial resources, the quality of care received may be reduced during a power outage. For example, personnel shortages during a blackout may result in some women delivering without a healthcare professional in attendance even within a facility, while power outages may make it more difficult for a woman to communicate with health professionals, preventing them from attending home deliveries.

Importantly, we did not observe any significant association between electricity interruptions and the likelihood of a caesarean section delivery. This lack of a statistically significant relationship may be due to the fact that caesarean sections are generally emergency procedures that require specialised health professionals and medical equipment and must therefore be performed in a healthcare facility, which may be more likely to own a generator. Indeed, rates of caesarean section are relatively modest overall, accounting for approximately 18% of births in our sample, and thus the majority of these procedures are likely non-elective, and are therefore given priority within a healthcare facility, even during a blackout.

Implications for policy and practice

This study highlights the importance of electricity in the use of maternal health services in India and suggests that improving the reliability of the supply may be an effective strategy for increasing the proportion of births that occur in a healthcare facility or are assisted by a skilled health professional in Maharashtra State, India. Given the link between institutional delivery, skilled birth attendance and maternal and neonatal mortality rates,[22 23] this finding is important and reflects the need to develop programmes and policies that aim to improve the quality of electricity in India. Such efforts could take the form of increased financial investments in power, and Prime Minister Narendra Modi's recent commitment to give 24 hour power to all by March 2019[13] is a promising start. Additionally, programmes that attempt to reduce the impact of electricity interruptions on maternal health service usage may be an important short-term strategy, and could include supplying facilities with additional generators or implementing mobile clinics, which would allow women to receive the care they need even when they are not able to deliver in an institution, for example, due to a power outage. Mobile clinics already exist in some low/middle-income countries such as in Tanzania, where they have been found to improve coverage of maternal and child health services to underserved populations,[24] and are now being implemented in India. Expanding the presence of trained midwives in low/middle-income countries may also prove effective at increasing skilled birth attendance, particularly in rural areas where health-care facilities are often few and far between. Increased midwife availability would reduce the need for women to travel to give birth during a power outage, and would eliminate any concerns about the quality of care received. Indeed, there is evidence to suggest that attendance at delivery by trained midwives can reduce maternal mortality in resource-poor settings,[25] and the WHO has thus promoted midwifery as essential in improving maternal and infant health outcomes in low/middle-income countries.[26] Despite this evidence, the Government of India has not invested substantially in midwifery training,[27] and there is thus a shortage of midwives in the country, with only about 2.4 nurses and nurse-midwives per 10 000 people, the majority of whom remain concentrated in urban centres.[28] Improving access to midwives would therefore result in positive outcomes, both in times of electricity interruptions and not.

Limitations

This study is not without limitations. First, although the availability of high-quality power outage data made Maharashtra State a suitable setting in which to conduct this study, it may not be representative of the country of India as a whole, or of other low-income countries in which electricity interruptions may be an issue. Indeed, Maharashtra State has high rates of electrification relative to the national average, and comparatively good maternal and child health indicators. While we do not have data for other states, it is probable that these areas also experience power outages, likely at higher rates than the relatively well-off Maharashtra State, and that they have even lower rates of institutional delivery. Therefore, it can be assumed that power outages are also an important determinant of delivering in a healthcare facility in these other states, and may in fact be an even greater impediment. Furthermore, our measures of power outages are weighted state averages for all mothers, regardless of their connection to the electricity grid and place of residence, and not all are likely to be affected in the same way. We also do not have data on the exact date of each birth, nor the exact date of the power outages. While more precise data would likely have allowed us to make more precise estimates of the impact of outages on delivery rates, we do not believe it substantially biased our results. Finally, we do not have data on whether or not each health facility or household owned a generator. Such information may have potentially allowed for a deeper understanding of the mechanisms behind the aggregate effect that is measured in this study.

CONCLUSION

In this study of women in Maharashtra State, India, we provided new evidence of an association between electricity interruptions and maternal health service usage. Specifically, we found that more frequent power outages predicted a reduced odds of delivery in a healthcare facility for women from electrified households, while longer and more frequent power outages were associated with a reduced odds of birth attendance by a skilled professional. Given the importance of these outcomes in order to reduce maternal and neonatal mortality rates, our results reflect the need to reduce the frequency and duration of power outages in India and throughout the developing world. In the meantime, future research should focus on developing practices and policies to lessen the effects of these electricity interruptions on maternal health services so that adverse health impacts on women and babies are minimised.

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