Technical Report

UNITED NATIONS UNIVERSITY
UNU-EHS

Interconnected Disaster Risks
2020/2021

Texas Cold Wave

Author: Caitlyn Eberle

Table of Contents

1. Event

During the week of February 6th, 2021, a powerful cold wave swept over much of North America, bringing with it snow, ice and record sub-zero temperatures in some areas. The cold weather was triggered in part by a sudden stratospheric warming event in January, in which atmospheric waves knocked the Arctic polar vortex off course. This disruption in the polar vortex weakened the polar jet stream and allowed it to become 'wavier', by which warm air flooded north into the Arctic, and polar air filled in the gaps to the south (see Figure 1) (Lindsey, 2021).

Though the winter storms and freezing temperatures affected many places, the state of Texas in the United States was the most severely impacted, with cold temperatures causing massive disruptions to electricity and water services. For the first time ever, all 254 counties in the state were placed under a winter storm warning (Villarreal, 2021). The city of College Station in south-central Texas measured 86 consecutive hours of below-freezing temperatures, and a -22oC departure from normal temperatures (National Weather Service, 2021).

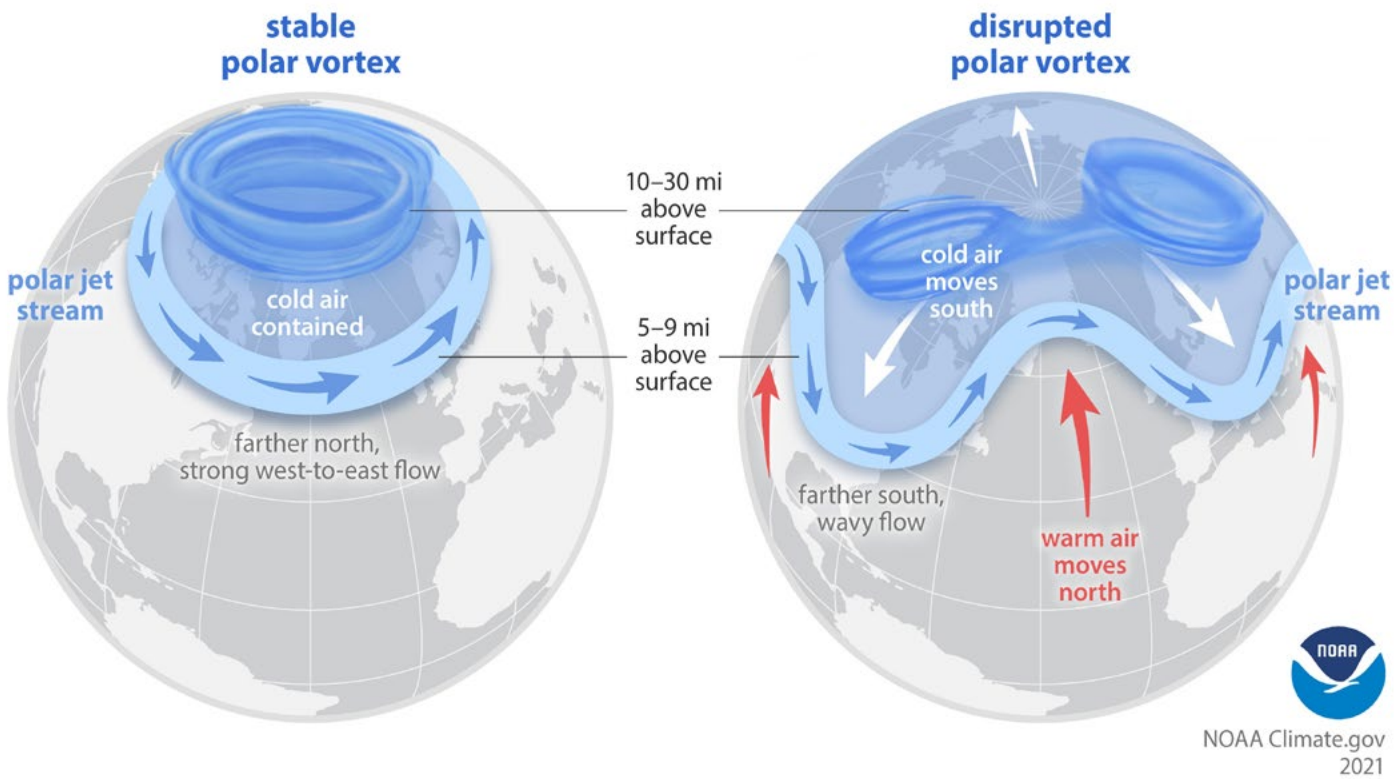


Figure 1: Understanding the polar vortex, adapted from Lindsey (2021).

2. Impacts

Direct impacts

This cold wave turned into a crisis through a combination of factors, primarily a failure of the electrical infrastructure when the cold weather drove up demand for electricity for heat, while also hampering supply from power-generation facilities, for example by freezing natural gas wells and wind turbine blades. The increase in demand and the limited supply meant the grid manager in Texas, Electric Reliability Council of Texas (ERCOT), ordered rolling blackouts – where power is periodically shut off for parts of the system – intended to reduce the demand by cutting power to around 4 million Texans for short, controlled amounts of time (Everhart & Molnar, 2021; Chang, 2021). The call for rolling blackouts began in the early hours of 15 February and lasted until 19 February; however, many outages actually lasted for several more days (ERCOT, 2021a; Cornish, 2021). The discrepancy in available power during the outages was widespread: some areas lost power for only a few hours, while others had power for only a few minutes – over a more than 36-hour period for some residents (Salam and others, 2021). Additionally, since large parts of Mexico also rely on natural gas from Texas, the Mexican Government also ordered power outages, affecting 4.7 million customers in northern Mexico for several hours (Angulo and others, 2021). Still further, the freezing temperatures caused disruptions to the water infrastructure, as pipes in homes and underground froze and burst. As many as 12 million Texans were put under 'boil water' notices due to malfunctioning sanitation facilities and a loss of system pressure as a result of line breaks, unable to use tap water for drinking or cooking (Riley, 2021; Chappell, 2021). Many Texas resorted to melting snow for daily activities, such as flushing toilets and for backup drinking water (Samuels, 2021). Water-supply issues persisted months after the initial freeze, as the COVID-19 pandemic created shortages in plumbing supplies needed to repair leaking pipes and other cold damage in homes (Agnew, 2021b).

Between 11 February and 5 March, officially 210 people died in Texas from cold-related causes (Texas Health and Human Services, 2021), though some sources estimate the actual number to be closer to 700 (Aldhous and others, 2021). The majority of verified deaths were associated with hypothermia, as well as vehicle accidents, carbon monoxide poisoning, medical equipment failure, exacerbation of chronic illnesses, lack of home oxygen, falls and house fires (Texas Health and Human Services, 2021). Carbon monoxide poisoning instances and some house fires were likely the result of unsafe methods for keeping warm, such as leaving a car running in a garage or venting the exhaust from a home generator into living spaces. Such exhaust emissions create carbon monoxide, which is odourless and tasteless, and when inhaled can quickly cause nausea, dizziness and loss of consciousness. More than 1,400 people sought emergency care in Texas for carbon monoxide poisoning from 13 February to 20 February, with officials deeming it a ‘public health disaster’ (Trevizo and others, 2021). Additionally, the lack of home oxygen combined with the power outages created complications for people recovering from COVID-19 infections at home. Due to statewide surges in COVID-19 hospitalizations, a record number of patients were sent home to recover and relied on plug-in breathing machines, which went offline during the outages (Hixenbaugh & Trevizo, 2021). Many people did not have enough backup oxygen tanks to last them through the entire power outage.

Indirect impacts

Already financially devastated by the COVID-19 pandemic through job losses, inflation in prices of essential goods and loss of health insurance, low-income families in Texas were disproportionately affected by the power blackouts. Many lacked the financial capacity to cope with the cold the way some more affluent residents could, such as fleeing the state or purchasing a hotel room (Dobbins & Tabuchi, 2021). Low-income neighbourhoods are also traditionally composed of older homes with poor insulation and pipe systems and were among the first to be hit with power outages, due to systemic underinvestment in some areas, or the tendency to live further away from critical infrastructures, which are prioritized to receive available energy in the event of an outage (Reta & Gout, 2021; Chang, 2021). Additionally, minority populations are more likely to live close to industrial sites and, by extension, are more exposed to pollution (Dobbins & Tabuchi, 2021). This was particularly a concern as around 200 oil refineries, chemical manufacturers and other industrial plants in Texas released 3.5 million pounds (approximately 1.6 million kilogrammes) of excess pollutants, such as sulfur dioxide and methane, due to weather-related systems failures between 11 February and 22 February (Uteuova, 2021). Many homeless people were also drastically affected by the freeze. For example, in Fort Worth, Texas, traditional shelters quickly reached capacity limits because of COVID-19 restrictions, so three emergency shelters had to be opened (Gordon, 2021). In San Antonio, a Christian ministry could not offer showers to their local homeless population due to a burst pipe (Dobbins & Tabuchi, 2021).

Due to the discrepancy in supply and demand, the market price of electricity jumped tremendously. The cost of electricity in Texas was around US$50 per megawatt-hour before the cold wave hit but spiked to a record high of $8,800 per megawatt-hour, a 17,600 per cent increase in a matter of days (Verma, 2021). Some customers on variable-rate plans, where electricity bills fluctuate with wholesale electricity prices, reported bills of over-$1,000 per day. The price spikes will not affect other customers on fixed-rate plans until later on in the year, when the rates are recalculated (Proffer, 2021). To a lesser degree, price spikes were also experienced across parts of Europe and Asia, as the sudden stratospheric warming event also caused frigid temperatures across the northern hemisphere. Spain recorded its coldest temperature, at -35.6oC in January, with prices peaking at nearly $116 per megawatt-hour, three times higher than the average in 2020 (IER, 2021). In Japan, as energy usage was around 90 per cent higher than expected, prices for wholesale electricity spiked from about $130 per megawatt-hour in December to a peak of more than $1,000 in early January (McDonnell, 2021).

The cold also disrupted industries in Texas, causing cascading and lasting effects nationally and globally. The power outages caused disruptions in plastics manufacturing, bringing the world's largest petrochemical complex to a halt, causing shortages and price spikes for polyethylene, polypropylene and other materials used to make plastic products. For example, polyvinyl chloride (PVC) prices have more than doubled since summer 2020 (Matthews and others, 2021). In the agricultural sector, the freezing weather destroyed citrus, leafy greens, and other fruit and vegetable crops. Around 55 per cent of grapefruit and 98 per cent of Valencia orange crops were lost. Only three of more than 40 vegetable crops grown during winter are expected to survive: onion, cabbage and potato, with farmers of even those crops reporting losses of over 20 per cent (Reiley, 2021).

In addition to human and industrial impacts, the cold also severely impacted wildlife in the area, killing hundreds of songbirds, antelopes and bats (CBSDFW Staff, 2021). As many as 3.8 million fish, consisting of 61 species, were killed off the Texas coast during the freeze event (TPWD, 2021). Cold water temperatures caused a mass stunning event of the endangered Green sea turtle. Around 12,000 cold-stunned turtles were recorded on the lower Texas coast, catatonic as the water lowered their body temperatures and rendered them unable to swim. Of the 12,000 affected, an estimated only 35 per cent survived, in large part thanks to volunteers, who brought the turtles in from the water and housed them in makeshift warming centres (Burnett, 2021).

3. Drivers

Conditions in the Arctic: ocean and atmospheric warming

The meteorological systems responsible for the cold wave are influenced by the complex interactions of the polar vortex, the polar jet stream and the North Atlantic Oscillation (NAO), which describes the difference in air pressure between the high-pressure zone west of Portugal and the low-pressure zone above Iceland (see Figure 2). When the polar vortex is strong, the polar jet stream exhibits a more linear flow from west to east, and the NAO tends to be in its positive phase. However, occasionally the polar vortex is knocked off its axis due to sudden stratospheric warming (SSW) events, where strong atmospheric waves from the troposphere break into the stratosphere, creating a spike in stratospheric temperatures. This is associated with a 'wavier' jet stream and the negative phase of the NAO (see Figure 2) (Lindsey, 2021).

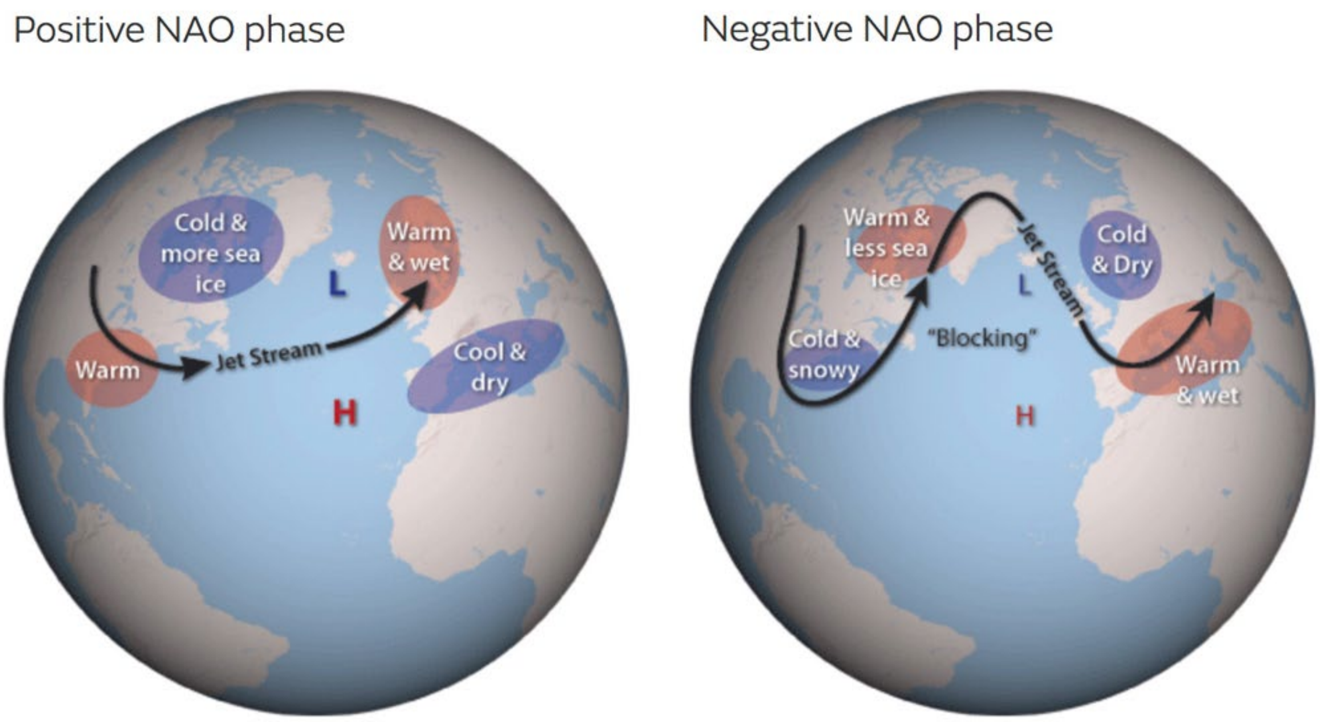


Figure 2: Positive and negative phases of the North Atlantic Oscillation (Met Office image taken from McSweeney [2019]).

Though it is difficult to determine causation, recent research suggests that warmer Arctic temperatures may be influencing these systems (McSweeney, 2019). Driven by a process known as 'Arctic amplification' (see section 4), a feedback loop forms as sunlight-reflecting sea ice melts and more heat is absorbed by the ocean, which in turn causes the sea ice to melt further. As the ocean warms, it creates a heat exchange with the atmosphere above it, increasing the temperature in the troposphere and bringing widespread meteorological implications. Firstly, as the troposphere above the Arctic warms it decreases the temperature differential between the colder air in the Arctic and the warmer air in the mid-latitudes. Since this difference drives the strength of the polar jet stream, its decline may lead to a weakened jet stream (Francis & Vavrus, 2015). A weak jet stream is more easily pushed from its typical path straight from west to east, instead becoming 'wavier' and creating north-south waves, known as Rossby waves, where high-pressure ridges move warm air north into the Arctic and force cooler, low-pressure troughs to the south (see Figure 1) (McSweeney, 2019; Lindsey, 2021). These larger waves also contribute to more persistent, lingering weather patterns, as it takes longer for weather systems to move from west to east (Francis & Vavrus, 2015).

Though the NAO is naturally variable, research also shows that the negative phase of the NAO has become increasingly common over the last few decades since a warmer, humid Arctic climate changes storm tracks and increases Eurasian snow cover in the fall,

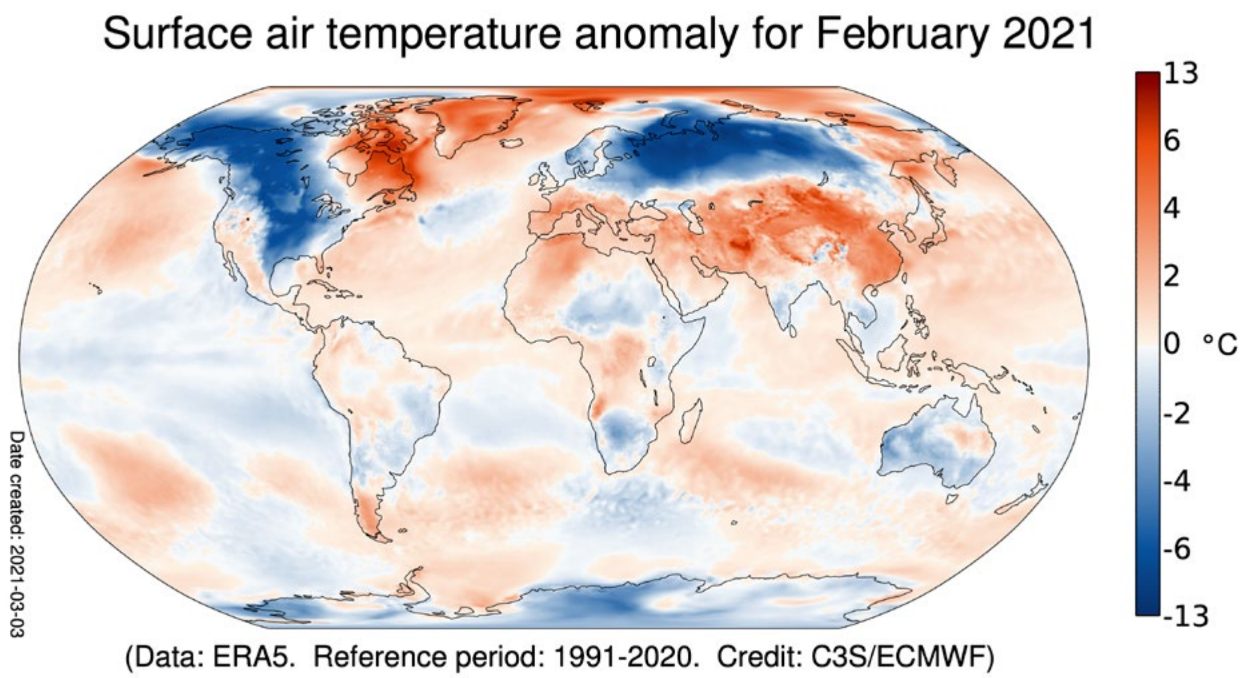


Figure 3: Map of surface air temperature anomaly for February 2021, taken from C3S (2021).

forcing a negative NAO during the following winter (Cohen and others, 2012). By creating a warmer, more humid Arctic climate, Arctic amplification may also contribute to the increased frequency of this phenomenon, known as the ‘warm Arctic, cold continents’ pattern, which has been observed in winter over the past few decades (see Figure 3) (Cohen and others, 2014).

Arctic amplification may also influence SSW events that cause the polar vortex to weaken and split. Like other meteorological phenomena, the frequency of SSWs is naturally variable, typically occurring once every two years, often triggered by the El Niño Southern Oscillation (Ineson & Scaife, 2008). Some research suggests that decreased Arctic sea ice cover in early winter enhances the atmospheric waves that trigger SSWs, weakening the polar vortex in mid-winter (Kim and others, 2014). Other research shows an increased frequency of weak polar vortex states in winter in the last 40 years, supporting the hypothesis that the phenomenon is linked to Arctic sea ice cover (Kretschmer and others, 2018).

As mentioned above, it is unclear whether Arctic amplification can explain the cause of these changes in the atmospheric system. Research is still ongoing into these systems and their interactions, with diverging consensus between observational studies, which conclude that Arctic amplification forces cold mid-latitude winters, and modelling studies, which do not come to that conclusion. However, researchers can agree that the observed trends cannot be explained without including the dynamics of Arctic amplification (Cohen and others, 2020).

Non-winterized electricity/water systems

The cold weather itself was not responsible for the Texas cold wave disaster; it was instead the interaction of the cold weather with non-winterized electricity and water infrastructure. In Texas homes, water lines are often kept in attic spaces and are generally not insulated. City water lines were buried too shallow underground to keep them from freezing as the temperatures fell (Waller, 2021). As mentioned above, many power generation facilities failed due to the cold-weather impacts, with boilers and turbines exposed to the elements to prevent excess heat build-up during summer (Storrow, 2021). Natural gas wellheads

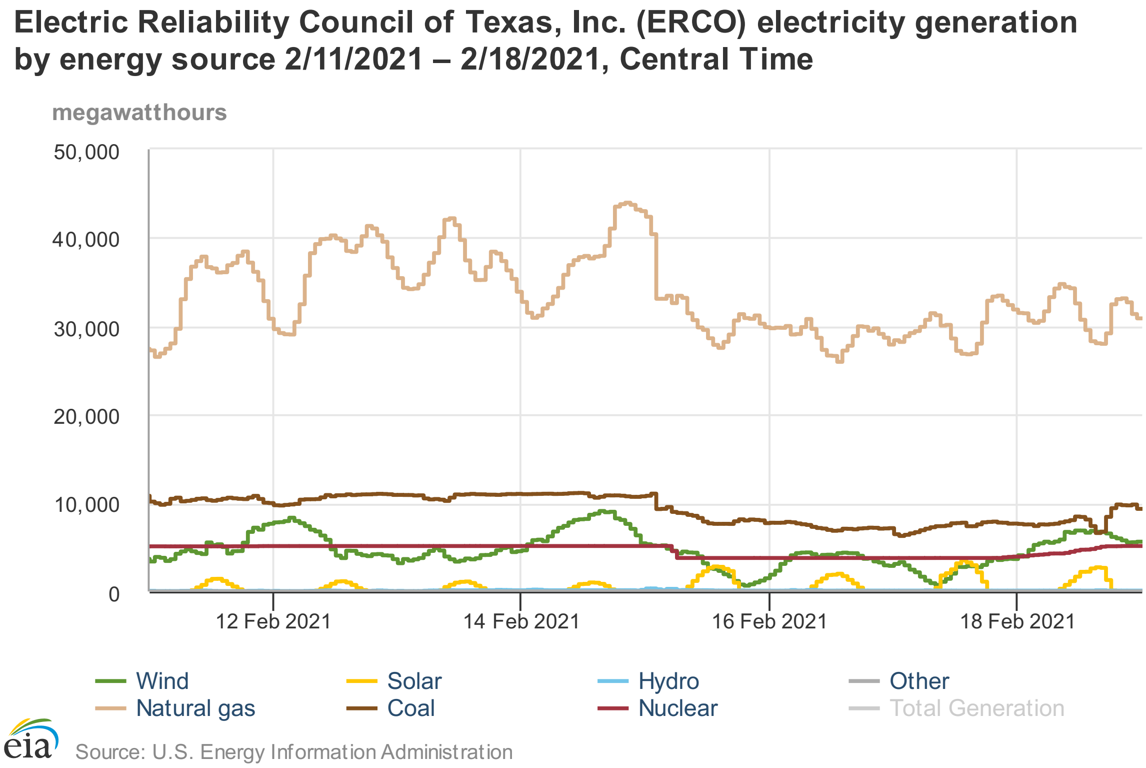


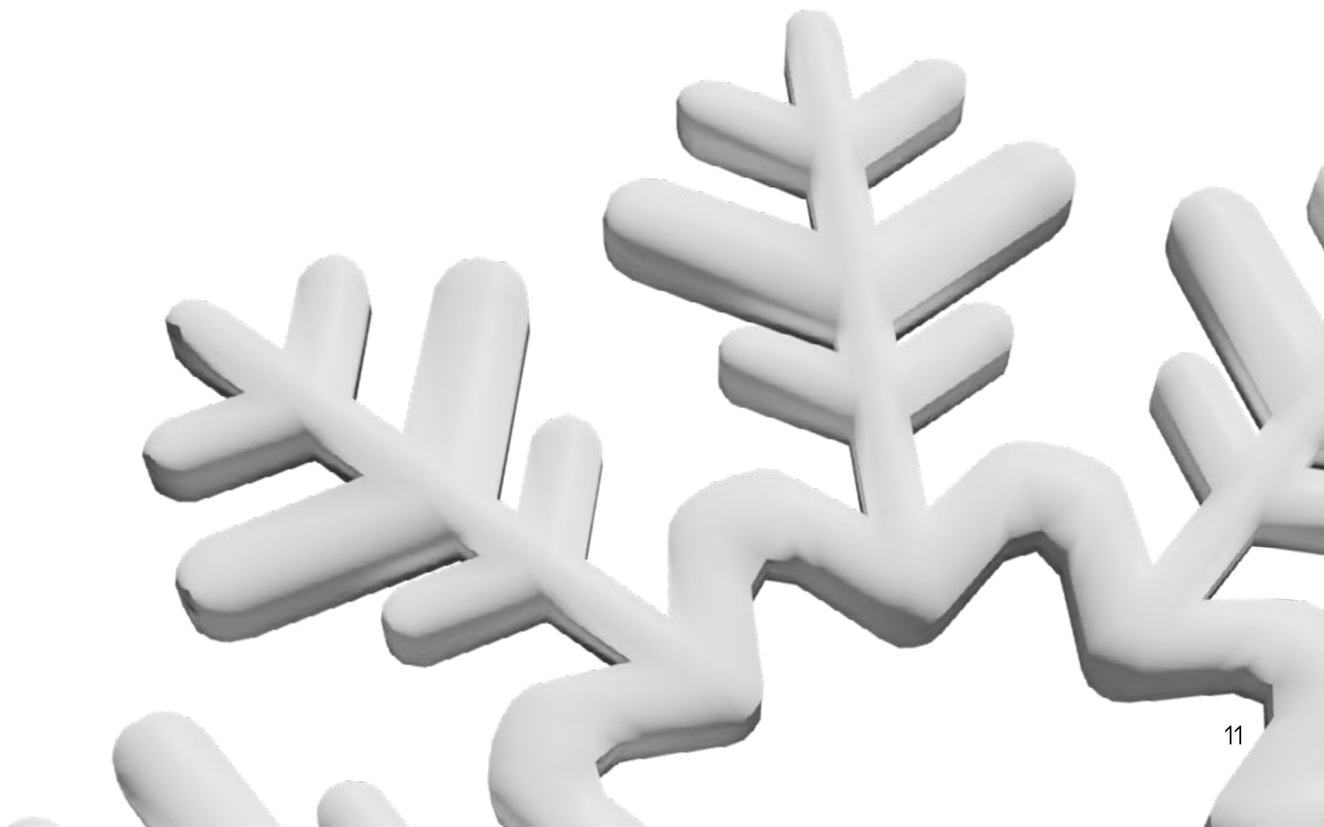
Figure 4: Electricity generation by energy source in ERCOT region, taken from EIA (2021).

froze, unable to draw the gas from the ground, and wind turbine blades iced over, unable to spin. Power generation from coal dropped by 40 per cent of expected generation, natural gas and wind dropped by around 50 per cent each, and even one of the four nuclear units went offline due to pipeline freezing (see Figure 4) (EIA, 2021; Everhart & Molnar, 2021). At its peak, 52,277 megawatts (MW), almost 50 per cent of Texas's total electricity generation capacity, was forced offline (ERCOT, 2021a). Electricity was also cut off from many natural gas facilities, which were unable to use the equipment and machinery required to pump the necessary natural gas that could be used to make more electricity (Douglas, 2021). The electricity demand was also much higher than expected. Around 60 per cent of Texans use electricity to heat their homes, which are not insulated well and are also designed for heat loss, not heat retention (Everhart & Molnar, 2021). The surge in electricity demand was at a winter record of 76,819 MW, around 7,000 MW above the expected 'extreme peak winter demand' (Everhart & Molnar, 2021; ERCOT, 2021a).

This was also particularly dangerous since the discrepancy between demand and supply could have forced an entire collapse of the grid. Equipment and infrastructure is designed to run on a frequency of 60 hertz (Hz), but if there is more demand for electricity than supply the frequency will drop, sometimes causing damage that must be physically repaired. The margin for error is tiny; the frequency of electricity flow on ERCOT's grid dropped below 59.4 Hz for more than four minutes, but if it had stayed that way for more than nine minutes the blackouts could have lasted for weeks (ERCOT, 2021a). To keep the frequency level, the demand-side had to be reduced as ERCOT ordered electricity providers to institute rolling blackouts, shutting off power periodically for parts of the system. Around 20,000 MW of demand was cut off from the system at one time (ERCOT, 2021a).

Insufficient communication

Even the blackouts themselves might not have been a problem if residents had the knowledge and resources to prepare. However, adequate announcements of the rolling blackouts were absent in this disaster. ERCOT, which manages the grid over much of Texas, does not have any enforcement authority over any electric generation facilities, transmission lines or substations (ERCOT, 2021a). Therefore, the most they could do was contact the power generators and tell them how much power they needed to cut and when. Though every locality has some form of emergency alert system, even local officials were at a loss as to where to find information, leaving residents with no way to plan for the loss of light and heat (Agnew, 2021a).



4. Root causes

Human-induced greenhouse gas emissions

Increased greenhouse gas (GHG) emissions in the atmosphere, such as carbon dioxide, methane and nitrous oxide, absorb and trap longwave radiation from the sun, increasing temperatures on Earth's surface and lower atmosphere. Most of this excess atmospheric heat ends up being absorbed by the oceans (EPA, 2021; IUCN, 2017). This warming of the oceans and atmosphere does not occur evenly across the globe. The Arctic region is warming nearly twice as fast as the rest of the planet, through Arctic amplification. Research is still ongoing on which climate forces are primarily driving this effect, but positive feedback loops in sea ice loss likely contribute significantly (Serreze & Francis, 2006). A warming ocean causes sea ice melt, which reduces the albedo effect – the process by which ice reflects solar energy into the atmosphere, allowing it instead to be absorbed by the darker ocean water (see Technical Report, Arctic Heatwave). Driven by increased GHGs, the increase in Arctic temperatures influence the meteorological patterns described in Section 3 (Stjern and others, 2019).

Insufficient disaster risk management

Though cold weather is unusual in Texas, it is not without precedent. Similar severe cold-weather events occurred in the south-west United States in 1983, 1989, 2003, 2006, 2008, 2010 and 2011 (FERC & NERC, 2011). The most severe events in 1989 and 2011 also caused power outages, primarily because the electrical infrastructure was designed for average southern climates, not for what had previously been relatively rare cold-weather extremes (Quanta Technologies, 2012). In 1989, the Public Utility Commission (PUC) of Texas recommended actions for power plants to withstand extreme cold. However, these actions were not made mandatory, which left winter readiness dependent on corporate choices. Facilities are not required to implement any minimum weatherization measures or conduct a review of cold-weather vulnerability. During the 2021 event, no entity, including the PUC or ERCOT, had rules to enforce minimum weatherization standards (ERCOT, 2021a). Though a post-event analysis is still being researched for the 2021 event, when the cold wave of 2011 hit more than two dozen power generators that failed in 1989 failed again, indicating that these facilities had not adequately prepared for cold weather after the 1989 event (FERC & NERC, 2011).

Not only were there inadequate regulations in place to prepare facilities before the storm, there were also myriad issues in communication and planning. For example, some natural gas facilities experienced forced power outages, meaning they could not run equipment to supply power generation facilities with the gas necessary for making electricity. As ERCOT ordered rolling outages, power companies inadvertently shut off electricity to some of these facilities because they were not on the lists of what is considered critical infrastructure, primarily because the natural gas companies had either failed to fill out a form or did not know the forms existed (Douglas, 2021). As mentioned previously, reports also suggest that the rolling blackouts were not well coordinated or communicated to the public. There was no statewide announcement for the rolling blackouts; the responsibility for emergency announcements was left to the local level, where officials were unsure of where to get information (Diamante, 2021). Although the Texas Division of Emergency Management (TDEM) can use the national Emergency Alert System to share important information and updates to residents directly via cell phones – such as 'boil water' notices or 'power outage' updates – it failed to provide any such alerts (Agnew, 2021a).

In combination with the lack of communication, individual residents were also largely unaware of how to deal with a cold wave of such magnitude. Since Texas residents rarely face cold weather, and rarer still without power, the cold wave caught many people unprepared. Many homes in colder climates keep a back-up heating source, extra generators and better clothing protection than could regularly be found in Texas. There were several automobile accidents, likely partly due to the inexperience of drivers to icy road conditions.

Insufficient national/international cooperation

When a power shortage occurs in other regions, local utilities can often buy extra power from adjoining areas. Texas, however, does not have the ability to import energy, as it is isolated from the rest of the United States. There are three power grids in the mainland United States: the Eastern Interconnection, the Western Interconnection and the ERCOT region in Texas. Texas is the only state on the mainland with its own electrical grid, which does not (effectively) cross state lines. This was done in response to the Federal Power Act in the 1930s, which allowed the federal government to regulate electric utility companies that engage in interstate commerce (Dyer, 2011). In an attempt to avoid this federal oversight from the Federal Energy Regulatory Commission (FERC), Texas's largest utilities cut their power line connections to other states and established their own form of electric cooperative (Dyer, 2011). This meant that when the power shortage occurred in Texas, they had a minimal ability to receive extra power from neighbouring states.

Prioritizing profits

In 1999, the Texas legislature passed Senate Bill 7, establishing that residents would no longer get their electricity from a local utility, but rather from a choice of retail electric providers, with the desired effect of lowered electricity prices through market competition (Scott, 2000; Krauss and others, 2021). This system is not unique to Texas and received industry, public and bi-partisan support (Krauss and others, 2021). A deregulated, market-based system of energy producers and retailers means they compete for customers, aiming to provide the most efficient service for the lowest price (Scott, 2000). This combination disincentivizes investment in specific weather protection and maintenance. Hot-weather protection is a must to maintain a consistent level of service, but disruptive cold weather in Texas happens too infrequently for companies to bother investing in preparing for its effects. An ERCOT-commissioned study wrote that of the natural gas infrastructure, the risk is a tradeoff between lost revenue from the loss of production versus the lost revenue from higher operating costs needed to implement winterization strategies (Black & Veatch, 2013).

ERCOT also has a thin margin of reserve capacities, at about 16 per cent, consistently lower than recommended targets for reliability (Mclaughlin, 2021; Comstock, 2019). Most places in the United States run on a ‘capacity market’, where the aim is to ensure reliable energy is supplied to the grid by paying generators for the capacity to meet forecasted demand, regardless of whether the power is actually provided, as long as the capacity to provide energy is there if it is needed (FERC & NERC, 2011). In contrast, Texas has an ‘energy-only’ market for electricity, where generators are paid for only the power they provide. This is meant to prevent consumers from paying for generation capacity that may never be used. However, some experts worry that with energy-only markets, low electricity prices may discourage generators from building new power plants since there is no guaranteed revenue as there is with a capacity market. Instead, regulators incentivize generation reliability with scarcity pricing, allowing generators to sell electricity at as much as $9,000 per megawatt-hour during peak demand. The allure of potential high prices is meant to incentivize generators to build new power plants and keep them operational (Bade, 2017). This system, however, can instead encourage scarcity so generators can increase revenue. During the February power shortage, one of the nuclear power plants shut down one of its two reactors due to pipeline freezing, yet the plant earned roughly $9 million in an hour when the scarcity pricing hit its peak. If the second reactor had kept operating, the plant would have been paid closer to $60,000 per hour (Mclaughlin, 2021). Additionally, scarcity pricing is not likely a long-term solution to incentivize greater reserve capacity as cheaper generation, such as from solar or wind, enters the market and keeps prices lower, and decreases the number of scarcity-pricing episodes (Bade, 2017).

5. Solutions

It is important to note that the issues the February 2021 cold wave presented are not isolated incidents. Extreme weather events are the leading cause of power outage events and are expected to increase along with other climate-related threats, such as sea level rise, flooding, wildfires and droughts (Allen-Dumas and others, 2019). Climate change combines with ageing grids and increasing electricity demand to strain and compromise vulnerable electrical infrastructure, with knock-on effects for other systems such as water and sanitation, transportation, communications and healthcare (Kenward & Raja, 2014; Nazir, 2021). While these solutions presented in this chapter will be focused on Texas specifically, these lessons may apply broadly to increase disaster preparedness and resilience in similar situations globally.

Winterize infrastructure

Much of the disaster can be attributed to the failures in the power system from the cold. The most obvious solution to this would be to implement winterization strategies for generation facilities. Techniques such as de-icing, heat tracing and insulation exist to keep energy systems operating in cold climates, such as Antarctica or Alaska. Therefore, the issue in Texas is to balance how much to invest in reducing the impact of these low-probability events (Fletcher & Jenkins, 2021). The cost of implementing changes to existing infrastructure can be high and impractical. The estimated cost to install federally-recommended equipment on all Texas's natural gas plants would be $95 million. For Texas's 13,000 wind turbines, blades with internal warming equipment can cost $400,000 per blade, and retrofitting existing blades is nearly impossible. This isn't always necessary, as applying coatings to the blades or sending de-icing drones is effective at a much lower cost (Golding and others, 2021).

Additionally, making sure new equipment can withstand the cold is far cheaper than modifying existing infrastructure. New natural gas plants or wind turbines could be outfitted according to climate change projections, recognizing that we can no longer use past events as a guide to determine the worst-case scenario (Fletcher & Jenkins, 2021). Although the cost of winterizing is high, it pales compared to the damage done by the cold wave. The economic damage associated with the power outages alone is estimated to cost $4.3 billion (Golding and others, 2021), added to the cost of other damages from the freezing temperatures, such as infrastructure damage to homes, roads and businesses, physical and mental health issues and loss of life. In deciding whether certain protections are worth the investment, one must consider not only the likelihood that an event will occur, but also the severity and extent of potential consequences (Fletcher & Jenkins, 2021).

Multiply, distribute and diversify generation

In addition to hardening existing infrastructure to cold weather, a system of distributed energy resources could help increase the resilience of the whole electrical system to several types of disasters, not just cold weather. Texas generates two-thirds of its electricity through natural gas power plants, the failures of which caused most of the power shortages during the cold wave (Fletcher & Jenkins, 2021). Diversifying types and locations of generation facilities can decrease the likelihood that one extreme event disrupts the whole system. Distributed generation and microgrids allow for power generation and transmission to be localized to small areas that can isolate themselves during severe weather events without the need for long transmission lines susceptible to failure (Panteli & Mancarella, 2015). ERCOT has committed to removing the barriers to distributed generation as part of its new roadmap to grid reliability (ERCOT, 2021b). Texas also consistently falls below target reserve margins and is the only grid in the mainland United States that does so (Comstock, 2019; Manzagol, 2020). This means that although Texas can produce as much as it usually needs, there is not much extra capacity to fall back on if extraordinary circumstances occur. Incentivizing the increase of available reserves through the adoption of a capacity market can also help implement planned redundancies that make the system more resilient (Iychettira, 2013). ERCOT has planned to almost double reserve margins by 2022 (ERCOT, 2020). Linking to one or both of the other grid systems could also increase the available power in times of shortage, therefore decreasing the likelihood of blackouts. More ambitiously, the United States could consider building a national grid, which could improve efficiency, distribute demand more evenly, better integrate more renewable energy, and reduce power prices (Roberts, 2018; Bloom and others, 2020).

Engage in energy efficiency

The previous fixes address the supply side of the power shortage, but there are other solutions that could help bring down future unexpected spikes in demand. Electricity can, and should, be considered as a ‘common-pool resource susceptible to the tragedy of the commons’, in that it can suffer from overexploitation with detrimental effects on the whole system (Pless & Fell, 2017). Incorporating active energy efficiency practices in Texas homes, businesses and industries would help conserve energy by cutting back on usage and reducing waste. Modifying infrastructure by increasing insulation in buildings, solar thermal heating and daylighting can help conserve generated heat, reducing heating loads during such a cold wave. Changing expectations of comfort and modifying behaviour can also decrease energy demand, such as turning off unnecessary electronics, adjusting thermostats and modifying clothing layers (Nesler, 2021). These measures should not only be considered in the face of such power shortages seen during the cold wave, but also during everyday life.

Improve governance, preparedness and response

The solutions presented above work most efficiently if they are supported by effective governance. Having regulations to ensure compliance with weather protection strategies and safety protocols during extreme events ensures that the systems are reliable. The flaws in the system were known after the similar events in 1989 and 2011, and recommendations for improvement had already been made (Quanta Technologies, 2012; FERC & NERC, 2011). Recommendations must be turned into imperatives where the cost of non-compliance is more than the cost of implementing changes. In the most recent Texas legislative session, the governor signed Texas Senate Bill 3, which creates a system by which winterization strategies suggested by a panel of experts must be implemented by critical generation facilities, with a minimum of $5,000 and a maximum of $1 million per violation if the strategies are not implemented (Paddie & Schwertner, 2021). However, this bill does not specify the length of time that operators have to implement those changes, nor does it specify how to determine the penalty amount; so much of this is still left to individual interpretation.

Improved communications are also necessary to coordinate and plan during such an event. This includes improving communication and mapping of critical infrastructure between responsible entities such as ERCOT, power generation facilities, and natural gas fields – as well as between the Government and its citizens. Texas Senate Bill 3 also aims to improve this, setting up the Texas Energy Reliability Council to ensure that the energy and electric industries meet high-priority human needs, and to enhance coordination and communication in the energy and electric industries (Paddie & Schwertner, 2021). The same bill creates a process to implement an alert when the power supply in Texas may be inadequate to meet demand, as well as a process to map the state's electricity supply chain in order to identify priorities for electricity service during extreme weather events (Paddie & Schwertner, 2021).

These are only some solutions that could have helped prevent or mitigate the effects of the February 2021 cold wave in Texas. Preparedness for such an event, such as having available early warning systems or setting up additional warming centres, is undoubtedly important. Emphasis should be put on investing in prevention, such as winterizing the electricity grid, diversifying energy sources, having back-up reserve systems in place and establishing better communication protocols before a disaster occurs – all done by using future demographic and climate change scenarios. Individuals can help here too: beyond reducing their own demand and preparing for disasters themselves, social demand for safety and security increases the likelihood that these preventative measures will be applied (Pescaroli & Alexander, 2016).

Acknowledgements

We’d like to thank Jonathan Hassel, Liliana Narvaez and Simone Sandholz for their support in this research.

References

Agnew, Duncan (2021a). As Texans Endured Days in the Dark, the State Failed to Deliver Vital Emergency Information. The Texas Tribune, 19 February. URL: www.texastribune.org/2021/02/19/texas-emergency-communication-power-outages/

Agnew, Duncan (2021b). Plumber Shortage and Supply Chain Issues are Delaying Storm Recovery Efforts in Texas. The Texas Tribune, 26 February. URL: www.texastribune.org/2021/02/26/texas-plumber-shortage-winter-storm/

Aldhous, Peter, and others (2021). The Texas Winter Storm and Power Outages Killed Hundreds More People than the State Says. Buzzfeed News, 26 May. URL: www.buzzfeednews.com/article/peteraldhous/texas-winter-storm-power-outage-death-toll

Allen-Dumas, Melissa, and others (2019). Extreme Weather and Climate Vulnerabilities of the Electric Grid: A Summary of Environmental Sensitivity Quantification Methods. ORNL/TM-2019/1252. Oak Ridge National Laboratory. URL: www.energy.gov/sites/prod/files/2019/09/f67/Oak%20Ridge%20National%20Laboratory%20EIS%20Response.pdf

Angulo, Sharay, and others (2021). Power Cuts Hit 4.7 Million Users in Northern Mexico After Cold Snap. Reuters, 15 February. URL: www.reuters.com/article/us-mexico-energy-idUSKBN2AF1G4

Bade, Gavin (2017). The Great Capacity Market Debate: Which Model Can Best Handle the Energy Transition? Utility Dive, 18 April. URL: www.utilitydive.com/news/the-great-capacity-market-debate-which-model-can-best-handle-the-energy-tr/440657/

Black & Veatch (2013). Long-Term Assessment of Natural Gas Infrastructure to Serve ELectric Generation Needs Within ERCOT. Black & Veatch. URL: www.ercot.com/content/committees/other/lts/keydocs/2013/BV_ERCOT_Gas_Study_Appendix_A.pdf

Bloom, Aaron, and others (2020). The Value of Increased HVDC Capacity Between Eastern and Western U.S. Grids: The Interconnections Seam Study. National Renewable Energy Laboratory. URL: www.nrel.gov/docs/fy21osti/76850.pdf

Burnett, John (2021). Texas 'Cold-Stun' of 2021 Was Largest Sea Turtle Rescue in History, Scientists Say. National Public Radio, 13 March. URL: www.npr.org/2021/03/13/976105783/texas-cold-stun-of-2021-was-largest-sea-turtle-rescue-in-history-scientists-say

CBSDFW Staff (2021). Bats, Birds Among Wildlife Harmed During Texas' Deep Freeze. CBS Dallas, 24 February. URL: https://dfw.cbslocal.com/2021/02/24/bats-birds-wildlife-harmed-texas-deep-freeze/

Chang, Alvin (2021). Why the Cold Weather Caused Huge Texas Blackouts – a Visual Explainer. The Guardian, 20 February. URL: www.theguardian.com/us-news/2021/feb/20/texas-power-grid-explainer-winter-weather

Chappell, Bill (2021). 8.7 Million People Under Boil Water Notices in Texas. National Public Radio, 22 February. URL: www.npr.org/sections/live-updates-winter-storms-2021/2021/02/22/970241763/monday-update-8-7-million-people-under-boil-water-notices-in-texas

Cohen, Judah, and others (2012). Arctic Warming, Increasing Snow Cover and Widespread Boreal Winter Cooling. In Environmental Research Letters, vol. 7. DOI: 10.1088/1748-9326/7/1/014007

Cohen, Judah, and others (2014). Recent Arctic Amplification and Extreme Mid-Latitude Weather. In Nature Geoscience, vol. 7. URL: www.nature.com/articles/ngeo2234

Cohen, Judah, and others (2020). Divergent Consensuses on Arctic Amplification Influence on Midlatitude Severe Winter Weather. In Nature Climate Change, vol. 10, No. 1, pp. 20–29. DOI: 10.1038/s41558-019-0662-y

Comstock, Owen (2019). NERC Report Highlights Potential Summer Electricity Issues for Texas and California. URL: www.eia.gov/todayinenergy/detail.php?id=39892

Copernicus Climate Change Service (C3S) (2021). Surface air temperature for February 2021. URL: https://climate.copernicus.eu/surface-air-temperature-february-2021

Cornish, Audie (2021). Texas Is Defined by Energy. How did the State's Power Grid Fail so Massively? 18 February. URL: www.npr.org/transcripts/967432968

Diamante, Reena (2021). Priority Bill Seeks to Establish Statewide Disaster Alert System After Texas Winter Crisis. Spectrum News 1, 09 March. URL: www.spectrumlocalnews.com/tx/san-antonio/news/2021/03/09/priority-bill-seeks-to-establish-statewide-disaster-alert-system-after-texas-winter-crisis

Dobbins, James, and Hiroko Tabuchi (2021). Texas Blackouts Hit Minority Neighborhoods Especially Hard. New York Times, 16 February. URL: www.nytimes.com/2021/02/16/climate/texas-blackout-storm-minorities.html

Douglas, Erin (2021). Paperwork Failures Worsened Texas Blackouts, Sparking Mid-Storm Scramble to Restore Critical Fuel Supply. The Texas Tribune, 18 March. URL: www.texastribune.org/2021/03/18/texas-winter-storm-blackouts-paperwork/

Dyer, R. A. 'Jake' (2011). The Story of ERCOT: The Grid Operator, Power Market & Prices Under Texas Electric Deregulation. The Texas Coalition for Affordable Power.

Energy Information Administration (EIA) (2021). Hourly Electric Grid Monitor. URL: https://www.eia.gov/electricity/gridmonitor/dashboard

Electric Reliability Council of Texas (ERCOT) (2020). ERCOT Report Shows Increasing Reserves in Coming Years: Accelerated Utility-Scale Solar Growth Boosts Reserve Margins. URL: www.ercot.com/news/releases/show/219347

Electric Reliability Council of Texas (2021a). Review of February 2021 Extreme Cold Weather Event. Texas Legislative Hearings: Senate Business and Commerce Committee, House Joint Committee on State Affairs and Energy Resources. Electric Reliability Council of Texas. URL: www.ercot.com/content/wcm/lists/226271/Texas_Legislature_Hearings_2-25-2021.pdf

Electric Reliability Council of Texas (2021b). Roadmap to Improving Grid Reliability. Electric Reliability Council of Texas. URL: www.ercot.com/content/wcm/lists/219694/ERCOT_Roadmap_Final_July_13_2021.pdf

Everhart, Keith, and Gergley Molnar (2021). Severe Power Cuts in Texas Highlight Energy Security Risks Related to Extreme Weather Events. URL: www.iea.org/commentaries/severe-power-cuts-in-texas-highlight-energy-security-risks-related-to-extreme-weather-events

Federal Energy Regulatory Commission (FERC), and North American Electric Reliability Corporation (NERC) (2011). Report on Outages and Curtailments During the Southwest Cold Weather Event of February 1–5, 2011. Federal Energy Regulatory Commission, North

American Electric Reliability Corporation. URL: www.ferc.gov/sites/default/files/2020-04/08-16-11-report.pdf

Fletcher, Sarah, and Jesse Jenkins (2021). As the Texas Power Crisis Shows, our Infrastructure is Vulnerable to Extreme Weather. MIT Technology Review, 06 March. URL: www.technologyreview.com/2021/03/06/1020389/texas-power-crisis-vulnerable-infrastructure-extreme-weather/

Francis, Jennifer A., and Stephen J. Vavrus (2015). Evidence for a Wavier Jet Stream in Response to Rapid Arctic Warming. In Environmental Research Letters, vol. 10, No. 1, p. 14005. DOI: 10.1088/1748-9326/10/1/014005

Golding, Garrett, and others (2021). Cost of Texas' 2021 Deep Freeze Justifies Weatherization. Dallas Fed Economics. Federal Reserve Bank of Dallas. URL: www.dallasfed.org/research/economics/2021/0415

Gordon, Scott (2021). Fort Worth Opens Emergency Homeless Shelters During Cold Spell. NBC, 09 February. URL: www.nbcdfw.com/news/local/fort-worth-opens-emergency-homeless-shelters-during-cold-spell/2547285/

Hixenbaugh, Mike, and Perla Trevizo (2021). Texans recovering from COVID-19 relied on machines to help them breathe. Then the power went out. The Texas Tribune, 9 March. URL: https://www.texastribune.org/2021/03/09/texas-covid-power-outages/

Ineson, Sarah, and Adam Scaife (2008). The Role of the Stratosphere in the European Climate Response to El Niño. In Nature Geoscience, vol. 2. DOI: 10.1038/NGEO381

Institute for Energy Research (IER) (2021). Extreme Cold and Lower Renewable Energy Output Spike Electricity Prices in Europe and Asia. URL: www.instituteforenergyresearch.org/international-issues/extreme-cold-and-lower-renewable-energy-output-spike-electricity-prices-in-europe-and-asia/

International Union for Conservation of Nature (IUCN) (2017). Ocean Warming. International Union for Conservation of Nature. URL: www.iucn.org/resources/issues-briefs/ocean-warming

Iychettira, Kaveri (2013). Orchestrating Investment in an Evolving Power Sector: An Analysis of Capacity Markets. Delft University of Technology. URL: https://repository.tudelft.nl/islandora/object/uuid%3Ab96aaa13-96fc-488b-be96-24c627c12be6

Kenward, Alyson, and Urooj Raja (2014). Blackout: Extreme Weather, Climate Change and Power Outages. Climate Central. URL: https://assets.climatecentral.org/pdfs/PowerOutages.pdf

Kim, Baek-Min, and others (2014). Weakening of the Stratospheric Polar Vortex by Arctic Sea-Ice Loss. In Nature Communications, vol. 5. DOI: 10.1038/ncomms5646

Krauss, Clifford, and others (2021). How Texas' Drive for Energy Independence set it up for Disaster: Texas has Refused to Join Interstate Electrical Grids and Railed against Energy Regulation. Now it's Having to Answer to Millions of Residents who were left Without Power in Last Week's Snowstorm. New York Times, 21 February. URL: www.nytimes.com/2021/02/21/us/texas-electricity-ercot-blackouts.html

Kretschmer, Marlene, and others (2018). More-Persistent Weak Stratospheric Polar Vortex States Linked to Cold Extremes. In Bulletin of the American Meteorological Society, vol. 99, No. 1, pp. 49–60. URL: https://journals.ametsoc.org/view/journals/bams/99/1/bams-d-16-0259.1.xml

Lindsey, Rebecca (2021). Understanding the Arctic Polar Vortex. URL: www.climate.gov/news-features/understanding-climate/understanding-arctic-polar-vortex

Manzagol, O. Nilay (2020). NERC Report Outlines How Pandemic Mitigation Could Affect Electric Reliability This Summer. URL: www.eia.gov/todayinenergy/detail.php?id=44296

Matthews, Christopher, and others (2021). Texas Freeze Triggers Global Plastics Shortage. The Wall Street Journal, 17 March. URL: www.wsj.com/articles/one-week-texas-freeze-seen-triggering-monthslong-plastics-shortage-11615973401

McDonnell, Tim (2021). Japan's Surging Electricity Prices are a Warning for Asian Countries. Quartz, 29 January. URL: https://qz.com/1965644/japans-surging-power-prices-are-a-warning-for-asian-countries/

McLaughlin, Tim (2021). Texas Power Grid Faces Summer Having Changed Little from February Freeze. Reuters, 24 June. URL: www.reuters.com/business/energy/texas-power-grid-faces-summer-having-changed-little-february-freeze-2021-06-24/

McSweeney, Robert (2019). Q&A: How Is Arctic Warming Linked to the 'Polar Vortex' and Other Extreme Weather? Carbon Brief, 31 January. URL: www.carbonbrief.org/qa-how-is-arctic-warming-linked-to-polar-vortext-other-extreme-weather

National Weather Service (2021). Valentine's Week Winter Outbreak 2021: Snow, Ice, & Record Cold. URL: www.weather.gov/hgx/2021ValentineStorm

Nazir, Hasna (2021). Lessons Learned from the February 2021 Texas Power Outage. Canadian Energy Research Institute. URL: https://ceri.ca/assets/files/Electricity%20Commodity%20Update_April%202021.pdf

Nesler, Clay (2021). Learning from Texas: How Active Efficiency Can Help Improve Grid Reliability and Resilience. URL: https://thecityfix.com/blog/learning-from-texas-how-active-efficiency-can-help-improve-grid-reliability-and-resilience/

Paddie, Chris, and Charles Schwertner (2021). Senate Bill 3: Relating to Preparing For, Preventing, and Responding to Weather Emergencies and Power Outages; Increasing the Amount of Administrative and Civil Penalties. TX SB3. Texas State Legislature. URL: https://legiscan.com/TX/sponsors/SB3/2021

Panteli, Mathaios, and Pierluigi Mancarella (2015). Influence of Extreme Weather and Climate Change on the Resilience of Power Systems: Impacts and Possible Mitigation Strategies. In Electric Power Systems Research, vol. 127, pp. 259–70. DOI: 10.1016/j.epsr.2015.06.012

Pescaroli, Gianluca, and David Alexander (2016). Critical Infrastructure, Panarchies and the Vulnerability Paths of Cascading Disasters. In Natural Hazards, vol. 82, pp. 175–92. URL: https://link.springer.com/content/pdf/10.1007/s11069-016-2186-3.pdf

Pless, Jacquelyn, and Harrison Fell (2017). Bribes, Bureaucracies, and Blackouts: Towards Understanding How Corruption at the Firm Level Impacts Electricity Reliability. In Resource and Energy Economics, vol. 47, pp. 36–55. URL: www.sciencedirect.com/science/article/abs/pii/S0928765516300069

Proffer, Erica (2021). The Cost of Electricity | Prices May Jump Around October. KVUE, 05 April. URL: www.kvue.com/article/news/investigations/defenders/texas-electricity-prices-rise-october-storm-aftermath/269-29839549-db0c-4005-80fa-601cabcb562d

Quanta Technologies, LLC (2012). Report on Extreme Weather Preparedness Best Practices. Quanta Technologies, LLC. URL: www.lrl.texas.gov/scanned/SIRSI/PUC_report_39646.pdf

Reiley, Laura (2021). Texas Freeze Killed Winter Produce, with Some Food Prices Expected to Spike. The Washington Post, 26 February. URL: www.washingtonpost.com/business/2021/02/26/texas-storm-produce-shortage/

Reta, Mikyla, and Elise Gout (2021). Advancing Equity Through Grid Modernization. URL: www.americanprogress.org/issues/green/news/2021/04/28/498839/advancing-equity-grid-modernization/

Riley, Carol (2021). Boil Water Notice – Winter Weather Update 2–16–2021. URL: www.beaumonttexas.gov/boil-water-notice-winter-weather-update-2-16-2021/

Roberts, David (2018). We've Been Talking About a National Grid for Years. It Might Be Time to Do It. Vox, 03 August. URL: www.vox.com/energy-and-environment/2018/8/3/17638246/national-energy-grid-renewables-transmission

Salam, Erum, and others (2021). Anger Mounts over Texas Power Blackouts as Icy Cold Maintains its Grip. The Guardian, 17 February. URL: www.theguardian.com/us-news/2021/feb/17/texas-power-blackout-weather-cold

Samuels, Alex (2021). Nearly 12 Million Texans Now Face Water Disruptions. The State Needs Residents to Stop Dripping Taps. The Texas Tribune, 17 February. URL: www.texastribune.org/2021/02/17/texas-water-boil-notices/

Scott, Natalie (2000). Implementation of Senate Bill 7: The Implication of Stranded Cost Recovery for Residential Electric Utility Consumers. In Baylor Law Review, vol. 52, No. 237. URL: www.heinonline.org/HOL/LandingPage?handle=hein.journals/baylr52&div=14&id=&page=

Serreze, Mark, and Jennifer Francis (2006). The Arctic Amplification Debate. In Climatic Change, vol. 76, pp. 241–64. DOI: 10.1007/s10584-005-9017-y

Stjern, Camilla, and others (2019). Arctic Amplification Response to Individual Climate Drivers. In Journal of Geophysical Research: Atmospheres, vol. 124, pp. 6698–717. DOI: 10.1029/2018JD029726

Storrow, Benjamin (2021). Why the Deep Freeze Caused Texas to Lose Power. Scientific American, 18 February. URL: www.scientificamerican.com/article/why-the-deep-freeze-caused-texas-to-lose-power/

Texas Health and Human Services (2021). Winter Storm-Related Deaths. URL: www.dshs.state.tx.us/news/updates.shtm#wn

Texas Parks & Wildlife (TPWD) (2021). At Least 3.8 Million Fish Killed by Winter Weather on Texas Coast. URL: www.tpwd.texas.gov/newsmedia/releases/?req=20210310c

Trevizo, Perla, and others (2021). Texas Enabled the Worst Carbon Monoxide Poisoning Catastrophe in Recent U.S. History. ProPublica, 29 April. URL: https://www.propublica.org/article/texas-carbon-monoxide-poisoning

United States Environmental Protection Agency (EPA) (2021). Climate Change Indicators: Oceans. US EPA. URL: www.epa.gov/climate-indicators/oceans

Uteuova, Aliya (2021). Texas Facilities Released 3.5m Pounds of Extra Pollutants During

Winter Storm: Emissions Releases Affected Communities that are already Disproportionately Exposed to Pollution. The Guardian, 26 February. URL: www.theguardian.com/us-news/2021/feb/26/texas-emissions-pollutants-winter-storm

Verma, Swati (2021). Texas Power Prices Spike as Deadly Cold Wave Overwhelms Grid. Reuters, 17 February. URL: www.reuters.com/article/us-usa-texas-power-prices-idUSKBN2AH0U0

Villarreal, Mireya (2021). All 254 Texas Counties Under Winter Storm Warning as Arctic Blast Heads East. CBS News, 14 February. URL: www.cbsnews.com/news/texas-snow-winter-storm-warning-arctic-blast-2021-02-14/

Waller, Allyson (2021). What a Texas Plumber Faces Now: A State Full of Burst Pipes. The New York Times, 21 February. URL: www.nytimes.com/2021/02/21/us/texas-plumber-frozen-pipes.html

Photo Credits

© iStock/PorqueNoStudios, cover, p. 16
© shutterstock/ Vic Hinterlang, cover, p. 19

Design: TEMPLO

UNITED NATIONS
UNIVERSITY
UNU-EHS