# Testimony before US House of Representatives Committee on Science, Space, and Technology


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March 18, 2021

Good morning Chairwoman Johnson, Ranking member Lucas, and other members of the Committee. My name is Varun Rai. I am a Professor of Public Affairs and Mechanical Engineering at the University of Texas at Austin. Thank you for the opportunity to appear before you for this important hearing.

I live in Austin, Texas and even before the major weather conditions hit broadly in Texas on Sunday, 14$^{th}$ February 2021, in Austin we had icing conditions since Thursday, 11$^{th}$ February. As a result, parts of Austin lost power starting Thursday. Texas-wide power outages started early morning of Monday, 15$^{th}$ February, eventually affecting 20 Gigawatts (GW) of load – about a quarter of the estimated peak demand (77 GW) – and more than four million customers over three days. In the neighborhood I live, we lost power for nearly a week followed by loss of water supply for four days. We have an electric stove – so normal cooking was disrupted as well. But we have a gas fireplace and gas heating. Of course, the gas heating didn't work because electricity is needed for the furnace controllers and for the fan. We were burning wood and cooking food in the gas fireplace for nearly a week. Inside our house the temperature went down into the 30s – like living inside of a refrigerator for days. We live in a modern, well-insulated house. Such passive weatherization becomes extremely critical in crises like this. At least we could live inside for a little bit longer, under layers of warm clothing, and not die of hypothermia. Sadly, some of my fellow Texans died due to the crisis and aren't around to tell their tales. For the rest, just the bill for the power supplied *during* the week of the crisis is estimated to be around $50 billion. The reasonableness and validity of this cost is being hotly debated by Texas policymakers currently, but if it holds, just one week's power bill for the overall Electric Reliability Council of Texas (ERCOT) market is equivalent to about three years of the market's typical power bill, so about 150 times higher than normal and roughly equivalent to $5000 per meter (household) in the ERCOT territory. I grew up in India in the 1980s and 90s, where we were used to *daily* power and water outages. But for all the years I spent in India, before I came to the US at the age of 21, there was nothing of this scale. This one beats them all.

There were three key contributors to the severity of the impact:

First, equipment, in both power generation and gas production systems, froze. This was indeed a very severe winter event, but not one without precedent. After another blackout in Texas in 2011, winterization of both power and gas equipment was identified as a high priority item[1]. Some changes were made based on these recommendations, but no standards or requirements tied to operational performance in extreme cold were set. While operators have financial incentives to winterize equipment, what makes short-to-medium term financial sense for plant operations doesn't add up to system-level reliability expectations. Relatedly, there is an issue of coordination failure: a natural gas plant owner needs to know that gas will reach the plant, and an owner of a wind farm that transmission lines will not fail. The need, but not requirement, to winterize the entire system means that, individually, owners of separate assets shy away from taking action, since they expect that others may not act either. This has meant that there is insufficient overall investment in winterization of the energy system in Texas, exposing the system to massive failure events – as we saw happen last month.

Second, as we know now, there were gaffes in communication and coordination. One of the more harmful mistakes was that as part of ERCOT's load shedding (i.e., deliberate shutdown of power to parts of the system), power to many oil and gas field operations was shutdown[2], which meant a further strain on gas production on top of declines in production due to the weather. This meant less gas for power generation, more load shedding, and more disruptions to gas plants – a vicious cycle. Power was also lost at water treatment and pumping facilities across the state. Gas, power, and water are an integrated, interacting set of systems that need to work in sync to deliver human wellbeing. Critical infrastructure is not a matter left to individual market participants. Wellbeing under extreme conditions depends on reliable functioning of critical infrastructure and coordination should be guaranteed. On the consumer side, there was an absolute lack of coordinated, consistent, and timely emergency communication to the people of Texas. Households and communities were clueless about what was happening, how to respond, and what to expect next. At the household level, it was utter chaos. We have an expansive infrastructure and significant spending in the U.S. for accurate weather forecasts to enable better emergency preparedness and communication. What we witnessed in Texas in mid-February 2021 is that even with reliable weather forecasts days in advance, the ball was dropped in assessing and conveying the urgency and direness of the situation. This translated the extreme weather-induced stress on the power system into a severe humanitarian crisis.

Third, even with clear warning of a severe weather event days and even weeks ahead[3], there were not enough calls in advance to reduce demand and conserve energy. Calls for voluntary conservation (i.e., reduced electricity and gas usage at homes and other facilities) leading up to the weather event and during it came too little, too late. A prudent approach when such events are expected in advance is to simulate the event's impact, foresee major supply disruptions and demand spikes, and ring the alarm bells. A coordinated and clear extreme conservation call – not just last-minute emails and texts – could have reduced the supply-demand gap substantially, enabling rotating outages, while relieving supply to catch up. Clearly, in the days preceding the severe weather event, and with the severity of the weather event in sight, there was gross underestimation of the scale of supply disruptions and demand increase. In my view, not mobilizing enough voluntary demand reduction (for both electricity and gas) during the weather

[1] FERC & NERC Report on Outages and Curtailments During the Southwest Cold Weather Event of February 1-5, 2011.

[2] Texas House hearings, as reported by CBS Austin.

[3] Bill Magness, Review of February 2021 Extreme Cold Weather Event – ERCOT Presentation.

event was the single biggest lost opportunity to minimize the impacts of the crisis. Voluntary demand reduction is typically not a reliable strategy for balancing the grid. But this was not a typical situation. It was an unprecedented disruption to the power system and it called for extraordinary measures to manage it. Timely and coordinated communication is the key to get people ready for a situation like this. People board up or evacuate to get ready before hurricanes. If people were communicated with what was coming, would they do anything differently regarding their electricity and gas consumption during the event? Yes, they would.

Looking ahead, to learn fully from the Texas power crisis of mid-February 2021 there are five questions that need further and immediate research to support decision making. The answers will enable the design and development of reliable, yet economic, electricity systems at the state and federal levels:

1. *What are load management strategies that minimize societal damage, while upholding equity and fairness during crises?* Over four million customers in Texas lost power during the crisis. The power outages lasted two or more days as 20 GW of load was ordered shed to prevent instability on the grid. The power outage led to a water crisis, with large parts of Texas left without a water supply or under boil water notices for several days and even weeks. The interdependent, cascading failures in the gas, electricity, food, transportation, and water systems that led to days of power and water failures put millions of Texans under extreme physical, mental, and financial stress. The load sheds were based on unsophisticated critical-load lists, which did not account for infrastructure interdependency[4]. Implementation was largely binary: entire subnetworks were either on or off. We need research to design load management strategies, including the sequencing of load shedding and the placement of strategic power backups, to minimize extreme stress for households, taking into account the interdependent nature of critical infrastructure and implications for fairness and equity.

2. *What is the full scale of the economic damages due to large-scale crises like the one in mid-February 2021 in Texas?* The scale of the maximum load shed (20 GW) was five times larger than what was shed (4 GW) due to the blackouts in Texas in February 2011 and lasted much longer (70 hours vs. 7 hours)[5]. One measure of the economic damage is the *Value Of Lost Load (VOLL)* – currently capped at $9000/MWh in the Texas electricity market (note: typical average price in the Texas market is between $20-$40/MWh). Using this metric implies roughly a $10 billion value of lost load (10-20 GW load shed for ~70 hours). But this is a very conservative estimate. Other, more comprehensive, estimates put the damages and economic losses upwards of $100 billion[6]. The $50 billion power bill across ERCOT during the crisis I mentioned before and the VOLL estimates do not capture the full scale and scope of costs and losses, which in crises as wide and long as this one might dwarf the more direct bill costs or VOLL. For example, the power failure led to widespread water damage across the state, damaging both municipal and household water infrastructure (e.g. pipes), equipment (e.g., water heaters), and flooding and other water damage inside homes. There are direct costs to repairing these damages. Moving forward, households across Texas will also likely face higher insurance rates. Other damages, sometimes overlapping, include bankruptcies of companies and local governments, lost wages

[4] Texas House hearings, as reported by CBS Austin.

[5] Bill Magness, Review of February 2021 Extreme Cold Weather Event – ERCOT Presentation.

[6] AccuWeather (Mar. 5, 2021): Damages from Feb. winter storms could be as high as $155 billion.

and jobs, and damage to health and life. And there is more: lost production at semi-conductor facilities; loss of trust in the electricity system, making people hesitant to invest in the future, or to build factories that need stable electricity. We should consider all these costs when we consider the cost of infrastructure investments like new transmission or gas storage capacity, or regulatory requirements like winterization standards for gas production and power generation facilities. Unfortunately, data and analyses to estimate damages are lacking[7]. There is critical need to support research that advances a more robust and comprehensive accounting and understanding of the full scale of damages that result from extreme events.

3. *Can demand response be rapidly and smartly deployed at a very large scale to minimize system impacts?* In the absence of coordinated messaging demand soared rapidly as temperatures plummeted. Supplying a unit of demand typically requires 1.2-1.3 units of generation, because of losses between the point of generation and the point of consumption. Thus demand reduction becomes even more valuable in extreme conditions on the grid with major disruptions to power supply. As I mentioned before, one of the biggest failures in the days leading up to the event was how poorly the demand side was engaged. Much of the communication early on during the crisis included generic or coarse messaging (e.g., "turn down thermostat to 68 degrees"). Extreme weather conditions like the ones Texas faced in mid-February 2021 necessitate much more sophisticated approaches to engaging demand, including a mix of hardware (smart meters, smart thermostats, distributed generation/storage), market design (demand aggregation, market participation, and communication protocols), and collective voluntary action (using emergency communication, community preparation, and messaging that could elicit coordinated, large-scale response across thousands and millions of households). Demand flexibility, both programmatic and voluntary, will inevitably need to play a much larger and effective role in the future to maintain system reliability in the face of extreme events. Achieving that flexibility at very large scale and over short timeframes (hours and days) is an important area for further research.

4. *How to improve system intelligence and performance through third-party monitoring, analysis, and feedback?* During much of the crisis there was very little information and data (other than system-level aggregate data) about the status of the system, where the system might be headed, what to expect next, and how to prepare and respond for maximal personal and social safety and wellbeing. People were not just in power darkness, they were also in information darkness. In extreme and rapidly evolving crises like the one in Texas last month, system interdependencies and cascading events make real-time and predictive system intelligence quite difficult but possible with modern computing technology. During times of extreme stress in complex systems like the modern energy system, no one part of the puzzle is individually critical – all are, together. All pieces need collective awareness of their role in contributing to the problem and in solving it. Yet, the analytical and communication capabilities across the different pieces of the system, for example utilities, regulatory bodies, system operators and consumers, are also stretched to the fullest, just when the need for them is paramount. To address this, there is a need to design data-sharing mechanisms and collaborative efforts including researchers at universities and national labs, with appropriate data governance mechanisms, to enable monitoring, analysis, feedback, and problem-solving by the broader community around and during crises.

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[7] LBNL Report (Nov. 2020): Case Studies of the Economic Impacts of Power Interruptions and Damage to Electricity System Infrastructure from Extreme Events.

5. *What is the societal value of connecting ERCOT to the eastern and/or western grids?* Given that ERCOT's neighboring power systems (including the Midcontinent Independent System Operator (MISO) and the Southwest Power Pool (SPP)) were also stressed during last month's extreme weather event in addition to ERCOT, it is unclear how much, if any, help could ERCOT have received if it were connected (AC ties) to the other two U.S. grids. However, with the frequency of extreme weather events expected to increase as impacts of climate change unfold further, the need to understand the long-term benefits and costs of connecting ERCOT to other grids is immediate. Impacts of future weather events might be very different across the different power systems and the ERCOT grid might get a lot of help from the other grids in such cases (and vice versa). Over the last decade all three major electric grids in the U.S. have seen a significant rise in the share of renewable energy sources, a trend that is expected to continue over the next few decades. Just on its own renewable energy is intermittent and needs to be managed, for example through complementary power generation or storage, to achieve high levels of reliability. It will be important to study how drastically increased amounts of generation from intermittent sources like renewable energy, in combination with sources that tend to fail together under extreme conditions, such as natural gas, can be made reliable economically. The value of integrating to other grids in a much higher renewable-energy penetration scenario might turn out to be very different compared to past estimates. To understand the benefits of connecting ERCOT to the eastern and/or western grids, we need research that accounts for climate-induced stresses on the energy system, system-wide vulnerabilities and options, changing energy mix, and changing nature of demand (more electrification, population change, responsive demand, including on-site distributed generation and storage).

Thank you again for the opportunity to present at this hearing and I look forward to the discussion.