Texan Energy Crisis

Lessons for Australian electricity markets

A report for the Australian Energy Council

Kieran Donoghue

info@newgrangeconsulting.com.au

+61 432653258

April 2021

Contents

Executive Summary

From 15-19 February, the US state of Texas endured a winter storm that dragged temperatures well below freezing, 20℃ or more below seasonal norms. Electricity generation plant and gas infrastructure proved unprepared for these temperatures and around a third of the state's effective capacity went offline for some or all of this period, just as demand was spiking to a new winter record. The collapse of the power system was averted only by instituting widespread load shedding, with some customers enduring power cuts for over three days. This led to several deaths and major discomfort for millions of Texans. While surrounding states also saw some power supply issues, the main Texas market (and system) ERCOT was much worse affected. This, coupled with the knowledge that a similar event had occurred only ten years previously (albeit with less severe consequences) has caused many to ask what was wrong with the ERCOT system.

Suggested culprits ranged from too many renewables to gas dependency, the energy-only market design, deregulation, and ERCOT's lack of interconnection with neighbouring systems. Several of those system features are shared by or similar to Australia's National Electricity Market (NEM). The West Australian market (WEM) is less similar but is another isolated grid with a similar generation mix. Accordingly, some questions have also been raised as to whether there are any lessons for the Australian electricity markets in this crisis.

The thesis of the report is that the lessons are extremely limited. Most of the features of ERCOT that have been blamed are essentially red herrings. The scale of the outages, and the fact that they largely had the same root cause (a rare extreme cold event), mean that the issue is one of failure to plan for system resilience to such weather. This is not to say that the ERCOT grid is not resilient to some threats – it rode through a major hurricane in 2017 without any need for load-shedding – but not to this type of weather, which appears to occur frequently enough to be worth planning for.

Successful planning will also require implementation of the necessary upgrades to generation plant, whether through mandatory standards or targeted incentives (noting that the main market incentive of scarcity pricing has historically not been adequate to drive widespread winterization). To maximise plant availability, the gas sector (which has a different regulator) would also need to be more resilient to the same type of extreme weather. All of this will cost money, so either directly or indirectly, consumers will pay more. They should be clear about the likely trade-offs. These factors all mean that from a governance perspective, the drive for increased resilience should come from the state government – it will not be sufficient for individual regulators or the market operator to

seek to improve resilience, albeit they are likely to be the best parties to be empowered to monitor and enforce any new resilience requirements.

NEM policymakers have devoted some resources to issues of resilience and ways to cost-effectively improve it following the lessons learned from the black system event in South Australia in 2016. There has been a recent rule change to empower the Australian Market Operator (AEMO) to plan for more high impact but low probability (HILP) events that go beyond what are normally considered credible contingencies for the power system. The WEM has also learned from the experience of the Varanus Island explosion which curtailed gas supplies, but where the electricity system managed to remain secure. At a national level, the Commonwealth has set up the Critical Infrastructure Centre and established a forum for owners and operators of energy infrastructure to share best practice on resilience. It has also created an Electricity Sector Climate information (ESCI) project to provide tailored climate information to the sector. This does not mean resilience has been “solved” for the NEM or the WEM. Notably, there is an outstanding recommendation from the Finkel review that there should be a regular (three-yearly) assessment of the NEM’s resilience to human and environmental threats.

1 Introduction

This report examines Australian electricity markets (and physical systems) in comparison to the main Texas market (and physical system). Australia's main market is the National Electricity Market (NEM), and this is the focus of the comparison, but the report includes a section on the Western Australian electricity market and system that covers Perth and the southwest of the state. This will be designated as the Wholesale Electricity Market (WEM), although the discussion will also cover aspects of the physical system (also known as the South West Interconnected System, or SWIS) and the retail market. The main Texan market (and physical system) is commonly called ERCOT after its market operator (the Electricity Reliability Council of Texas). Parts of Texas in the North, east and west of the state are instead connected into other US systems and markets. These are referenced later in the report but are not the subject of the comparative analysis.

1.1 Purpose of report

The purpose of the report is to consider the similarities and differences of ERCOT to the NEM and the WEM in the context of the Texas Energy Crisis of 15-19 February 2021. Over this period, storms and a very cold snap led to up to a third of the ERCOT system's capacity going offline (or being unable to restart in the case of some units under maintenance). This resulted in severe power outages leading to loss of life as well as widespread physical hardship for many Texans. It also triggered an extended period of maximum prices, which is having significant financial repercussions including retailer bankruptcy, four figure bills for residential households and major controversy over whether ERCOT overcharged customers by maintaining the maximum price far longer than necessary. The crisis is described in greater detail in section 3.

These events triggered instant diagnoses of what is "wrong" with the ERCOT market, and also comparisons with the NEM, given the many similarities between the two markets. Section 2.1 provides a detailed comparison of these markets, while section 2.2 compares and contrasts ERCOT with the WEM, a quite different market in many ways.

With these sets of facts as background, section 4 carefully considers the central questions – a) what was the root cause of the crisis (other than the weather, which while unusual for Texas is pretty normal winter weather for other parts of North America, and b) in the light of this, how relevant is the Texan electricity crisis for Australia?

2 Comparison of the Australian and Texan electricity markets

2.1 The NEM and Texas (ERCOT)

The NEM and ERCOT are both energy only markets (EOM), where high scarcity prices and secondary financial markets priced off the probability of scarcity pricing are the drivers of commercial investment decisions. While the NEM covers a much larger physical area, they are roughly similar in terms of annual generation and peak demand. The NEM is a standalone grid, while ERCOT has very limited interconnection with other grids, so is essentially reliant on in-area resources and its own market signals for meeting demand. Both have deregulated and disaggregated industry structures, with competitive retail markets across most of their services area and open access network regimes. These similarities mean that the markets are often points of comparison with each other and contrasts to most other electricity markets, which have separate capacity payments. **Table 1** below lists the key elements of each market and its underlying physical power system, while **Figure 1** and **Figure 2** following the table illustrate the geographical boundaries of ERCOT and the NEM respectively.

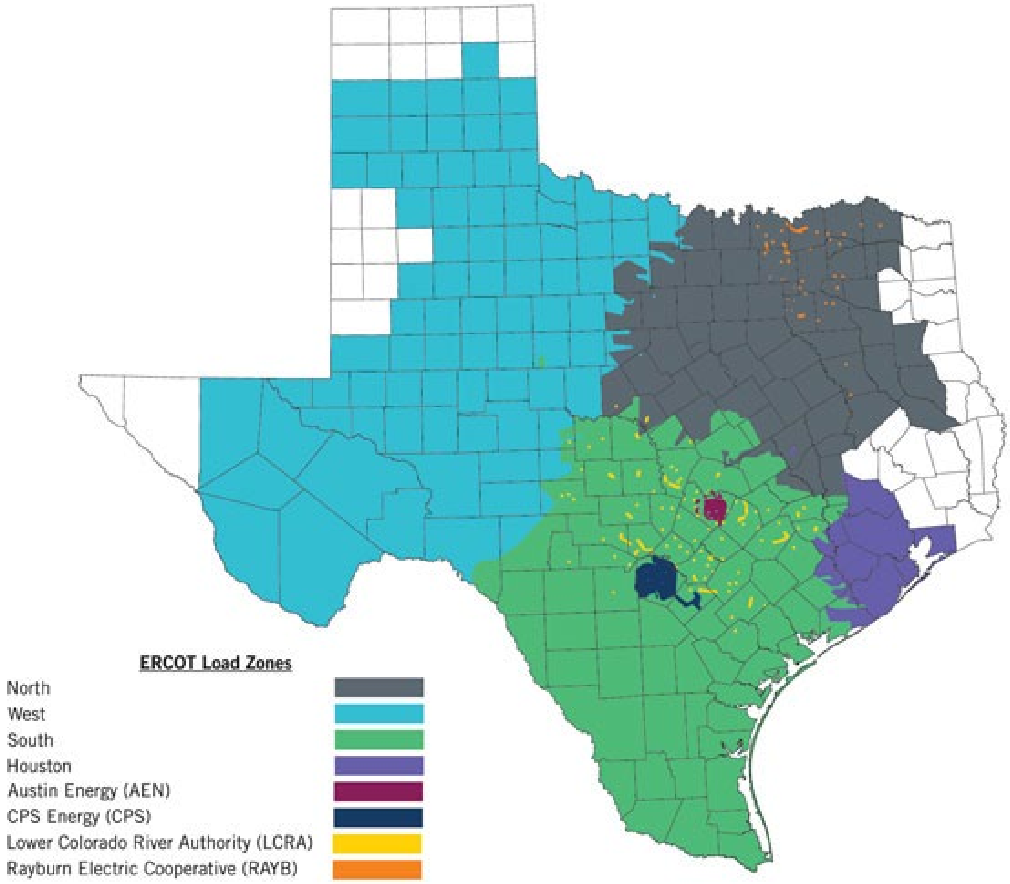
Table 1: The NEM and Texas (ERCOT)

Market element	**Australia (NEM)**	**Texas (ERCOT)**
Wholesale market type	EOM zonal, real-time single pass	EOM nodal, day ahead and real-time market
Hedging markets	Mix of over the counter (OTC)/exchange traded, standard swaps and peaks. New products emerging to reflect impact of variable renewable energy (VRE).	Extensive range of exchange-traded products Congestion revenue rights (CRRs) to hedge against nodal price differences.
Price cap	$15,100/MWh, Cumulative price threshold (CPT) $224,600/MWh	US$9,000, no CPT, but see LCAP rule in section 2.1.1

Market element	Australia (NEM)	Texas (ERCOT)
Reliability Standard	Interim reliability measure of no more than 0.00006% USE in any given year.	Loss of load expectancy (LOLE) of 1 in 10 years
Reserve instruments	Strategic reserve - formerly the Reliability and Emergency Reserve Trader (RERT)	Operating Reserve Demand Curve (ORDC)
Generation mix	Coal-dominated, increasing VRE, ~10% hydro, ~10% gas	Gas-dominated, increasing VRE, ~20% coal, ~10% nuke
Annual Demand, Peak demand, # customers	206 TWh (2016) 35,551 MW (2009) Around 10m customers (connections)	376 TWh (2018) 74,820MW (12/8/19) 25m customers (by population, not connections).
Investment drivers	Increasingly policy-based: renewable energy targets, UNGI, government ownership (Snowy 2.0, CleanCo), ARENA	Market-based. VRE has had some support via federal tax credit
Transmission	Regulated monopolies x 5	Regulated monopolies x 6
Network extension	RIT-T, REZ processes developing	Successful implementation of REZs to date

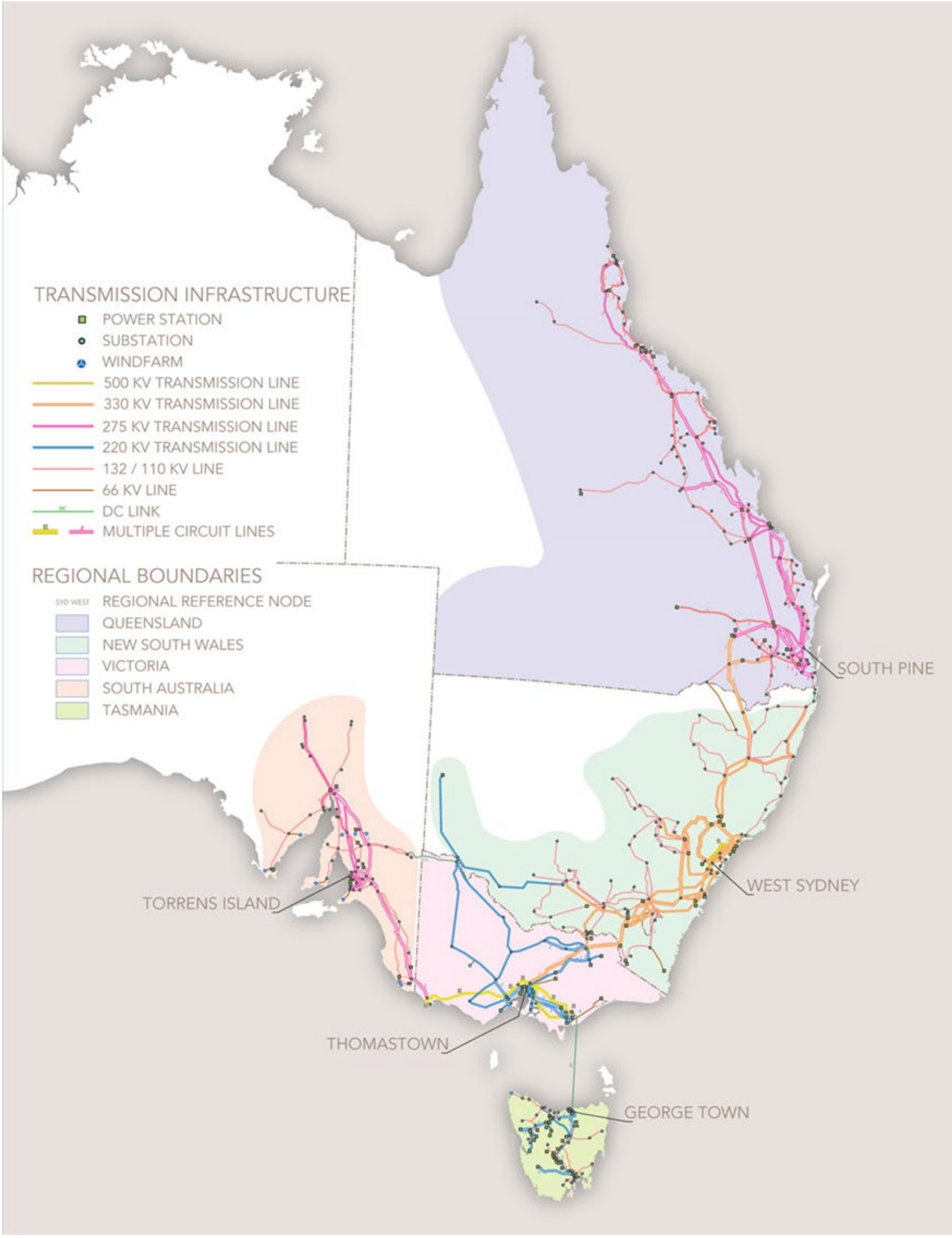
Market element	Australia (NEM)	Texas (ERCOT)
Interconnection	NEM as a whole is standalone but covers a bigger geographical area, and thus typically has some weather and demand diversity. Regions have some interconnection with more planned via the Integrated System Plan (ISP).	Very low. Two lines totalling 820MW to the Southwest Power Pool (SPP) and three lines totalling 430MW to the Mexican grid (all are HVDC). In 2019, ERCOT exported c.1,500GWh and imported c.2,000GWh.
Regulation/policy	Mix of federal, NEM-wide and state-based oversight. Primary energy market bodies are AER, AEMC, AEMO.	PUC for electricity, RRC for gas. FERC has very limited jurisdiction over ERCOT.
Weather stresses - summer	Frequent high summer temperatures. Geographical spread means diversity of peak demand.	Frequent high summer temperatures.
Weather stresses - winter	Hardly ever subzero, even then only in few localities, so mostly summer peaking. Limited need for infrastructure winterization.	Infrequent (c. 1 in 10-20 years) very cold snap, even then demand records are summer not winter.
Retail markets	Competitive in most regions, range of price caps/quasi-caps	Competitive in many parts (no price caps) but not all.
Financial resilience	Retailer of last resort (ROLR) – to date this has been effective when needed for periodic small retailer default.	Provider of last resort (POLR) – this is intended to be a temporary (and relatively high-priced) back up.

Figure 1: ERCOT by load zone



Source: ERCOT

Figure 2: The NEM



Source: AEMC

2.1.1 Wholesale market design

Both the NEM and ERCOT are energy only markets (EOMs) so they rely on a high price cap to incentivise and reward capacity. The NEM's is slightly higher (at market exchange rates) at $15,100 compared to US$9,000 for ERCOT, which translates to A$11,790[i].

ERCOT's price cap rule has a quirk, however. There is a second cap, the LCAP, which is defined as the higher of $2,000/MWh or 50 x the current gas price (in MMBtu) at the Katy market hub. This supersedes the $9,000 cap if, at some point in a calendar year, a figure called the "peaker net margin" is exceeded, being three times the estimated cost of entry of a new gas peaker (currently 3 x $105,000 = $315,000). But this happened during the crisis. In theory this should have resulted in a switch to the LCAP, which is in some ways perverse to reduce a price cap in the midst of a scarcity event. But the fall in gas production and gas pipeline constraints meant that some localised gas prices reached unprecedented levels, including Katy, where the gas price peaked at $359.14/MMBtu on February 17. The LCAP would thus have been higher than the price cap, at up to $17,957/MWh. So PUCT suspended the rule temporarily. They are apparently considering whether to revert to the higher price cap for the summer[ii].

Unlike the NEM, ERCOT has a day ahead market (DAM) with hourly settlement. The day ahead market is voluntary, and volumes are around 60 per cent of the real-time volume supplied on average. It then also has a real time market (RTM) similar to the NEM. Prices in the two markets tend to track quite closely.

ERCOT is a bigger market than the NEM, with peak demand more than double that of the NEM. ERCOT's peak demand is growing, with the record set in 2019 versus 2009 for the NEM where peak demand growth has stalled in recent years.

2.1.2 Generation mixes and fuel supply

The NEM had 55,269 MW of registered capacity at April 2020, and in addition 9,980MW of distributed solar (at May 2020)[iii]. 68 per cent of generation in 2019/20 came from coal-fired power stations; 8 per cent from gas, 7 per cent from hydro and the remainder from renewables (including distributed solar. ERCOT has more capacity, as it has more demand to serve: 119,183 MW of registered capacity at January 2021[iv] (a small amount of this is classed as out of service, and wind and solar resources are derated to the average peak contribution, so effective capacity was around 83,000MW going into the winter). In 2018 the mix was 45 per cent gas, 25 per cent coal, 19 per cent wind, 11 per cent nuclear and 1 per cent solar.

So ERCOT was actually slightly ahead of the NEM in terms of variable renewable penetration, although the NEM may be catching up. Capacity additions of variable renewables in the NEM has run at around 6-7 GW a year (including distributed solar) for the last two calendar years[v]. In ERCOT the run rate is more like 2-2.5 GW per year in recent years[vi] on a larger capacity base.

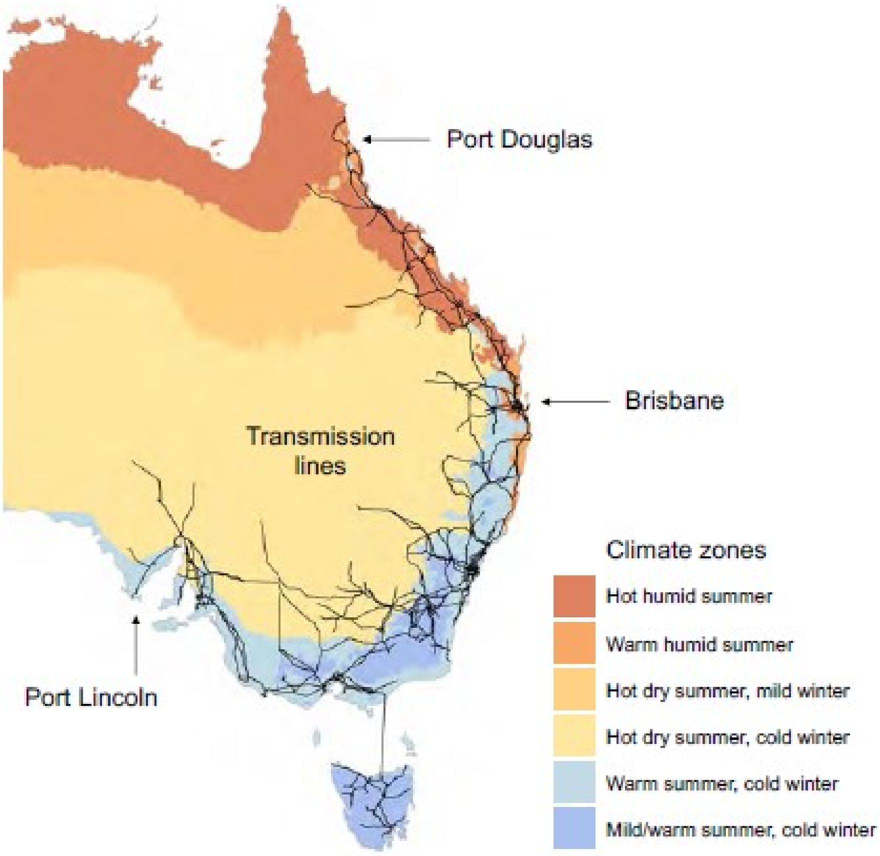
Where ERCOT and the NEM differ is in terms of the primary fuel sources. The NEM is still very heavily coal dominated, and many of the coal plants are mine-mouth plants. While an individual plant may have coal supply issues from time to time, and occasionally two or three plants may be affected simultaneously, systematic supply issues do not occur. Flexibility is provided by hydro almost as much as gas, although hydro can be energy-constrained in periods of extended drought. The two main hydro systems do not necessarily face these conditions at the same time. So, in general, the NEM does not have systemic fuel supply issues to worry about.

Conversely, the main fuel for ERCOT is natural gas, making it reliant on efficient gas production and pipeline transportation. Normally this is no issue, as Texas is the largest gas producing state in the US[vii] and so there is plentiful supply with the ability to flex production to meet demand. Because of this, gas-powered generation in ERCOT does not typically have on-site storage. This means that if there are interruptions to gas supply, then the electricity system is vulnerable, as discussed in section 3.3 below. Further, there is a potential vicious circle as some compression stations are now electric-powered rather than gas powered. If there are widespread power outages, then the compressor stations may be affected, meaning supply interruptions to GPG, meaning in turn, the outages may continue if there is insufficient supply.

2.1.3 Weather and climate

The NEM has a larger geographic spread – It's considered the largest interconnected grid at over 5,000km long from Port Douglas to Port Lincoln. Put another way it covers almost 27° of latitude (just under a third of the distance from the equator to the south pole) and 18°of longitude. Consequently, it faces a diverse range of climates, from the tropical north to the windy and temperate "roaring forties" in the south (**Figure 3**).

Figure 3: NEM weather zones



Source: Grattan Institute

The grid needs to be resilient to extreme heat in the summer – up to 50℃ in some areas[viii] - both in terms of its physical integrity and the need to meet peak demand due to air conditioning load. However, it is rare for this level of heat to manifest in multiple regions simultaneously, although a protracted hot spell can result in Adelaide and Melbourne experiencing high heat levels simultaneously. It's also rare to have more than 3 days in a row where the temperature peaks over 40℃, or for the heat to persist overnight (on the hottest nights it may get down to around 30℃. Consequently, demand peaks are usually for a few hours at a time.

By contrast there are few parts of the NEM that have to be robust to very cold weather. Winter temperature records are largely confined to mountainous areas with very little load to serve, although there may be some specific infrastructure requirements, as some of these areas are home to the major hydro schemes. Outside of Mt Kosciusko, the country's highest peak, records are in the order of -10 to -13℃[ix]. But major load centres rarely get below freezing. Only Tasmania and parts of inland NSW have winter peak demand higher than summer. This is partly due to the prevalence of reticulated gas heating in much of Victoria, Adelaide and major population centres in NSW. Further north there are few heating degree days (HDDs) in any case.

Drought and storms are a relevant concern for the NEM. The multi-year millennium drought culminated in reduced availability for water-cooled coal plant and for the hydro schemes, especially in 2008-09. Even then there was limited impact on prices. Some newer coal plants are air-cooled to reduce water requirements and over the long term coal exit will reduce this risk (although hydro may play an increasingly important role as backup for renewables).

Storm damage can be a significant threat to infrastructure and was the trigger for the NEM's worst blackout – the South Australia black system event of 28 September 2016[x].

Climate change is expected to lead to more frequent and potentially higher heatwaves, more storms and the potential for both extended droughts and very high rainfall at different times and places. But cold snaps may well be fewer – most temperature records date back 40 years or more. Crucially for the purposes of comparison a Southern hemisphere "polar vortex" event is not considered plausible.

Texas is the second largest state of the US (after Alaska) and so has some diversity of climate. Coastal regions are typically humid and subtropical, while central Texas is somewhat elevated and is drier, and the mountainous west drier still. Winter temperatures frequently below freezing in the central and west zones, while summer temperatures in the 40s are not uncommon across the state. In these respects, the ranges are not dissimilar to the NEM. A key difference however is the occasional "polar vortex" event. Technically this is a weakening of the normal polar vortex that normally traps cold air within the Arctic during winter. In these weakening events, the cold air escapes and spills to the south potentially as far as Texas. On these rare occasions, temperatures can drop to -10℃ or lower in the major cities and remain low for several days. Climate change means a warmer Arctic which could lead to more frequent such events, even as underlying winter temperatures may be getting warmer.

Texas is also prone to major storms and the grid has often proven resilient to these. For example, in 2017 a category 4 storm, Hurricane Harvey hit Texas and Louisiana. It was the wettest tropical cyclone on record in the US but ERCOT did not need to order any load-shedding to keep the system secure[xi] (there was likely some localised network damage that resulted in power outages) despite widespread flooding, infrastructure damage and a 21 per cent fall in natural gas production.

2.1.4 Networks

ERCOT has 75,000km of transmission lines, spread among six major network businesses who own both transmission and distribution. Despite being longer the NEM actually has less - 40,000km, spread across five transmission operators. There are twelve distribution networks. As natural monopolies, network businesses are subject to price and service-level regulation in both cases, and they are ringfenced from participating in competitive markets. As storage, which can play a role in providing network and market services, becomes more widely deployed, the policing of the boundary between the two will attract greater attention. ERCOT has extended its network in recent years, in particular to the west, where there are abundant wind resources, in order to facilitate the connection of new renewables. The NEM is embarking on a similar process of extending out into Renewable Energy Zones.

2.1.5 Retail market and customers

Most regions of the NEM have competitive retail. The main exceptions are regional Queensland and Tasmania where small customers are served by a single state-owned retailer. After a period of deregulation of prices, there has been a partial re-regulation. Victoria has retained its own retail regulations but the rest of the NEM is overseen by the AER. There were 44 retailers registered to serve small customers in 2020.

About three-quarters of ERCOT load is contestable at the retail level. The remainder is served by integrated utilities owned by local government or co-ops. There were 116 registered retailers in 2018. There are no price caps. Some of the reported behaviour during the crisis, such as retailers trying to offload customers and Griddy charging its customers daily or even more frequently as the bills mounted up appear inconsistent with NEM rules, suggesting that in general the market is more lightly regulated in Texas.

2.1.6 Financial flows

Given both the NEM and ERCOT are energy only markets with the potential for highly volatile energy prices, they both need derivative markets to allow participants to manage their risks.

ERCOT futures can be exchange-traded on the ICE US Futures market. Available products include DAM and RTM futures, for peak and off-peak periods for the major zones, load futures and ancillary service futures. There appears to be relatively little regulatory interest in monitoring the outcomes of secondary markets; there is no reference to hedging levels or forward pricing signals in the annual market review by the Independent Market Monitor (IMM), for example.

This used to also be the case in the NEM, where the secondary markets were left to their own devices. Following the ACCC inquiry into retail prices, regulators and governments have taken more interest in secondary market activity, and this interest is somewhat formalised by the Retailer Reliability Obligation (RRO), which obliges retailers to contract against a 1-in 2 year peak load and empowers the AER to review compliance with the obligation.

2.1.7 Governance

The NEM is subject to what is becoming an increasingly crowded set of regulatory agencies as individual states boost their own regulatory capabilities. On the face of it, the key energy market bodies are the regulator (AER), rule maker (AEMC) and market operator (AEMO), all under the collective oversight of the Energy National Cabinet Reform Committee (ENCRC) and the energy ministers' meeting (EMM). The energy market bodies are also members of the Energy Security Board (ESB), alongside an independent chair and deputy chair.

ERCOT – either famously or notoriously, depending on your point of view – has avoided any significant oversight on its market design from the Federal Energy Regulatory Commission (FERC). This is because FERC's jurisdiction, as with many federal agencies, only applies when there is interstate trade. ERCOT's very limited connection to other US grids (the two small HVDC lines noted above) means there is no interstate trade in electricity. Some national policies relating to tax breaks and environmental regulation have impacted the generation mix in Texas.

There is some interaction between the national energy bodies, FERC and the North American Electric Reliability Corporation (NERC), and ERCOT. ERCOT is subject to many of the general reliability and security requirements as the rest of the US, although elements of this are devolved to Texas Reliability Entity, Inc. (TRE), the designated local reliability authority.

Market rules are developed by ERCOT itself in consultation with market participants. Electricity regulation within Texas is carried out by the Public Utilities Commission of Texas (PUCT), which administers the Public Utility Regulatory Act and has oversight and enforcement authority of the ERCOT rules and protocols. It subcontracts some of this role to the IMM – currently Potomac Economics - and to TRE.

The natural gas industry has a different regulator, the Railroad Commission of Texas (RRC)[xii].

2.2 Policy and regulation

Market signals remain the primary investment driver in ERCOT. Large-scale wind and solar have benefited from federal tax credits, making them lower cost than otherwise. The competitive REZ framework has enabled new generation in areas with good renewable resources but previously less transmission capacity to take it to load centres. Texas has a renewable portfolio standard (RPS) that targeted 10,000 MW by 2025[xiii], which was exceeded in 2009, suggesting it has long ceased to be an investment driver. Federal air pollution rules may be a factor in coal plants closing. New investment is predominantly wind and solar, with some gas and storage (more than 10GW of new gas plants have been commissioned since 2013). Across Texas as a whole, there has been 86GW of capacity added since 1995 and as at January 2021, there was 36GW of capacity proposed to be commissioned by the end of 2023. At a broad level, the market design appears effective in incentivising new capacity. Reserve margins have been declining, but aside from the crisis, there has been sufficient capacity online to meet demand even at peak times.

The NEM similarly has met reliability requirements in recent years, albeit with the use of the RERT. By contrast, however, it is less clear that the market is the main driver of new investment. As a proportion of the market, the MRET is much bigger than the Texan RPS and so has been a major driver of renewables investment. Now the MRET has plateaued, most states have taken on the mantle by setting their own renewables targets, with a variety of instruments to achieve them, ranging from creating state-owned businesses with a renewables mandate to reverse auctions. All large scale batteries in the NEM have been underpinned by government support. Meanwhile there has been a net loss of traditional firm capacity. Several coal plants have been retired from 2014-17 years totalling 4,153MW, while none have been built. One large new gas plant (AGL's Barker Inlet) has been built in the last eight years (AER, 2021) (in addition to two emergency diesel generators commissioned by the South Australia government, some small plant and some minor upgrades to existing plant). Given further coal retirements are expected over the next decade, the declining amount of traditional firm capacity has become a cause of concern for policymakers. Several policy initiatives have been introduced to attempt to address this: including the federal Underwriting New Generation Investment scheme (UNGI), the Retailer Reliability Obligation (RRO) and sundry state schemes. Additionally, resource adequacy is a key theme of the ESB's post-2025 market design project[xiv].

Unlike ERCOT, peak demand is not rising, with the NEM-wide demand record being set in 2009. This may change if there is a major switch to electric power from other sectors, such as gas and transport (i.e., electric vehicles).

Both markets have had an increasing focus on the changing requirements for grid security as their systems transition to an increasing share of variable renewables (VRE). This has resulted in reforms to ancillary services markets.

2.3 The WEM and Texas

The WEM is quite different from Texas (and the NEM) in several key respects. The WEM is a capacity market, with an annual capacity payment mechanism. Since capacity is explicitly paid for separately, the energy price cap is much lower. While the capacity mechanism does not guarantee resource adequacy, it has historically resulted in sufficient resources to meet a 1-in-10 peak demand with a reserve margin. Actual capacity currently exceeds this reserve capacity requirement, leading to a further buffer (AEMO, 2020). The flip side is that West Australian electricity users pay for this buffer, which does not happen when there is excess capacity in energy only markets.

The WEM is a more isolated grid even than Texas, with no interconnection to the rest of Australia. It's also a much smaller market, peak demand is around 4GW served by around 6GW of utility-scale generation, including 1.2GW of wind and solar. There is also 1.4GW of distributed solar.

One similarity is that gas is the dominant fuel, unlike the NEM. Gas supply is sourced from the large offshore gas deposits and there is a requirement to sell at least 15 per cent into the domestic market to ensure sufficient gas for gas-powered generation, industrial and household users. Of the 3GW of gas-powered generation, 1.3GW is dual fuel (AEMO, 2020), so it can run on distillate. This gives the WEM a good deal of flexibility in cases of gas shortages.

The resilience of the WEM was tested in 2008, when an explosion at the Varanus island gas processing facility resulted in the loss of 30 per cent of the state's gas supply (WA Senate Standing Committee on Economics, 2008). The facility took several months to repair and bring the gas supply back to normal levels. In the weeks after the shortage, oil and diesel went from powering one per cent of the electricity supply to thirty-one per cent as generators switched fuel. Coal plants were brought back from maintenance ahead of schedule. While households were asked to conserve gas and electricity use where possible, no forced load-shedding occurred. The electricity price for small customers was (and still is) regulated so there were no price increases as a direct result of the switch to more expensive fuels.

On the gas supply side, commercial and industrial users bore the brunt of the gas shortages. There was significant discontent with the way gas allocation was prioritised and with energy price rises, although the latter helped to allocate gas to the highest value uses.

The increase in renewables makes WA less dependent on gas for electricity supply in volume terms although it remains very important in meeting residual demand. The extensive dual fuel capability gives it a source of flexibility to respond to fuel shortages that Texas does not have (it has some dual fuel capability, but proportionally less than WA).

3 The Texan Energy Crisis of February 2021

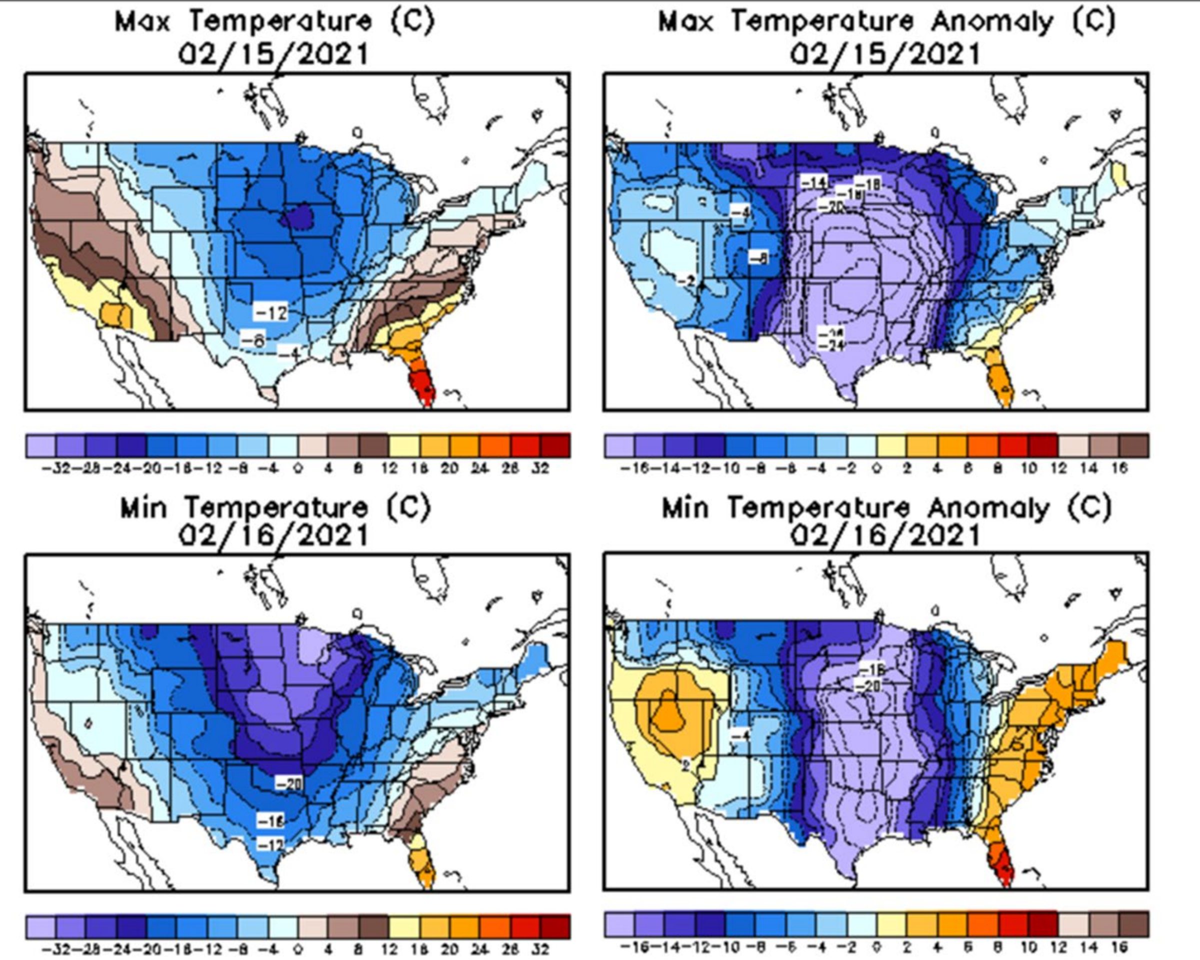
3.1 The weather

The winter storm that struck Texas and neighbouring states may well be the worst in a century, when considering its geographical extent, the duration and the minimum temperatures. It was the first time a storm warning had covered every single county in Texas. Temperatures were colder than Alaska. This is less surprising when analysis showed that the cold air originated in Canada's Northwest Territories[xv].

In Dallas, one of the three main population centres, the temperature never climbed above -9℃ on 15 February[xvi], making it 25℃ colder than a normal February day. At the capital, Austin, overnight lows were -15℃. In total 35 record low minimum temperatures and 62 record low maximum temperatures were set across the state between 15-19 February. Several snowfall records were also set.

The charts below (**Figure 3**) show the maximum and minimum temperatures for 15 February, as well as the temperature anomaly, i.e., the difference from the seasonal norm. As can be seen, much of the state was around 20-24 ℃ below the seasonal norm.

Figure 4: Absolute temperatures and temperature anomalies, 15 February



Source: National Oceanic and Atmospheric Administration (NOAA)

3.2 The performance of the electricity system

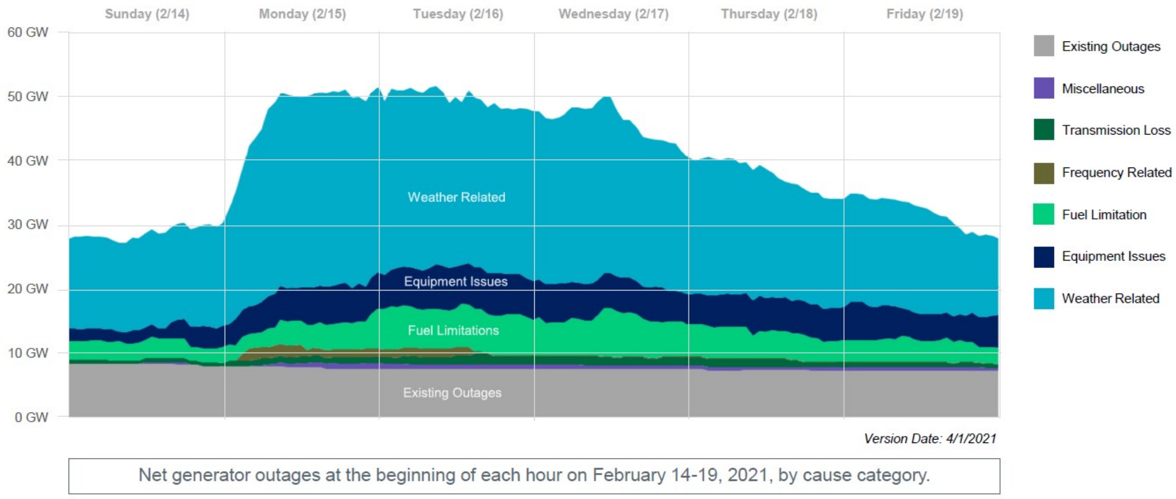
The severity of the winter storm appeared to catch ERCOT and generators somewhat unaware. There were two broad weather- based causes of generator unavailability. One of these was lack of gas supply (discussed further in section 3.3 below)

The larger of the two was generator unavailability due to weather impacts. All major generation types were impacted, including gas, coal, nuclear and wind. A key cause was frozen equipment—including frozen sensing lines, frozen water lines, and frozen valves; ice accumulation on wind turbine blades, ice/snow cover on solar panels, exceedances of low temperature limits for wind turbines, and flooded equipment due to ice/snow melt (ERCOT, 2021). Some units that were offline failed to start because of the cold.

These outages are hardly unknown, with the most recent example of major outages due to extreme cold occurring in 2011. Following that event, a combined FERC/NERC report recommended increased "winterization" of generators in the affected area (FERC & NERC, 2011). This is essentially a catch-all term for ways to make generators robust to extreme winter weather. However, neither ERCOT nor the PUCT has the power to require such expenditure. The legislature passed a bill that required generators to make winter preparedness plans and allowed ERCOT to review these, but actual winterization was not mandatory.

At the worst point, over 50,000MW of generation was suffering forced outages, or almost half of ERCOT's total capacity. Given this includes some renewables (and potentially other plant) that would not be expected to be running at full capacity through the period, the maximum gap between expected and actual generation was more like 30,000MW. The quantum of unavailable generation across the period is shown in **Figure 4** below.

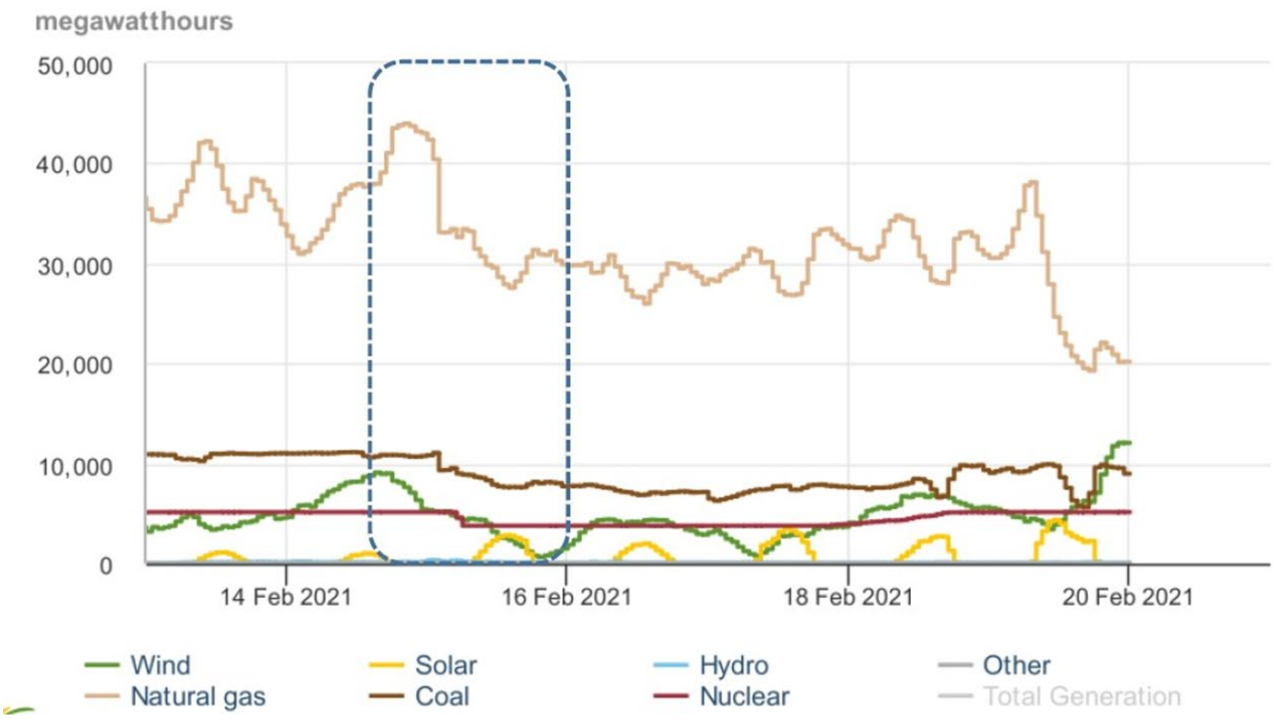
Figure 5: Generator outages by cause, 14-19 February



Source: ERCOT

At the same time, electric heating pushed demand up to an all-time winter peak (69,150MW) and several gigawatts more than ERCOT had forecast. But with so much capacity unavailable, this demand could not be met. As voltage levels dropped, ERCOT began to instruct the networks to begin load-shedding. The substantial drop in available generation that necessitated action can be seen in **Figure 5** below.

Figure 6: Generation mix, 14-20 February



Source: US Energy Information Administration (EIA)

About 10,500 MW was shed at the highest point according to ERCOT. While load shedding is normally carried out on a rolling basis to share the pain around, the scale of necessary load shedding and the fact that many circuits contain connection points deemed critical infrastructure meant that some unlucky Texans were stuck with extended blackouts. For comparison, the 2011 extreme weather event, which was broadly similar in terms of temperatures and widespread generator outages resulted in 7 hours of load shedding compared to over 70 in 2021.

Unsurprisingly, the spot price hit the price cap and stayed there for four days. For at least part of that period, it was an administered price set by ERCOT with the sanction of the PUCT. This has subsequently proven controversial, as discussed in section 3.6.

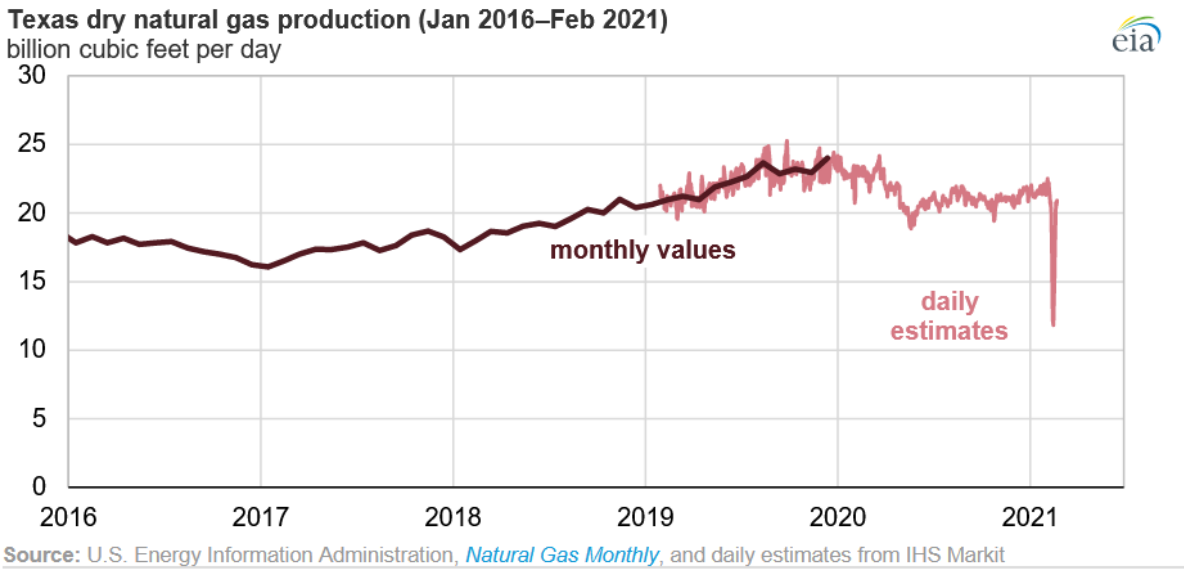
At least one retailer, Griddy, offered wholesale pass-through prices to its customers. With prices at the cap for four days straight, some customers who did retain power also had four figure electricity bills for less than a week's supply.

3.3 The performance of the gas system and the interrelationship with electricity

The cold weather impacted gas production. Much like the electricity system, there is limited economic incentive to weatherize gas wells, pipelines and compressor stations to be robust to temperatures well below freezing. Analysis by FERC and NERC after the 2011 incident estimated that weatherising a gas well cost between $2,800 per well in capital costs (if a methanol injection system was added as an antifreeze) to $35,000 if a heated enclosure was put around the well. Annual costs of running a methanol injection system were around $6,800 per well (FERC & NERC, 2011). Much of the gas production in Texas is from shale gas, which requires a lot of wells. Texas had 122,879 wells in 2019. So full weatherisation for these periodic cold snaps would cost between $350m and $4,300m and over $800m annually (2011 prices). This is a non-negligible additional cost to protect against a one in ten or twenty year event, even for a gas market worth $27bn annually.

Accordingly, there was widespread falls in production as gas wells froze under the extreme low temperatures. There was a 45 per cent fall in Texan gas production (**Figure 6**), while at the same time demand was high, driven by residential heating requirements.

Figure 7: Texas gas production



3.4 The consequences of the blackouts

Millions of Texans endured blackouts up to three days long, just at a time when they needed heat available. At least 125 deaths are attributable to the weather event[xvii], though it's not yet clear how many are due to the blackouts. Causes of death include hypothermia, carbon monoxide poisoning (as people brought generators indoors or started their cars to generate some heat) and failure of essential medical devices. Widespread water supply issues, including burst pipes inside freezing buildings and water treatment plants shutting down due to lack of power[xviii]. Most residents were told to boil water first. But that could prove a challenge with no power. Many shops were closed, making it hard for people to buy food and other essentials.

In short, the consequences were much more severe than most rolling blackout events, which are inconvenient but rarely dangerous.

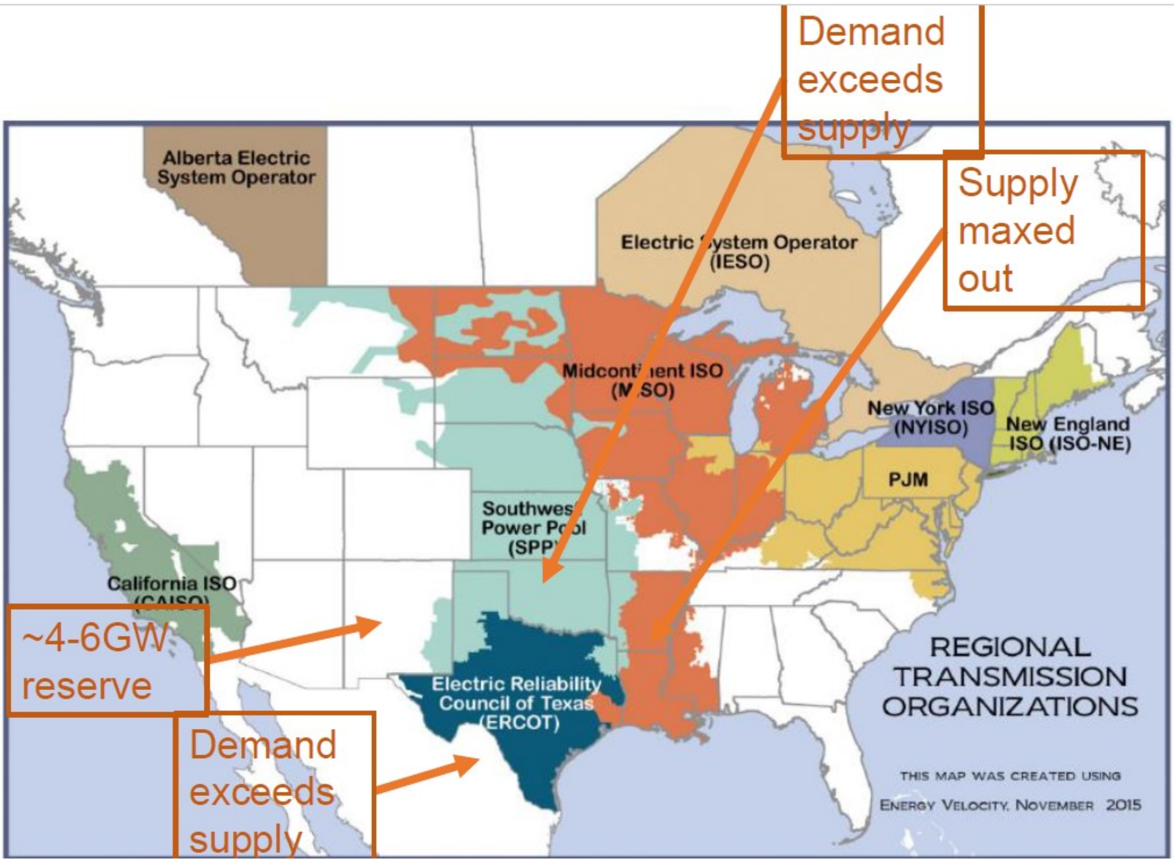
3.5 Weather impacts on non-ERCOT areas

The cold snap extended well beyond Texas. Record-low temperatures hit much of the Midwest and Southwest United States.

Two main neighbouring markets, the Southwest Power Pool (SPP)and Midcontinent Independent System Operator (MISO) regions both experienced rolling blackouts as system operators struggled to balance supply and demand. SPP declared a period of "conservative operations" from 9-20 February and was in danger of exhausting all available reserves through 15-18 February. It had to shed load for 50 minutes on 15 February and just over three hours on 16 February, to reduce load by 1.5 per cent and 6.5 per cent, respectively[xix]. In the MISO South region, covering most of Arkansas, Louisiana, Mississippi and parts of Southeast Texas, loss of generation and transmission led to some emergency load shedding on 15 and 16 February[xx]. This was despite fully committing every available operating asset and seeking voluntary load reduction from consumers.

Power outages in northern Mexico, which relies on gas from Texas, affected nearly 5 million customers too. A snapshot of the overall situation is shown below:

Figure 8: Snapshot of other power systems around ERCOT



Source: IEEE Smart Grid Webinar, 19/02/21

3.6 The aftermath and financial fallout

ERCOT has already lost most of its directors and its CEO[xxi]. Two PUCT commissioners have also resigned. A key issue is that ERCOT intervened to maintain prices at the price cap level for almost two days after the last firm load shed instruction, with the authority of PUCT. This was described as a necessary action to correct a “computer glitch” that was dispatching off available generation that had bid high prices[xxii]. Subsequently, the IMM, Potomac Economics, issued a recommendation that these prices were unjustified and should be unwound. They claimed that gross overcharging amounted to $16bn, although after netting out corporate positions, the repricing would be worth $5.1bn. Of this, $1bn relates to make-good payments for generators for energy that was offered below the price cap but not dispatched (this appears akin to intervention pricing in the NEM). Finally, there was almost $1bn of ancillary services that was priced above the price cap. IMM’s view is that there is no justification for pricing such services above the price cap (but ERCOT evidently felt they could and should do so). To date ERCOT and the PUCT have stood firm (except for the ancillary services) despite political pressure and now futures settlement has taken place on these original prices, making them harder to unwind. It is hard to imagine an analogous situation in the NEM where there could be an equivalent level of ambiguity over the prices charged in an emergency situation.

On the retail side, the wholesale pass-through retailer Griddy has had its licence cancelled, and three other retailers have declared bankruptcy[xxiii]. In Griddy's case, this will make it even harder to reimburse its customers should 17-19 February prices be ultimately re-set.

This being the US there is a lot of litigation to come and it may be some time before all these issues are resolved. That there have not been more retailer failures suggests many were mostly well-hedged and were not directly exposed to the peak prices. While further details may become clear over time it seems the retailer failures to date may be more driven by liquidity issues, i.e., they have to settle with ERCOT before they receive customer bill payments.

4 Analysis

4.1 Diagnosis of why the Texas system failed

During and immediately after the blackouts, several parties rushed to cast judgment on the causes of the severe blackouts. There was a general recognition that while this kind of weather was unusual for Texas, it was by no means unprecedented. The 2011 event, which was similar in many respects, but less extreme in its consequences, had resulted in clear recommendations from the national regulator that Texan generators should be better prepared for extreme weather both through winterization of plant and upgrading their procedures (FERC & NERC, 2011). It was also widely accepted that the temperatures would be considered well within normal winter ranges for many other parts of North America (and far northern Europe, come to that) and that gas and electricity infrastructure there was robust to those temperatures.

Had the national recommendations been implemented, it's likely that the blackouts would have been avoided altogether and certainly been much more limited in scale (e.g., similar to the MISO/SPP level of load-shedding over the same period). While it is hard to be definitive pending the more detailed reviews and investigations that will be carried out over the ensuing months, it appears clear that the weather-driven failure of plant was so extensive in number and diversity of generator type that nothing other than widespread winterization would have made any real difference. The peak demand while unprecedented for winter was still well below the all-time peak of summer 2019. Had there been only a marginal failure of available capacity to meet demand, there might be the case for a nuanced discussion around market design settings, say, and whether a higher price cap would have incentivised some more dispatchable plant. But when a third or more of generation is unavailable that is not a credible argument. Even if all the plant had been winterized, the gas supply issues may have led to significant GPG capacity becoming unavailable. So, it is likely that gas infrastructure vulnerability would need to be addressed too.

In other words, it is more useful to think of the event as a *resilience* issue rather than a *reliability* issue. There was adequate installed capacity to meet the peak demand, so market incentives for adequate investment were broadly working, and the price hit the market cap for almost four days straight, so the short-term incentives for availability were very strong. But too much capacity was left unable to make itself available because the electricity system, and the gas supply system were not resilient to the extreme weather. System security was only preserved by instituting the rolling blackouts (the system was apparently less than five minutes away from collapse at one point).

Resilience in a system is about the capability to be robust to extreme circumstances, such as (but not limited to) extreme weather. The AEMC defines system resilience as “the ability of the power system to avoid, survive and recover from non-credible events”. The definition of credible and non-credible in a power system context is a little different from their usage in plain English (put another way “non-credible” does not mean the same as “incredible”). Credible events are occurrences that are moderate in impact, relatively frequent and thus fairly straightforward to assess and model, such as a single power station unexpectedly going offline, or the failure of a single transformer or transmission line. These are the kinds of events that market operators, such as AEMO, are normally empowered to prepare for, monitor and respond to as necessary to keep the system operating securely. Non-credible events occur relatively infrequently and are generally more difficult to model. This means their impact is much less predictable and potential consequences much less known. Major events affecting multiple components of the system, such as the South Australia black system event and the Texas electricity crisis are clear examples of non-credible events.

With the recommendations from the 2011 event having not been implemented there is a clear sense of failure to have heeded the lessons of past incidents. This indicates that this is fundamentally a question of governance. Some party with the appropriate heads of power, needs to decide that this scale of incident is not acceptable to Texans and that steps needed to be taken to prevent such incidents in the future. It’s likely that the only party in a position to do this is the Texas government. None of ERCOT, the TRE or the PUCT could arrogate to itself the power to enforce winterization of electricity infrastructure, they would need to be given the ability to do so. As was clear from the aftermath of the 2011 event, neither FERC nor NERC had sufficient jurisdiction to insist on winterization, only to recommend it. Finally, to address the gas system vulnerabilities and the interaction with the electricity system, RRC would also need to be involved and none of the electricity market agencies have any power to compel RRC.

It's beyond the scope of this report to present a detailed plan for how to avoid a future event. It is ultimately up to Texans whether it is important enough and to have a clear understanding of the costs involved as well as the benefits. It's likely that widespread winterization of electricity infrastructure and ideally gas too will be required. An alternative might be to look at increasing dual fuel capability, but then fuel delivery and or storage would be required. Consideration will need to be given as to how this will be paid for. Existing market incentives are apparently insufficient. Mandatory standards would risk alienating investors, who would have to spend money on existing assets with no expectation of revenue recovery. Some marginally economic units might choose to exit rather than comply, which would be somewhat counterproductive. Applying standards only to new generation would take too long to become sufficiently widespread given the lifespan of electricity assets. There may be a way to fund or co-fund the necessary investment through a central pool of funds that was then recovered from consumers through an electricity levy, say. But the political optics of this approach may be challenging. In any case monitoring and enforcement protocols to check units remain up to scratch would be necessary. There are practical decisions of how to frame the standard: is it based around meeting design standards for electricity infrastructure for a certain temperature? If so, how low: -10℃, -20℃? None of these issues are insuperable, but it won't be a simple process to find the right balance.

4.2 Debunking some of the claims of causes of the crisis

4.2.1 Renewables

Renewables were one of the first scapegoats, with the Texas governor suggesting they were the root cause of the problem. While many wind turbines were forced offline due to the weather, the available wind output at times exceeded expectations. In any case there was a fair greater impact from gas, coal and nuclear capacity going offline. Finally, the wind outages may well have been avoidable with greater winterization, as is the norm further north.

A more nuanced version of this claim is one made by an RRC commissioner[xxiv]. This is that subsidised renewables have unfairly pushed out more reliable capacity from the market. As with most electricity markets around the world, including the NEM, there is some debate about the impact of subsidies on the overall fuel mix and how to ensure resource adequacy as systems transition to a high renewable mix. But the specific claim is not credible. Texas has met higher electricity demand in recent summers, albeit with a diminishing reserve capacity and has seen continued investment in new gas plants even as wind and solar are ramping up. Even if there would hypothetically be a few more dispatchable plants in the capacity mix if there was less wind and solar depressing the price at other times, unless those plants were weatherized, they wouldn't have been much use anyhow.

4.2.2 Fossil fuels

The early finger pointing at renewables led to a backlash from renewables advocates blaming fossil fuels, and specifically, Texas's high dependency on gas. This dependency has been a source of strength for Texas affording them plentiful, low cost, flexible energy. So, the issue is more about being resilient to gas supply interruptions than abandoning the fuel as unreliable (though in the long run, even Texas may look to decarbonise its electricity system).

As with many energy systems, it's worth thinking through the issues that would arise in a world where everything has been electrified. The demand spike for winter heating that is currently spread across gas and electricity would be confined to a single energy source and new sources of peaking supply would be needed to replace gas. While batteries have great promise for providing short-term flexibility to a power system, Texas would have needed a lot of batteries to keep the lights on for four days.

4.2.3 The energy only market

Capacity market advocates miss no opportunity to criticise energy only markets. What's key to note is that even capacity markets are no guarantee of resource adequacy. In particular, Texas is a summer peaking market, so capacity procurement would be oriented around summer capacity, not winter capacity. It's possible, but by no means a given, that capacity payments would have been predicated on winter availability too, but since Texas has to date declined to ensure winterization of plant, there's no reason to think that this would have been written into capacity contracts. Similarly, whatever penalties might accrue for failing to be available, it's not clear that they would be a stronger incentive to winterize than the incentive under the energy only market to ensure availability for the opportunity of earning scarcity prices. Gas plants would have to consider how they ensured fuel supply as well as the reliability of their own plant under extreme cold conditions if they were to qualify for capacity payments or be confident of avoiding penalties for non-delivery.

Capacity markets also dependent on accurate forecasting of peak demand. Actual peak demand exceeded even ERCOT's high demand expectations as expressed in its seasonal assessment of resource adequacy (SARA) of 67,208MW[xxv]. It's not obvious that decentralised capacity procurement would be inherently better either. Further, to reiterate, ERCOT had previously set higher peak demand in the summer months, so it had adequate installed resources.

Nonetheless, shocks like this can be a catalyst for change, so it will be worth following events in Texas to see if they revisit their market design.

4.2.4 Deregulation and privatisation

This claim rests on a couple of fallacies. Firstly, that vertically integrated, centrally planned systems (or government owned utilities) are axiomatically capable of preparing for extremes. This is not the case, as proven by the second fallacy, that these kinds of events never happened in the good old days. They did. Centrally planned systems are subject to budget constraints and decisions are still taken by humans under imperfect knowledge.

4.2.5 The lack of interconnection

In principle, greater interconnection could have assisted Texas in that more resources could have been available. In practice, neighbouring energy markets also had to institute load-shedding, as discussed in section 3.5, albeit to a lesser extent. Nonetheless the supply and demand balance was very tight across the storm period. So, it's not clear that there would actually have been spare resources, and it seems unlikely that they could have filled the supply gap completely.

Greater interconnection would also have had a dynamic impact on the level of resources within ERCOT. Given it's a competitive market with access to low cost fuel and good renewable resource, it might have had more and been a net exporter but not necessarily. And it might have led the market operator to assume more imports would be available at peak times than would eventuate in practice, as happened in California in summer 2020.

4.3 Lessons and parallels for Australian electricity markets

Providing the diagnosis of sections 4.1 and 4.2 are correct, then there are limited implications for Australian electricity markets. There's currently no case for preparing the NEM or the WEM for the kinds of low temperatures experienced in Texas. And if the fundamental causes weren't ERCOT 's renewables, gas, the market design or the lack of interconnection, then those features that are shared with the NEM or the WEM should not give policymakers here pause for thought.

It's true that as renewables penetration increases, each of these three markets will be essentially reliant on local resources to meet the system's needs for dispatchable supply. The NEM and ERCOT especially will have to monitor their resource adequacy tools to be confident they can continue to drive sufficient supply to meet demand as their load duration curves (net of renewables) continue to steepen.

But given that the key issue for Texas was resilience rather than resource adequacy *per se*, it is resilience where policymakers' attention should focus. The interaction between gas and electricity systems highlighted the importance of considering resilience at a holistic, multi-system level and to understand how such interactions can exacerbate a major event. For gas and electricity interaction, the fact that energy market bodies in the NEM oversee both should be helpful. In a broader sense though, the continuing fragmentation of NEM governance as state governments become more actively involved and create new agencies (VicGrid, multiple entities to deliver the NSW infrastructure roadmap) risks hindering resilience analysis. The WEM has an advantage in that respect.

This is not to suggest that Australian governments or energy market bodies need to launch new reviews relating to resilience in the wake of the Texas crisis. Improving resilience has been a feature of the ongoing reform program since the South Australia system black in 2016. Reviews of that event have resulted in a range of rules and other recommendations being implemented to better prepare for and protect the system from HILP events.

While one cannot draw conclusive evidence about the adequacy of the latest rules, monitoring and protocols, South Australia in particular has been robust to some significant disturbances in recent years. Transmission storm damage in Victoria effectively islanded the state for about a month during which security was maintained (AEMO, 2020). Only last month, a series of events resulted in South Australia losing around 55 per cent of its firm capacity at the same time as the sun was setting and there was little wind[xxvi]. Plus, interconnector capacity to import from Victoria was down due to maintenance. Again, the lights stayed on. Fortunately, demand was moderate, but even so, this was certainly a test of the resilience of the system.

The Finkel Review contained several recommendations relating to resilience. Some of these relate to specific threats such as cybersecurity. Two are quite pertinent to this discussion, though:

2.7 The Australian Government should lead a process to regularly assess the National Electricity Market's resilience to human and environmental threats. This should occur by mid-2019 and every three years thereafter.

2.11 In recognition of the increased severity of extreme weather, by end-2018 the COAG Energy Council should develop a strategy to improve the integrity of energy infrastructure and the accuracy of supply and demand forecasting. (Finkel, 2017)

The latter is rated as "on track" according to the 2020 Health of the NEM report (ESB, 2020). It appears that the Commonwealth has a number of initiatives under way to address it. It has set up a Critical Infrastructure Centre[xxvii], which covers multiple sectors, and established a forum for owners and operators of energy infrastructure to share best practice on resilience. It has also created an Electricity Sector Climate information (ESCI) project to provide tailored climate information to the sector[xxviii]. The latter is especially important in terms of ensuring that the industry and policymakers have a realistic understanding of the envelope of climate risks they should be preparing for. Given Australia's climate, extreme cold is not one of them with the priorities being heat, bushfires, wind and rain/flooding. These initiatives are national in scope so will benefit both the NEM and the WEM.

However, the former recommendation is rated as "on hold" according to Health of the NEM. To the extent that any action by Australian governments and policymakers is relevant in the light of the Texas crisis, then revisiting this recommendation may be the most appropriate response.

On the financial side, the NEM's cumulative price threshold (CPT) – which effectively caps the maximum cost of energy over a week to the equivalent of 15 half-hourly settlement periods[xxix] at the price cap, provides a safety valve against very high settlement requirements. The downside of a CPT is its impact on incentives for additional capacity to meet the very highest peak demand. But it's not clear that it has much impact over and above the impact of the price cap. The WEM being a capacity market has a low price cap and such a situation would not arise.

5 Conclusion

Texans have much to consider in the aftermath of the electricity crisis. They will need to collectively decide how much they value the resilience of their system to extreme weather that may only occur once every ten or more years. They will then need to figure out the most cost-effective way to achieve that resilience and how it will be paid for.

Here in Australia, we can be relieved that we don't face the risk of such extreme cold. Steps have been taken in recent years to improve the resilience of our electricity systems to extreme heat, storms and other threats. While resilience can never be taken for granted there is no need for a knee-jerk response based on broad similarities to Texas in electricity market design or the generation mix.

The Author

Kieran Donoghue is the Director of Newgrange Consulting. His career includes over 7 years as the energy policy lead at three major industry associations, 4 years at the British energy regulator Ofgem and over 9 years as a chartered accountant in a range of corporate and advisory roles.

In his role as head of networks financial issues at Ofgem, he specialized in issues such as cost of capital, tax pensions and financial modelling as well as incentive design for gas and electricity networks. He developed the first Return on Regulatory Equity calculation and also the annual price control reporting process for gas distribution. This involved the introduction of standardised annual reporting of cost, revenue and quality of service information, including data that could be used to derive consistent profitability measures of the sort discussed in this report.

Kieran holds Masters degrees from the Universities of Oxford and London.

Acknowledgement

The author would like to express sincere thanks to Brendan Ring and Todd Bessemer of Market Reform, who kindly provided invaluable insights into the ERCOT market. Any errors in the report are the author's alone.

Bibliography

AEMO. (2020). *2020 Electricity Statement of Opportunities (WEM).*

AEMO. (2020). *Final Report - Victoria and South Australia Separation Event on 31January 2020.*

AER. (2021). *State of the Energy Market 2020.*

ERCOT. (2020). *Seasonal Assessment of Resource Adequacy for the ERCOT Region (SARA) Winter 2020/2021.*

ERCOT. (2021). *Preliminary Report on Causes of Generator Outages and Derates For Operating Days February 14 – 19, 2021 Extreme Cold Weather Event.*

ESB. (2020). *Health of the National Electricity Market.*

FERC & NERC. (2011). *Report on outages and curtailments during the Southwest cold weather event of February 1-5, 2011.*

Finkel, A. (2017). *Independent Review into the Future Security of the National Electricity Market.*

WA Senate Standing Committee on Economics. (2008). *Matters relating to the gas explosion at Varanus Island, Western Australia.*

---

[i] Based on market exchange rate of 1.31 at 6/4/21. Other than in this section, all currency figures are in the relevant local currency.

[ii] https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/030321-texas-cuts-ercot-cap-from-9000mwh-to-2000-summer-exemption-mulled

[iii] Fact sheet – The National Electricity Market, AEMO, 18 July 2020

[iv] Source: EIA

[v] https://boardroomenergy.com.au/2021/02/03/2020-the-year-in-renewables/

[vi] See New Electric Generating Plants in Texas since 1995, at https://www.puc.texas.gov/industry/electric/reports/Default.aspx

[vii] https://www.eia.gov/state/?sid=TX

[viii] http://www.bom.gov.au/climate/extreme/records.shtml

[ix] http://www.bom.gov.au/climate/extreme/records.shtml

[x] There was also a black system event in North Queensland in 2009, however, load was fully restored within two hours.

[xi] https://www.utilitydive.com/news/lessons-from-the-2021-texas-electricity-crisis/596998/

[xii] Curiously, it has no role in regulating the rail sector.

[xiii] http://www.puc.texas.gov/agency/rulesnlaws/subrules/electric/25.173/25.173ei.aspx

[xiv] See post 2025 market design microsite at https://esb-post2025-market-design.aemc.gov.au/

[xv]https://weather.com/storms/winter/news/2021-02-19-record-cold-snow-winter-storms-stretch-recap

[xvi] https://www.iea.org/commentaries/severe-power-cuts-in-texas-highlight-energy-security-risks-related-to-extreme-weather-events?utm_campaign=IEA%20newsletters&utm_source=SendGrid&utm_medium=Email
[xvii] https://dshs.texas.gov/news/updates.shtm#wn
[xviii] https://weather.com/news/news/2021-02-16-winter-storm-uri-impacts-power-outages-boil-water
[xix] https://spp.org/newsroom/press-releases/a-statement-from-barbara-sugg-southwest-power-pool-president-and-chief-executive-officer/
[xx] https://www.misoenergy.org/about/media-center/miso-load-demand-reaches-an-all-time-high-in-western-south-region/

[xxi] https://www.utilitydive.com/news/texas-puc-loses-2nd-commissioner-as-lt-gov-presses-ercot-to-correct-16b/596378/
[xxii] http://www.puc.texas.gov/consumer/facts/factsheets/elecfacts/WinterStormPriceExplainer-FIN.pdf
[xxiii] https://www.power-technology.com/news/industry-news/texas-snow-storm-bankrupt-fallout-energy-prices-ercot/
[xxiv] https://www.rrc.state.tx.us/news/021921-christian-spending-priorities/

[xxv] SARA winter 2020/2021, accessed at http://www.ercot.com/content/wcm/lists/197378/SARA-FinalWinter2020-2021.pdf
[xxvi] See overview of this situation at https://wattclarity.com.au/articles/2021/03/down-55-but-not-out/
[xxvii] https://cicentre.gov.au/
[xxviii] https://www.climatechangeinaustralia.gov.au/en/projects/esci/
[xxix] Effectively 90 5 minute settlement periods once this change to the Rules comes into effect. In both cases this totals 7.5 hours.