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2021 Texas Electricity Black-out Crisis: Root-cause Analysis and Recommendations

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ABSTRACT

In this paper, we discuss the structure of the U.S power grid and various sources of electricity generation and potential vulnerabilities that the grid can face. We also discuss the role of Electric Reliability Council of Texas (ERCOT), the organization that is primarily responsible for managing electricity in Texas, and the sequence of events that led to the power crisis in Texas during February 2021. Finally, we do a root cause analysis for the power crisis and provide recommendations to minimize the impact of these type events on the Texas grid in the future.

The paper is organized as follows: In section one, we discuss the energy sources, how the electricity grid in America works, and some potential vulnerabilities of the power grid. Section two is entirely devoted to an explanation of how ERCOT works in Texas. In section three we discuss the events that took place in February 2021 that led to blackout. In section four we discuss why did the events unfold and break down the causes. We also discuss advantages and disadvantages of the current structural elements of Texas electricity industry. In section five we offer some recommendations to remedy the situation.

1. Understanding the Electricity Grid

The electric grid is fundamentally a network that 1) connects the suppliers of electric power to consumers of electricity and 2) needs to balance the supply with the demand all the time. There are different types of energy generation sources, and they all function in different ways and vary in efficiency and advantages to achieve the objective of generating electricity. The electricity generating source, a power plant, could use various fuel sources as input to generate electricity. These fuel sources can be non-renewable like coal, oil and natural gas, water which are conventionally used. There are also other renewable sources like solar or wind farms, which are renewable, and they make up a smaller, but increasing percentage of energy production. By using renewable or nonrenewable fuel sources electrical energy is generated in the power plant and then sent out through power lines to substations and reach homes, factories, offices, and businesses. It is important to keep in mind that if the load (demand) exceeds the supply and if the demand is not curtailed by imposing a blackout, then there is a potential for catastrophic generator equipment failure to happen. For more comprehensive discussion about the industry, we refer the reader to the U.S department of energy website. [1] The U.S electrical industry being the birthplace of commercial electricity generation has a rich history. [2]

1.1 Power grid in U.S

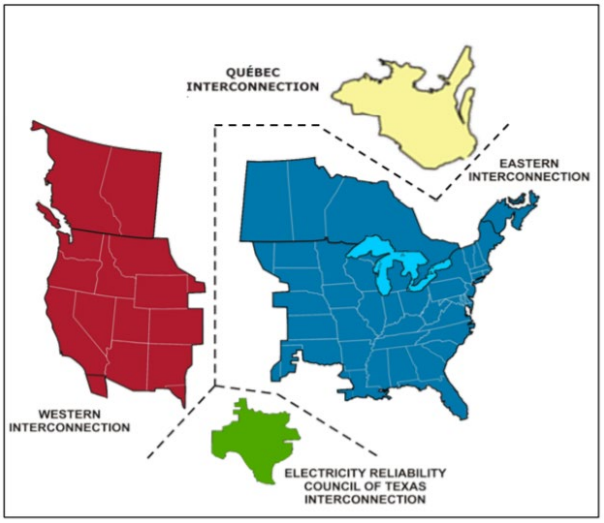
The power grid in America is split into three sectors: The Eastern interconnect, the Western interconnect, and Texas, which is called the ERCOT grid. Texas is not connected to any other states to depend on support when an emergency occurs. ERCOT covers 75% of land area of Texas, and essentially has a monopoly on power distribution for most of

the state excluding the El Paso area in the west, Longview, Marshall and Texarkana in Northeast Texas and Beaumont, Port Arthur and The Woodlands in Southeast Texas. [3]

1.2 Power Sector Vulnerabilities

There are several vulnerabilities that could lead to power grid failure whereby supply can't meet the demand. The most obvious one is extreme weather condition, such as heavy snow or extreme heat which could increase the demand for electricity and or disrupt the generation of electricity. Natural disasters like tornadoes and hurricanes could also cause issues with the grid and the flow of electricity. It's also possible for the grid to be shut off by cyberterrorists. So far there has not been any case of this happening in America. Manmade accidents also can cause damage and black-outs, say if someone made an operational error at the power plant, or with the grid. In other cases, the company itself could decide to implement blackouts in order not to lose money. Theft and physical attacks are also capable of disrupting the grid. [4]

2. How ERCOT works



ERCOT, the **E**lectric **R**eliability **C**ouncil **O**f **T**exas, is one of three interconnections in the US with more than 24 million consumers, 46,000 miles and more than 600+ generation units. ERCOT gets its policy direction from the Public Utility Commission of Texas (PUCT) which is responsible to the Texas legislature. ERCOT covers 90% of the state population but some areas within Texas like El Paso and Beaumont are independent of the ERCOT network. [5]

ERCOT provides a central control point where electricity generation is dispatched out onto the grid where the generation (supply of electricity) and load (demand for electricity) has to be balanced at all times. It is helpful to understand ERCOT using Air Traffic Control operation as an example. Air Traffic Control doesn't own planes or airports or runways but ensures that everything is flowing efficiently so that passengers reach their destinations on time. Similarly, ERCOT doesn't own the generators or the transmission grid but ensures the flow of electricity and keeps the electricity markets running so that consumers get electricity when they need it.

ERCOT has multiple responsibilities which are all interconnected with each other. It has the responsibility of managing the operational flow of electricity from the generating sources to consuming sources. This involves monitoring of generation, transmission, and the forecast demand. ERCOT also runs a wholesale marketplace which is just like a stock exchange where the wholesale electricity price when various generators compete to sell their energy supply into the grid to meet the demand. ERCOT provides the right technology and financial and accounting services to the wholesale market and ensures that transactions are handled accurately and efficiently. It has the responsibility to manage the financial side of the energy market. This involves collecting money from users of electricity and paying resources that create electricity. Managing reliability of the network is another important responsibility. This involves design of new tools - Alerts and forecasting of weather, power generation and power consumption and also to prepare for expected and unexpected conditions.

Other activities of ERCOT are to manage power generation sources that are closer to the consumer - these sources are called distributed generation. An example of distributed generation is rooftop solar panels. ERCOT also manages the transmission planning process but does not own transmission assets. Transmission service providers

build, own, and maintain the transmission equipment. Eventually consumers pay for using these transmission lines through monthly fees. ERCOT activities are managed from a control room in Austin, Texas.

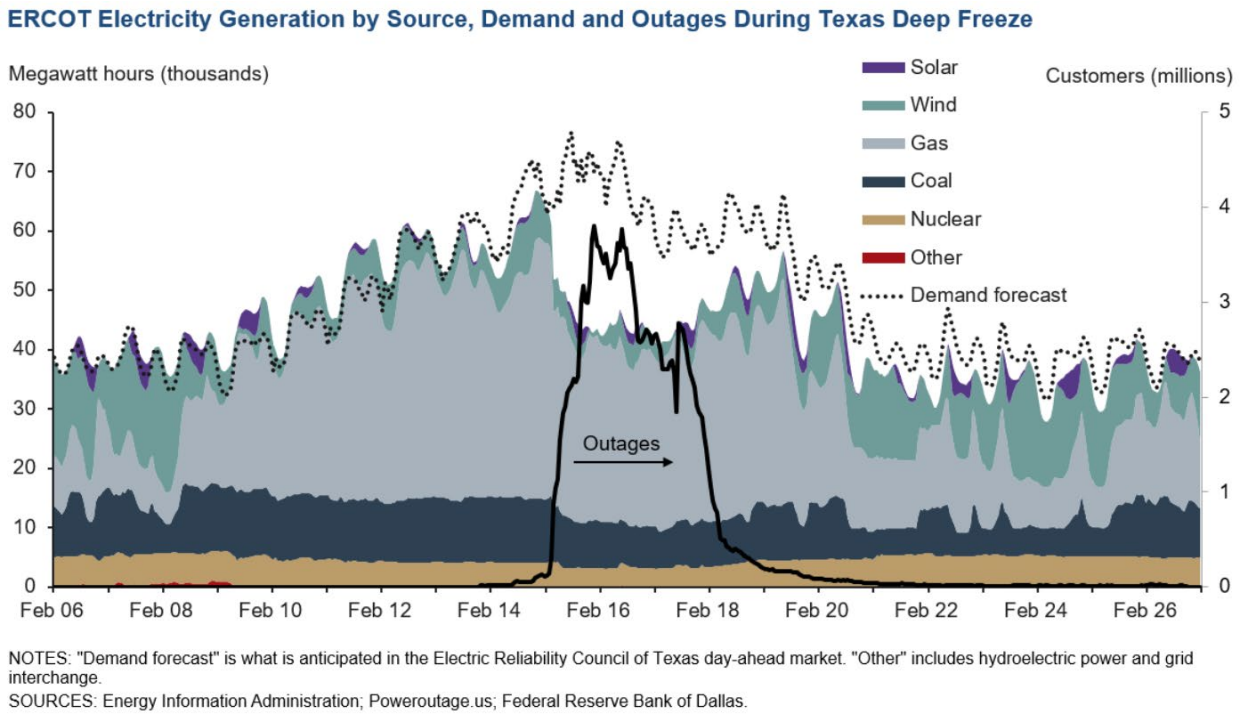
ERCOT not only manages the supply side but also has a program to manage the demand through a demand response program. [6] The objective of this program is to try to lower the demand for electricity when grid conditions are tight. Industrial and commercial customers voluntarily agree upfront that ERCOT can reduce their load when ERCOT finds it necessary to do so. Consumers who volunteer to participate in this program will have their power supply reduced or stopped in response to higher demand on the grid relative to the supply of available electricity.

ERCOT grid is an island network that covers only the state of Texas. It is not connected to other interconnections and therefore can't buy or sell electricity from outside. This is unlike other two interconnections in the U.S that cover multiple states. It has been intentionally structured to be an isolated network to not to come under federal oversight by the Federal Energy Regulation Commission (FERC) by avoiding interstate commerce of buying or selling electricity to other states.

3. Texas Winter storm of 2021

In February 2021 a winter storm hit Texas hard. Temperatures dropped to low levels, causing pipes to freeze. Five inches of snow fell in north/central Texas, making it hard for planes to land and for shipments to be transported. Storm warnings were issued across the state and were shown on TV on Feb 14. The temperature was below freezing from 5pm on Feb 9 to 2pm on Feb 13, and this again happened for 139 hours starting on Feb 13 and ending on Feb 19. A flaw in the Texas Power grid left millions freezing in this unprecedented and historical freeze. The storm impacted nearly every energy source, from natural gas to wind farms. ERCOT, failed to supply energy in the cold, as power plants shut down one by one, and had to implement rolling blackouts. The power source that ERCOT uses the most, natural gas, was hit the hardest, causing an even higher crisis. Due to lack of power, several people died from hypothermia, or carbon monoxide poisoning from trying to heat their homes. [7]

The following graph shows the time series of supply of energy and the demand during February 2021 and how many people got affected (on the second axis to the right). [8]



NOTES: "Demand forecast" is what is anticipated in the Electric Reliability Council of Texas day-ahead market. "Other" includes hydroelectric power and grid interchange.
SOURCES: Energy Information Administration; Poweroutage.us; Federal Reserve Bank of Dallas.

The winter front that moved across Texas began on a Sunday night, causing temperatures to lower rapidly and beyond what was prepared for. This caused people to use the heat for longer periods of time, resulting in the highest recorded winter demand: 69 gigawatts. ERCOT's main objective was to keep supply and demand in line, otherwise, the imbalance could permanently damage power generation equipment that would be devastating and take long time to recover.

Power plants went offline rapidly due to frozen parts of the supply chain, mostly. Unfortunately, this didn't help the demand. At 1:25 AM on Monday, ERCOT called on providers to start rolling blackouts. A nuclear powerplant near the Gulf of Mexico shut down around 5:30 AM due to water supply freeze, which caused the pumps to fail. These pumps made water into steam to generate electricity. More plants also went offline, and natural gas pipelines froze. Wind turbines that were made for heat froze. ERCOT called for more outages, leaving millions without power. The rolling blackouts started to fail as they were not enough, and a total blackout spread. [9]

Before this meltdown, Texas' grid was highly regarded. In early 2000s, it has implemented a deregulated marketplace so that the cost of power can be competitively determined among producers which would benefit the consumers. However, the shut-down of the power plants spelled disaster for many businesses, which were left without power and ways to preserve their products. In Texas the equipment is built to last through the summer, not extreme winter conditions as these conditions are considered rare. In a world that is impacted by climate change, all power markets now face the questions of how to prepare for extreme, unpredictable events.

3.1 How did it happen?

Texas powerplants were not fully prepared for the sheer magnitude of the storm that swept Texas. This caused several power plants to become unavailable to ERCOT, since the snow and ice had put them out of commission. Natural gas, coal, nuclear, and wind power were all heavily affected by the harsh weather, with natural gas, the main provider, being hit the hardest out of all of them. [8]

State's power plants were not prepared for the frigid weather conditions and went offline. The grid lost five times more power from natural gas than they did wind power. Demand for Natural Gas also spiked, which led to issues with not being able to supply since the roads were snowed in. 80% (67 gigawatts) of the grid's capacity comes from Natural Gas, compared to the 7% (6 gigawatts) that wind energy provides. Many coal plants and one of the four nuclear plants were also shut down due to the harsh weather conditions. To avoid any long-term damage to the plants, the grid operator implemented blackouts. It was not in financial interest for these companies to keep on providing electricity to their customers, since the market was not prepared for a storm. This indicates a flaw in policy and the system that is in place, which further means that there needs to be reform in the system.

Nearly half of Texas electricity was generated by natural gas-fired power plants in 2019. Coal-fired plants and wind power each generated about 20 percent. The state's two nuclear power plants — the South Texas Project near Bay City and Comanche Peak near Glen Rose — supplied a total of 11 percent. Solar, hydroelectric and biomass resources provided most of the remainder. [10] Some critics of the state's system say having many Texas energy oversight bodies, which includes other agencies regulating oil and natural gas, resulted in inaction.

4. Why did the blackout happen?

Since Texas is a state that has abundant supply of natural gas, when natural gas supply got hit the hardest out of all energy sources, a large amount of the state lost power. Blame was placed largely on ERCOT and the Texas legislature. There were warnings of the storm even before it hit Texas that were largely ignored causing necessary precautions to not be implemented.

The demand for electricity had peaked at 69,000 megawatts and crossed what was estimated for the worst-case scenario, which was predicted to be 67,000 megawatts, and it wasn't profitable or feasible for some operators to

continue to provide power as their supply chains were disrupted by the weather. The result was that millions were stuck in freezing homes due to the power plants closing. Unfortunately, Texas regulations don't reprimand companies for not providing power in times of high demand as they believe that a higher price will automatically entice power generators to supply more power. [11] It would have caused more consequences for the companies operationally and financially if they had continued to provide power rather than shut down due to equipment freezing in the cold.

Potentially, they could have bought power from other states, but ERCOT had decided to be structurally isolated to avoid being controlled federally. It could have also been avoided if power plants had been constructed like northern power plants, which are designed to work in cold weather, however, since storms like this were widely accepted to be a rare event (once in hundred years), energy companies felt no need to prepare for it. Unfortunately, the weather swings have been extreme because of climate change, and storms like what happened in February 2021 and in February 2011 may become more common.

4.1 Why is it important?

The February 2021 "snowmageddon" affected 4.4 million people in the state of Texas, 200 of which died due to trying to heat their homes, carbon monoxide poisoning, and hypothermia. The cold weather caused several pipe bursts and property damage which indicates that Texas was not prepared for the weather that has been increasing in extremity over the years due to climate change.

A similar event occurred a decade ago and knocked out 200 power plants. Many of them were coal plants, which was and is one of the main sources of energy for Texas. ERCOT had called for rolling blackouts then as well. Again, in January 2014, ERCOT called for blackouts again when there was another cold snap. Neither of these incidents lasted as long as the 2021 snowmageddon (lasting eight hours and four hours respectively), but they are indicative of a larger root problem that needs to be fixed.

4.2 Pros and Cons of Texas Electricity Structure

We list various characteristics of the Texas ERCOT program below and discuss their relative advantages and disadvantages.

	FOR	AGAINST
Texas ERCOT grid is one large stand-alone grid that covers 90% of the state of Texas	By limiting the grid to the state, Federal bureaucracy and oversight is avoided leading to quicker and efficient solutions to be implemented by ERCOT	ERCOT can't depend upon external energy source during emergencies. Also, ERCOT can't sell excess electricity outside of Texas especially when Texas is becoming a leading producer of renewable energy.
Texas has lot of different energy sources to generate electricity	There is good diversification of energy sources	There could be multiple reasons for failures.
Texas leads in wind energy	This is environmentally friendly renewable resource	Winds are not predictable source of power
Texas has solar farms to generate electric power	This is environmentally friendly renewable resource	Weather could make solar energy unpredictable
Texas has abundant source of natural gas	This energy source generates 46% of Texas electricity	Natural gas is not a renewable resource. Also, supply chain infrastructure depends upon electricity to move natural gas to generators

Texas has a wholesale power market where producers compete	Market mechanism usually ensures that the prices are competitive.	Spot markets don't ensure future power availability to meet increase in demand due to weather etc.
Natural gas is regulated by the railroad commission of Texas while power is regulated by Public Utility Commission of Texas	Each regulator can make quicker decisions.	One regulator could see the problems in a holistic fashion and address the trade-off quickly better than two regulators.
Texas is a high temperature state	Usually, the peak loads happen in summer due to AC running at homes, but solar power is also available during summer helping to meet the increased demand.	Winter needs and need for weatherization of equipment has been underestimated as winters are usually milder compared to the rest of the nation.
ERCOT allows voluntary participation of consumers of electricity to curb their demand as part of the emergency demand response program	By ensuring that volunteers cut their demand, the supply of electricity can be managed to meet demand without any forced blackouts.	No emergency demand response customer should be part of ERCOT's critical load registry
Competitive marketplace for power generation	This is usually good for the consumer as generators are forced to become efficient	Generators have no incentive to voluntarily spend money for weatherization to prepare for events they deem are improbable to happen.

4.3 Root Cause Analysis (Five Whys)

- Why did 200 people die?
  - There was a lack of heat within homes and medical equipment failed without electricity.
    - ERCOT could no longer keep up with demand for power and resorted to rolling blackouts.
- The price of electricity increased dramatically for some citizens who had an electricity contract that was variable.
  - The clearing price of electricity dramatically increased to meet a demand surge as supply meets the higher demand only at a higher price and customers on variable contract must pay the higher prices. Customers should go on fixed contract (or) agree to get their power cut.
- Generators have no incentive to deliver power when they have structural impediments like frozen pipes.
  - Germany has reserve national power generator that's run by the government on an ad hoc basis.
- Millions of Texans were left in the dark. Why were there blackouts?
  - To conserve power and prevent any permanent damage to the grid.
    - We don't have excess sources of power generation to bring them online.
  - We have a lack of power storage as the technology is not mature.
    - As of 2016, utility-scale electric storage projects represented less than 2 percent of total generating capacity in the United States.
      - The vast majority of this capacity is pumped-hydro storage, which makes up 22 GW, or 95 percent of electric capacity and batteries are the second largest category of electric storage technology with 560 MW of nameplate capacity in 2016.
    - In 2013, California adopted targets for utilities to procure 1,325 MW of energy storage capacity by 2024 and subsequently increased the capacity requirement target and reduced timelines.

- Other states, including Massachusetts and New York have also created targets for energy storage procurement

- Too much demand due to unexpected cold weather.
  - Climate change led to colder temperatures.
    - Greenhouse gasses heated the atmosphere, making it trap sun rays which heated it further.
      - Switch main power source to something more environmentally friendly
- Too much power used in a short time
    - Under-forecasted demand: Models did not capture extreme events (Are there better forecasting models that predict extreme events)
- Too little supply of power
  - The Texas network is an island and couldn't buy from outside
    - ERCOT did not want to be federally regulated
      - They should consider a policy change.
      - They might benefit from buying (and selling) emergency power.
      - El Paso has left ERCOT and gotten power from other parts of the country
  - Some power plants were on scheduled maintenance when crisis happened were not operational.
  - The price of electricity went up dramatically (to meet the demand), and the average citizen could not pay.
    - Not all nuclear power plants were operational; One out of the four nuclear plants were down (10.8% of total energy)
      - Building new nuclear plants are highly capital intensive and takes a long time to get approval and build as they are highly regulated
      - Environmental concerns about nuclear waste
  - A new natrium nuclear plant and has replaced a coal plant in Wyoming. [12]
  - Cold weather shut down solar farms. (1.1% of total energy)
    - Solar panels not weatherized (exploration needed to better weatherize a solar panel)
      - No incentive/regulation to weatherize
  - Cold weather shut down wind farms. (20% of total energy)
    - Wind turbines were frozen over.
      - No incentive nor mandate to weatherize
        - Minnesota wind turbines were weatherized (so were Iowa's) and successfully work in cold weather.
  - Cold weather shut down natural gas power generators. (47.4% of total energy)
    - Compressors that provide power to the generators were down.
      - The plants participated in the voluntary emergency response service program whereby they agreed to have their electricity cut in case of emergency (67 plants were enrolled, 5 identified themselves as critical infrastructure).
      - ERCOT should reevaluate who should not participate in the emergency program.
      - Get batteries to run compressors when power fails.
    - Plants were not built to withstand cold weather.
      - Texas is mostly hot all year round. Cold weather was not common.

- There is no legislature to force energy companies to invest as they don't have an economic incentive on their own to spend.

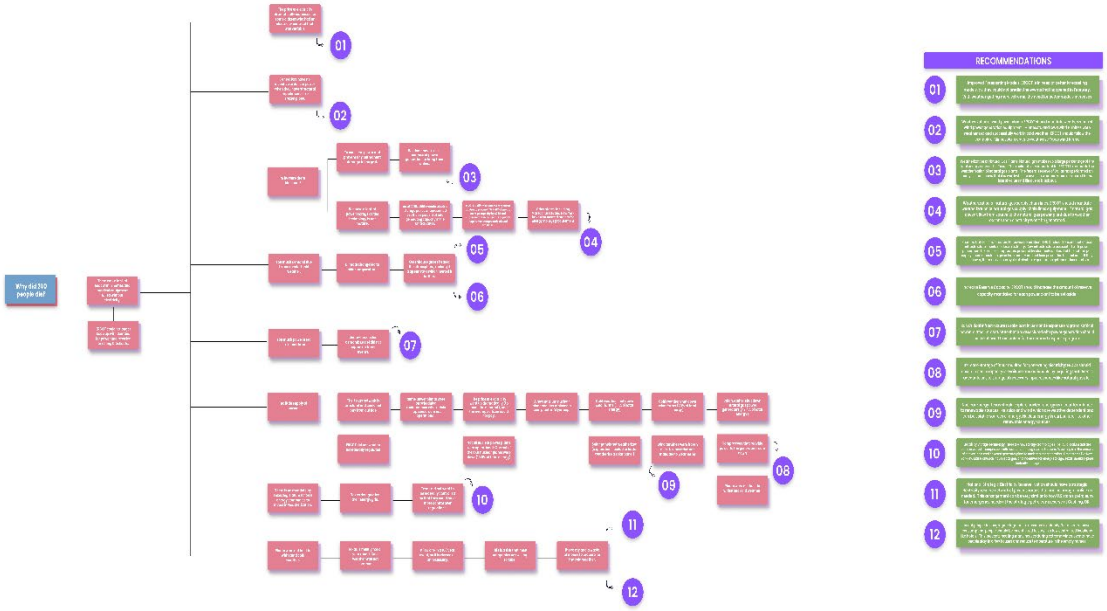
- There is no mandate by Texas legislature to force energy companies to invest in weatherization.
  - Texas deregulated their energy grid.
    - Texas did not want to be federally controlled so that they could have more control over regulations.
- Plants were not built to withstand cold weather.
  - Texas is mostly hot all year round. Cold weather was not common.
    - It is a one in a 100-year event, so it is viewed as unnecessary.
      - This is a risk that most companies are willing to take.
        - It wouldn't be profitable.
          - It's costly and a waste of money to prepare for the cold weather.
            - Companies don't face economic consequences if the grid goes offline in a storm, but they do face consequences if they promise to deliver and can't live up to that.
            - For this reason, if the equipment for the cold fails, it only hits them harder than it did originally to shut down and not provide power.

5. Recommendations

- Improved Forecasting Models: ERCOT needs better forecasting models, as they could not predict the events that happened in February. With weather getting more extreme, the need for better models increases.
- Weatherization of wind power plants: ERCOT should mandate weatherization of wind power generation equipment. Minnesota and Iowa wind turbines were weatherized and successfully work in cold weather. ERCOT should follow the example of Minnesota to weatherize Texas wind farms.
- Weatherization of Natural Gas Plants: Natural gas makes up a large percentage of the total energy sources for Texas. This makes it very important for ERCOT to mandate the weatherization of natural gas plants. The federal reserve of Dallas has performed an analysis that shows that it is worthwhile to invest in weatherization compared to the loss of value and life due to black out. [8] 20.3% of Texas energy is from coal. Increasing coal power plants will be counterproductive as they contribute to climate change leading to further extreme weather events.
- Weatherization of natural gas supply chain lines: ERCOT should mandate weatherization of natural gas supply chain lines equipment. If natural gas doesn't flow from source to the natural gas power plant due to weather reasons, then electricity won't be generated.
- Prioritize Critical Infrastructure for power generation: ERCOT should ensure that critical infrastructure should not lose electricity. Any infrastructure associated with power generation (example: compressors powered by electricity and part of the natural gas supply chain) should be given high priority and not lose power due to blackouts. If they lose power, there is a vicious cycle of electricity generation getting reduced further. Germany has a reserve national power generator that's run by the government for reserves.
- Increase Reserve Capacity: ERCOT should increase the amount of reserve capacity mandated for each power plant to be set aside.
- Ban Critical Infrastructure to take part in Demand Response Program: Critical power related infrastructure that are associated with power generation should not be allowed to volunteer for the demand response program. [13]
- Increase Storage of input required for generating electricity: ERCOT should ensure reserve capacity is available and actionable by requiring that there is adequate onsite storage of necessary input resources like natural gas etc.

- Nuclear Energy: Texas should explore nuclear energy as a counterbalance to renewable sources like solar and wind which are weather dependent and can be volatile sources of energy. Nuclear energy is carbon free like other renewable energy sources. [12]
- Electricity Storage Technology: There are new storage technologies like liquid sodium that are being explored in conjunction with nuclear technology called Natrium. Wyoming is in the process of converting a coal powered generator plant to nuclear plant generation. Other states like New York and Massachusetts have set targets and incentives for energy storage. Texas should explore electricity storage.
- National Strategic Electricity Reserve: Nation should have a strategic electricity reserve network of power sources that can be brought online as needed. This arrangement can be very similar to how U.S stores petroleum for emergency needs at the strategic petroleum reserve at Cushing, OK. [14]
- Incent people to congregate together to conserve electricity: To minimize power consumption, people should be incentivized to stay in a few centralized locations like hotels. This prevents heating many houses during extreme winter events, have people stay in a few houses and reduce temperature in the empty homes.

6. Causal Chart



7. Summary

In this paper we discussed the impact that the extreme weather event of a winter storm of February 2021 had on Texas electricity supply. Texas has a diversified set of energy generation sources, a unique grid network, a market structure and a governance structure that is relatively isolated from the rest of the nation's network. We discussed the root cause analysis about the reasons for power failure. We have summarized some recommendations such as need to mandate the weatherization of electricity generation equipment and natural gas supply lines, development of better forecasting models, enforcement of higher and reliable reserve generation power capacity. We also suggest exploration of electrical storage technology, ideas for having a national electrical energy reserve supply to handle extreme events as well as to provide incentives for the population to curb the demand. With the increased adoption of electrical vehicle technology, the requirement for a more robust and reliable electrical grid becomes even more important in the future.

Acknowledgements

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