Johanna Bowyer, Lead Research Analyst for Australian Electricity
Gabrielle Kuiper, DER Specialist and Guest Contributor
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IEEFA.org

A Grid Dominated by Wind and Solar Is Possible

South Australia: A Window Into the Future

Executive Summary

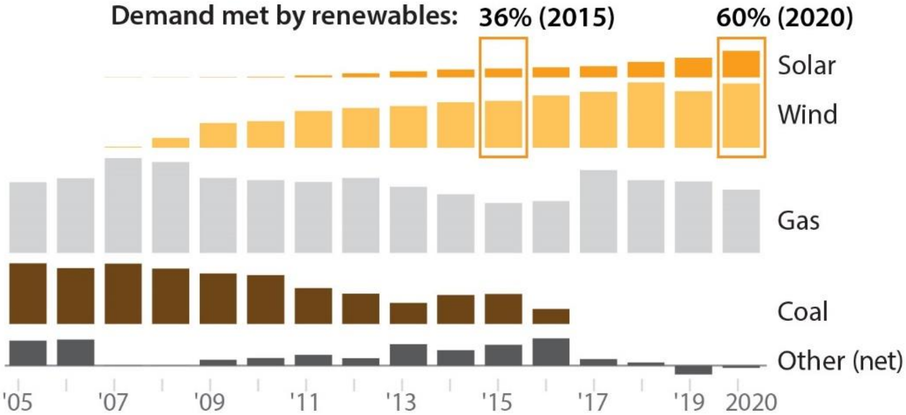
South Australia (SA) is a window into the future of an electricity grid dominated by wind and solar, and backed up by storage.

Lessons from South Australia can help inform other jurisdictions on how to integrate large amounts of variable renewable energy (VRE) generation and distributed energy resources (DER) into the electricity system.

This report presents seven key lessons from the South Australian experience for other states and nations that are transitioning from a fossil fuel-based grid to a low emissions, high renewables penetration grid.

1. 60% of Annual Demand Has Been Provided by Wind and Solar and 100% In Certain Time Periods

South Australia's Rapid Uptake of Renewables
Wind and solar gained traction while coal dropped to zero



Source: OpenNEM (AEMO data) IEEFA

In 2006, South Australia generated all its electricity from fossil fuels.[1] The state Labor government, elected in 2002, introduced an initial target of 26% renewables generation by 2020 which was viewed as ambitious at the time.[2]

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[1] OpenNEM. (AEMO data). Note a small amount of renewables may have been installed, but rounds to 0% renewables in 2006.

[2] RenewEconomy. Against the odds, South Australia is a renewable energy powerhouse. How did they do it? 2 March 2021.

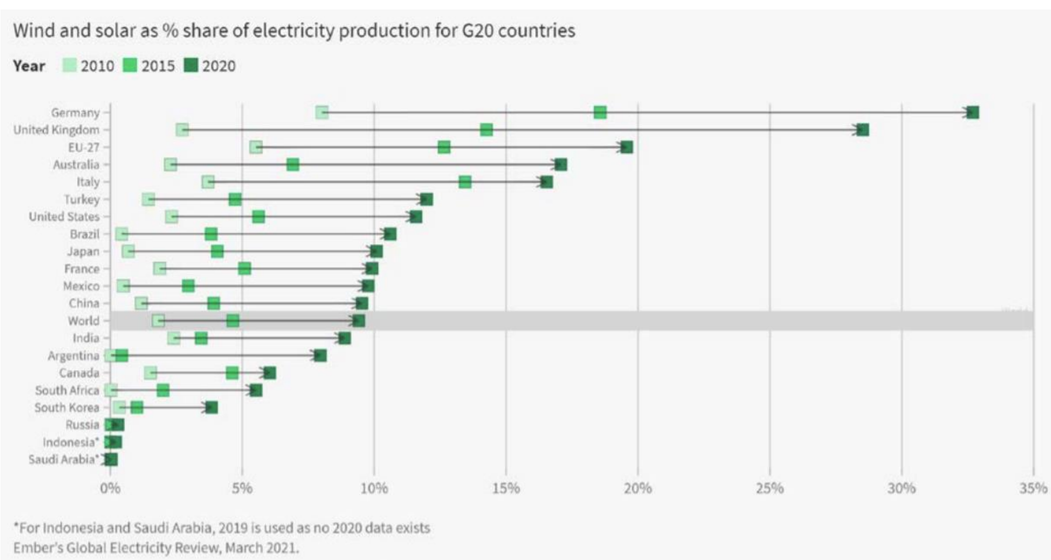
South Australia has far exceeded this initial target with 60% of demand served by variable renewable energy in 2020.[3] South Australia's 2020 electricity demand was served by 13% rooftop solar, 4% utility-scale solar and 42% wind. The remainder was provided by gas generators (42%) with minor contributions from interstate imports, exports and batteries. In October 2020, South Australia experienced an hour in which 100% of its power demand was met entirely by small and large-scale solar with no operational issues.

The government has increased its renewables target to net 100% renewables by 2030. Now, in 2021, the Australian Energy Market Operator (AEMO) expects the state to achieve its net 100% renewables target by 2025, five years ahead of schedule, as the transition is happening far more quickly than expected.[4]

The state is tracking far above most regions of the world in terms of variable renewable energy (i.e. wind and solar) uptake. Leading G20 regions which have the highest share of wind and solar in regional electricity production include Germany at 33%, UK at 28%, EU-27 at 19% and Australia at 17% (Figure 1). Australia as a country is one of the G20 leaders, and South Australia is the leading Australian state in terms of wind and solar deployment.

South Australia therefore provides valuable lessons for the rest of the world, showing what is possible with variable renewable energy (VRE) and distributed energy resources (DER) integration. In particular, South Australia shows that the historical concept of "coal baseload" is not necessary for a reliable electricity system.

Figure 1: Wind and Solar as % Share of Electricity Production for G20 Countries



[3] OpenNEM. (AEMO data).
[4] RenewEconomy. South Australia could meet state Liberals' 100 pct renewables target 5 years early. 22 April 2020.

2. Government Policy and Market Features Can Drive High Adoption of Renewables

Supportive government policy and particular features of the regional market helped drive South Australia's quick transition from a fossil fuel-based grid to one dominated by renewables.

Historically, South Australia has not been heavily reliant on fossil fuel exports. This fact, as well as the long incumbency of South Australia's Labor government, (2002-2018[5]) helped the state government gain traction with pursuing renewable energy and decarbonisation policies. State government policies implemented included government renewable energy supply contracts and solar feed-in tariffs. The state government's efforts were assisted by the federal government's Renewable Energy Target (RET) introduced in 2001 which incentivized renewable energy installations through a Renewable Energy Certification scheme. Furthermore, the state government allowed the closure of the last coal generator in the state, Northern Power Station, to proceed as dictated by market conditions, rather than subsidising the plant to stay online. Coal generation was phased out by the end of 2016. This meant renewables penetration continued to grow to fill the energy supply gap left by exiting coal plants.

Market features in South Australia also drove the high uptake of wind and solar. South Australia is blessed with strong wind and solar resources and in the past had high retail and wholesale electricity prices. Many early projects incentivized by the Renewable Energy Target were installed in South Australia as the market was attractive to investors and developers.

3. Ambitious Renewables Plans (500%) Can Drive Economic Growth

The South Australian government now has an aim to reach 500% renewables by 2050. It is focused on becoming a renewable energy superpower, exporting renewable energy to the neighbouring states of New South Wales and Victoria, and exporting green hydrogen, green steel and other low emissions products internationally.

To reach this goal, investment will be needed in new grid transmission capacity, renewable energy infrastructure and green manufacturing capability.[6] Ambitious renewables plans in South Australia are already resulting in manufacturers setting up in the state, and jobs being created. For example, Sonnen and Alpha-ESS have established manufacturing and assembly facilities in SA. Ambitious decarbonisation plans are expected to drive economic growth into the future.

[5] South Australia Labor. Party Leaders. 2021.
[6] RenewEconomy. South Australia set sights on stunning new target of 500 pct renewables. 16 December 2020.

4. Wind and Solar Bring Down Wholesale Electricity Prices

At present renewables are the cheapest form of generation in Australia's National Electricity Market (NEM). With very low operation and maintenance costs and zero fuel costs, renewables are bidding into the market typically at zero or negative prices, undercutting gas and coal plants which have to pay for fuel (even absent a price on carbon emissions).

The increasing amount of renewables in South Australia's grid has rapidly driven down wholesale electricity spot prices in line with the merit order effect (due to lower-cost electricity being available in the wholesale market), especially in the middle of the day when prices are often negative. Daytime prices in the first quarter of 2021 between 10am and 3.30pm were on average *negative* $12 per megawatt hour (MWh).[7] South Australia was the state that recorded the lowest wholesale prices in the National Electricity Market in the last four months of 2020. The last time South Australia had been the lowest price region was 2012.[8]

5. System Reliability and Security Can Be Maintained in a High Renewables Grid

Overall South Australia has met its reliability standard for the past 15 years except for 2008-09 when extreme temperatures in Victoria and South Australia reduced the availability of the interconnector between the two states.[9] This shows reliability can be maintained in a 60% variable renewable energy grid.

However, South Australia is facing technical transition challenges with integrating large amounts of renewables before other Australian states and many other regions in the world. There are a larger number of generators in the grid due to the increasingly distributed nature of energy resources, and there is more variation in generator output due to the variable nature of wind and solar generators. This requires a more dynamic operating regime.

Adjustments have been made in South Australia to maintain system security. The Australian Energy Market Operator (AEMO) had to intervene in the market 253 times in 2019-20 compared to 153 times in 2018-19 to direct "synchronous generators to maintain the system in a secure operating state." These were security directions for the provision of fault current. [10] Electranet, the South Australian transmission business, is installing and commissioning four new synchronous condensers to help manage system strength and inertia.[11] Other reforms and rule changes are also being progressed to manage system security.

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[7] AEMO. Quarterly Energy Dynamics Q1 2021. April 2021.
[8] AEMO. Quarterly Energy Dynamics Q4 2020. 29 January 2021.
[9] AEMC. Information Paper – The Reliability Standard. March 2020.
[10] AEMO. South Australian Electricity Report. November 2020.
[11] Ibid.

A recent IEEFA report[12] argued that investments in synchronous condensers, and the development of market mechanisms to procure inertia (currently under consideration by regulators) should be scrutinized, and some measures should only be temporary, as they may be superfluous in a post-transition grid. The electricity industry needs to develop a more sophisticated, dynamic control and communication system using AI, grid-forming inverters and improved data management systems, so that electronics and software can provide grid security and stability. Long term planning for a digitalized, zero-inertia, zero-emissions system needs to start now in order to avoid unnecessary regulations or investment in technology that may become obsolete.

For South Australia to reach 100% net renewable generation by 2030[13] and 500% by 2050, work will need to be accelerated in the development of a smarter grid and more intelligent system operation.

6. Batteries Can Help Maintain System Reliability and Security

Batteries have played a significant role in maintaining system security and reliability in South Australia. The state has four grid-scale batteries in operation, another two have commenced construction, and the South Australian energy minister has stated “we’ll get more and more of those.”[14]

The world’s largest battery energy storage system (at the time of commissioning), the Hornsdale Power Reserve, was installed in South Australia by Tesla and Neoen in 2017. It is a technical success, helping to keep the lights on when faults have occurred in the grid. It is also a financial success, recovering its capital cost in a little over two years of operation.[15] It has earned significant revenue by providing Frequency Control Ancillary Services (FCAS), as well as through energy arbitrage and other services (detailed below).

7. High Penetrations of Rooftop Solar Can Be Managed With Distribution Network Innovation

The South Australian example shows it is important to plan for high penetrations of rooftop solar. The percentage of households in South Australia with rooftop solar photovoltaics (PV) is 40.3% making the state one of the global leaders (Queensland is estimated to be 41%).[16]

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[12] IEEFA. Australia’s Opportunity To Plan Ahead for a Secure Zero-Emissions Electricity Grid. March 2021.
[13] RenewEconomy. South Australia minister aiming for 100 per cent renewables before 2030. 6 May 2020.
[14] Dan Van Holst Pellekaan – SA Energy Minister. ABC Four Corners Fired Up. 12 April 2020.
[15] RenewEconomy. Tesla big battery recoups cost of construction in little over two years. 15 May 2020.
[16] Australian PV Institute (APVI). Mapping Australian Photovoltaic installations. 31 December 2020.

This has led to concerns about voltage rise and declining minimum operational demand. However, high voltages are a pre-existing significant issue in the distribution network with rooftop solar only being a minor contributor.[17] In fact, a University of New South Wales (UNSW) analysis commissioned by the Energy Security Board (ESB) found that many sites experience higher voltages during the night when rooftop solar is not operational.[18]

A regulation was introduced in 2020 stating that rooftop solar inverters must be able to be remotely disconnected when directed by the market operator. IEEFA has raised concerns regarding the technical need, economic efficiency and lack of social licence for this regulation.[19]

More productive innovations have been the LV monitoring, transformer tap changes, and especially the development of dynamic operating envelopes (DOEs). DOEs allow distributed energy resources (DER) to import and export within the constraints of distribution networks on a 5-minute basis, set 24 hours in advance.

Incorporating DER into distribution networks is not costly. In fact, South Australia Power Networks (SAPN) is currently managing 40% rooftop solar penetration with less than 1% of its regulated network revenue.[20] Additionally, it is expected that an additional interconnector to New South Wales being constructed by 2024 will negate most minimum demand risk and, over time, the adoption of behind-the-meter and front-of-meter batteries, electric vehicles (EVs) and associated vehicle to grid (V2G) technologies will all but eliminate any other real or perceived challenges with rooftop solar exports.

The transition to a zero-emissions, zero-inertia electricity grid,[21] with a comprehensive demand response regime, and optimisation of both large scale and distributed energy resources has yet to be achieved anywhere in the world.

South Australia has the potential to achieve this outcome within a decade with thoughtful planning and policy.

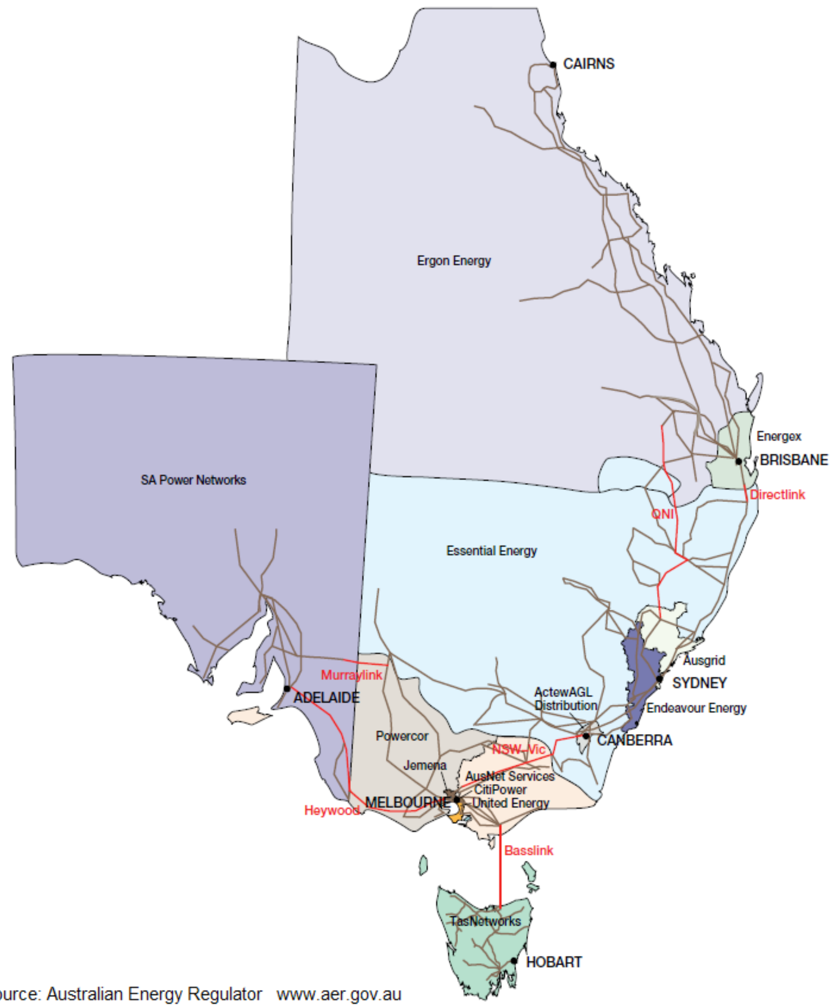
[17] See Energy Ministers: LV Voltage Report.
[18] Ibid.
[19] Gabrielle Kuiper & Steve Blume, Blunt Instrument: Uncompensated Solar Cut-Off Isn't the Only Solution to the Minimum Demand 'Problem', IEEFA April 2020.
[20] Australian Energy Regulator. SA Power Networks - Determination 2020-25. June 2020.
[21] IEEFA. Australia's Opportunity To Plan Ahead for a Secure Zero-Emissions Electricity Grid. March 2021.

Table of Contents

About South Australia

South Australia (SA) has a population of 1.7 million people, approximately 7% of Australia's total, and is at the eastern edge of the National Electricity Market (NEM) which extends along Australia's east coast (Figure 2). The capital city, Adelaide houses 1.3 million people and the majority are employed in service industries, although there is also employment in agriculture, manufacturing and mining.

Figure 2: Australia's National Electricity Market, Including South Australia



Source: Australian Energy Regulator www.aer.gov.au

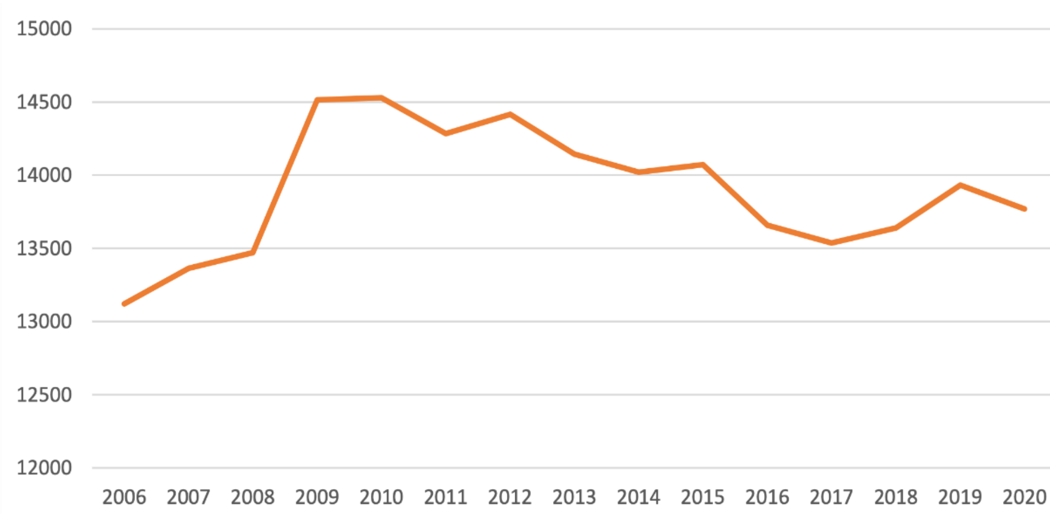
Note: SA shown in dark purple - Electranet (transmission) and SA Power Networks (distribution) network area.

Overall installation of rooftop solar, energy efficiency improvements, and the cessation of motor vehicle manufacturing in SA have caused a decline in demand from the grid (Figure 3). The Australia Energy Market Operator (AEMO) expects a continued slow decline in SA grid demand over the next decade.[22] This will depend

[22] AEMO. South Australian Electricity Report. November 2020. p. 4.

on electric vehicle (EV) uptake and progress towards the SA government's aim to reach 500% renewable energy (further detailed below).[23]

Figure 3: South Australia Total Annual Generation (GWh)



Source: OpenNEM (AEMO data).

Australia has the highest average solar radiation per square metre of any continent in the world. SA has extremely high solar potential, with many areas receiving over 23.5 MJ/m^2 yearly average irradiance. [24]

SA also has abundant wind resources (Figure 4). The Eyre Peninsula has four wind zones with wind farm capacity factors above 38%. This area is estimated to have the potential to support over 10,000 megawatts (MW) of wind generation.[25]

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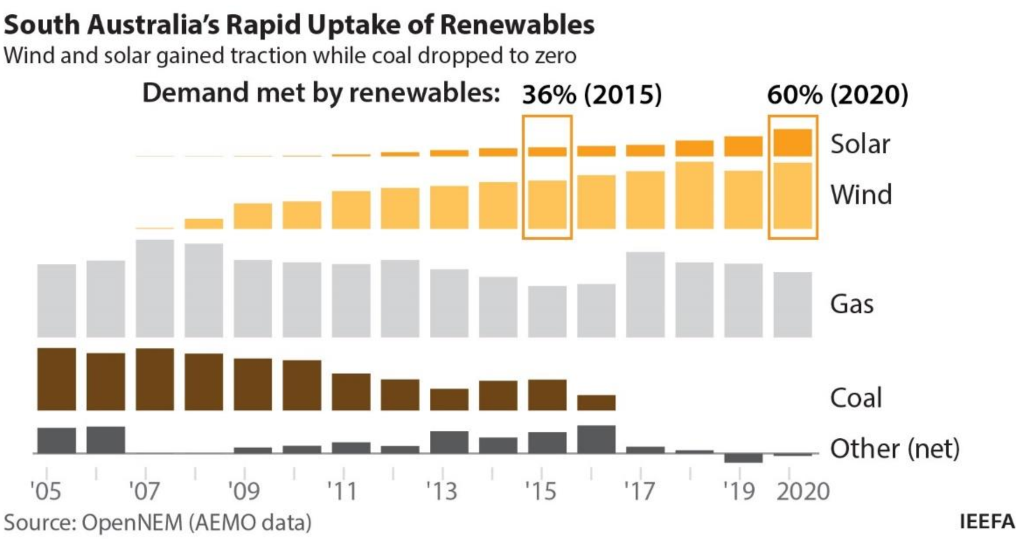
[23] Government of South Australia. South Australian Government Climate Change Action Plan 2021–2025. 16 December 2020.
[24] Government of South Australia. Renewable Energy Atlas. 2019.
[25] Ibid.

Figure 4: South Australia's Wind Resources

Source: Government of South Australia.[26]

Lesson 1: 60% of Annual Demand Has Been Provided by Wind and Solar and 100% in Certain Time Periods



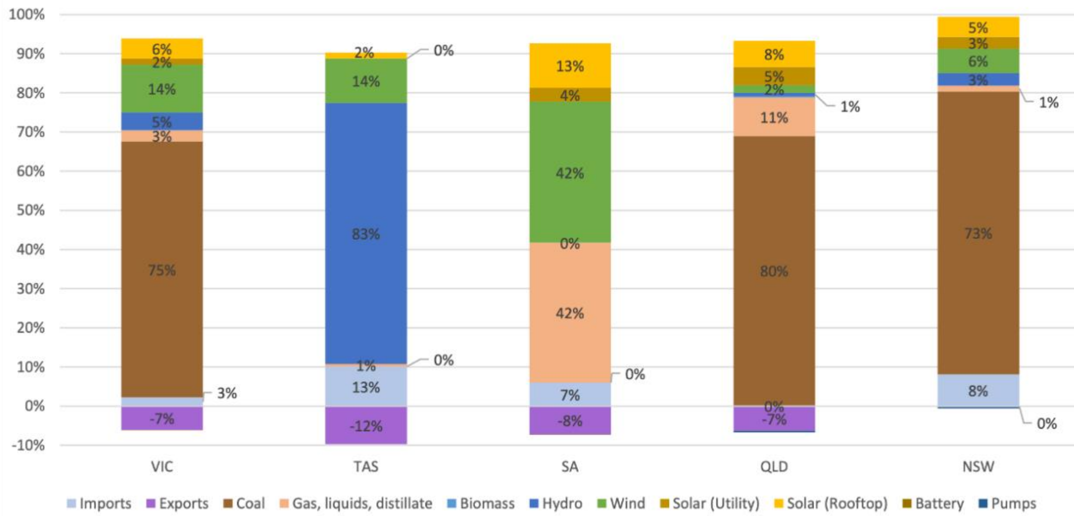
In South Australia, variable renewable energy (VRE) generation grew from meeting 0% of electricity demand in 2006 to 60% of demand in 2020.

In 2020, 13% of demand was provided by rooftop solar, 4% by utility-scale solar

[26] Government of South Australia. Renewable Energy Atlas. 2019.

and 42% by wind. The remainder of demand was provided by gas generation (42%), imports and exports from the neighbouring state of Victoria, and a minor contribution from batteries.[27] Wind and solar penetration in SA are now higher than any other Australian state (Figure 5).

Figure 5: Demand Served by Each Technology in Each State, 2020



Source: OpenNEM (AEMO data).

While SA had 60% of demand served by VRE for 2020 overall, VRE generation was much higher in certain time periods, especially spring and autumn when cooling and heating loads are low and renewable energy generation is strong. For example, variable renewable energy generation was 73% for the month of September 2020.[28]

Wind and solar resources tend to complement each other in SA. When solar resources are low at nighttime, wind resources are often abundant. Figure 6 below shows a 24-hour period in 2019 in which 30% of the state's energy demand was generated by solar PV during the day and 39% by wind power including at night, totalling 69% total renewables. Batteries provided 0.6% of the state's demand.[29]

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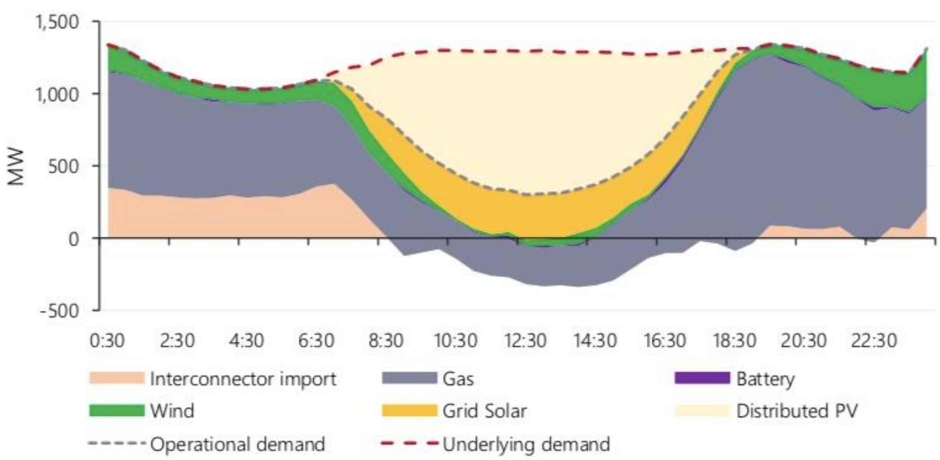
[27] OpenNEM. (AEMO data). Note a small amount of renewables may have been installed, but rounds to 0% renewables in 2006.
[28] RenewEconomy. South Australia wind and solar served stunning 73% of demand in September. 2 October 2020.
[29] David K Clarke. South Australia's great success in changing toward renewable energy. November 2020.

Figure 6: South Australia's Power Generation Over One Day

Source: OpenNEM. South Australia's power generation sources over a 24 hour period, 7-8 December 2019.

The SA example has shown that 100% solar generation is possible in daytime. For one hour between 12.30-1.30pm on 11 October 2020, a mild spring day, 100% of SA demand was met by solar energy—a first for any major jurisdiction in the world. Three quarters of the supply was from rooftop systems (with 288,000 rooftop solar installations generating 992MW) and another 313MW was generated by large-scale solar plants (Figure 7).[30] There were no operational issues associated with this milestone.

Figure 7: South Australia Generation Mix – 11 October 2020



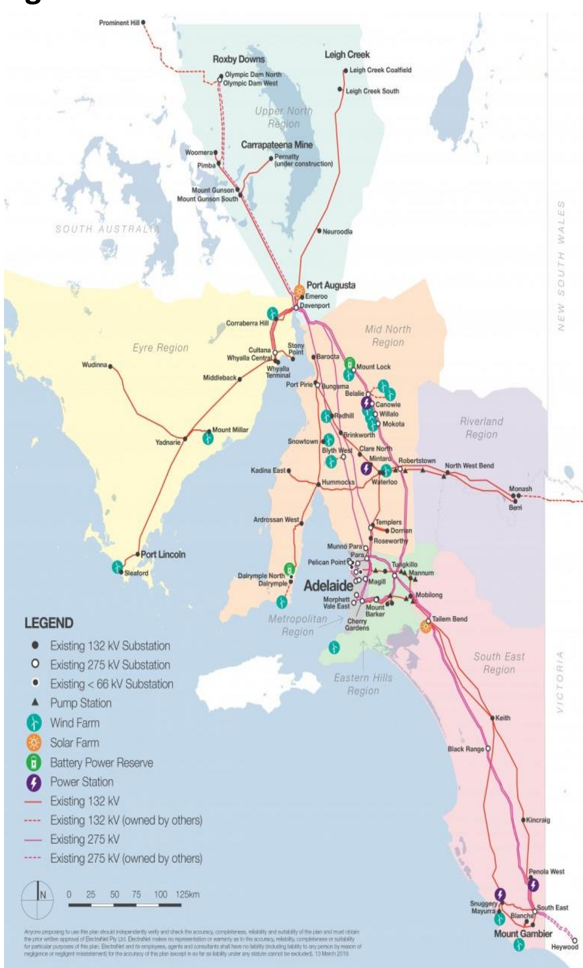
Source: AEMO

[30] Rethink Technology Research. Solar reached 100% of generation in South Australian noon. 29 October 2020.

In the current market, gas, liquids and batteries turn on when there is not enough renewable generation to satisfy demand. Gas generation is seen as a temporary generation technology in SA, with the energy minister stating: “we'll use less and less gas over the time”.[31] Coal generation was phased out in SA in 2016.

SA also has the ability to import power from Victoria, which provides additional firming when required.[32] This includes 2 interconnectors between SA and Victoria: the 650MW Heywood interconnector (shown on bottom right in Figure 9) and the 220MW Murraylink interconnector.[33] The planned construction of another interconnector with the state New South Wales (NSW) will allow SA to balance with a second NEM region in addition to Victoria. As AEMO identifies, this will ‘alleviate the most challenging system security issues’.[34]

Figure 9: South Australia's Network and Generators



Source: Electranet.[35]

[31] Dan Van Holst Pellekaan – SA Energy Minister. ABC Four Corners Fired Up. 12 April 2020.
[32] Electranet. Project Overview.
[33] AEMO. South Australian Electricity Report. November 2020.
[34] Australian Energy Market Operator. Minimum Demand in South Australia (SA). May 2020
[35] Elecranet. Network Map.

AEMO now expects SA will achieve its net 100% renewable energy target by 2025, five years ahead of schedule (the state government's original target was net 100% renewables by 2030).[36]

The SA example shows:

- **The historical concept of "coal baseload" is *not* necessary for a reliable electricity system. A system can operate on 60% wind and solar,** backed up by storage, peaking gas and imports from neighbouring regions (however note that neighbouring regions currently contain coal generators).

- **It is possible to have 100% of a state's energy demand met by solar PV generation**.

Lesson 2: Government Policy and Market Features Can Drive High Adoption of Renewables

The SA Labor government, elected in 2002, introduced an initial target to generate 26% of South Australia's electricity from renewables by 2020.[37] This target was viewed as ambitious at the time.[38] Australia's Federal Government also introduced a national Renewable Energy Target (RET) in 2001 which incentivized renewable energy installations through a Renewable Energy Certification scheme. It initially aimed to source 2% of Australia's electricity generation from renewables by 2020.[39]

In 2006, approximately 0% of electricity demand was served by renewables in SA. In 2009, the national RET was raised, aiming to generate 20% of Australia's electricity from renewable sources by 2020. At this time, SA had market features which made wind investment very attractive, including high quality wind resources, high wholesale power prices[40] and higher retail electricity prices than other states in Australia (Figure 8). Also, much of SA's best onshore wind resources are located near existing transmission lines running 300km from Port Augusta to Adelaide.[41] This meant that wind generation projects were often more attractive in SA than in other states. As a result, SA could compete nationally for investments incentivized by the RET. By 2009, wind contributed to 16% of SA demand, when the proportion

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[36] RenewEconomy. South Australia could meet state Liberals' 100 pct renewables target 5 years early. 22 April 2020.
[37] RenewEconomy. Against the odds, South Australia is a renewable energy powerhouse. How did they do it? 2 March 2021.
[38] Dr Michael Greevey, Colin MacDougall, Dr Matt Fisher, Mark Henley, Fran Baum. Expediting a renewable energy transition in a privatised market via public policy: The case of south Australia 2004-18. January 2021.
[39] Clean Energy Regulator. History of the Scheme. 30 November 2016.
[40] In the past, SA had higher wholesale power prices compared to most other Australian states, due to lack of a low-cost quality coal resource, and peakier demand which led to greater reliance on higher cost gas generators. This has however changed recently due to the flood of new renewable generation, and SA at present has very low wholesale prices (explored further below)
[41] Government of South Australia. Renewable Energy Atlas. 2019.

in all other states was still below 5%.[42] By 2015, wind contributed to 30% of demand in SA.[43]

The state government's solar feed-in tariff also drove growth in rooftop solar installations. In 2008 South Australia was the first jurisdiction to have a subsidised net feed-in tariff for rooftop solar exports.[44] This, along with the historically high retail price of electricity (as shown in Figure 8) made rooftop solar more attractive to householders than in other Australian states early on in the transition.

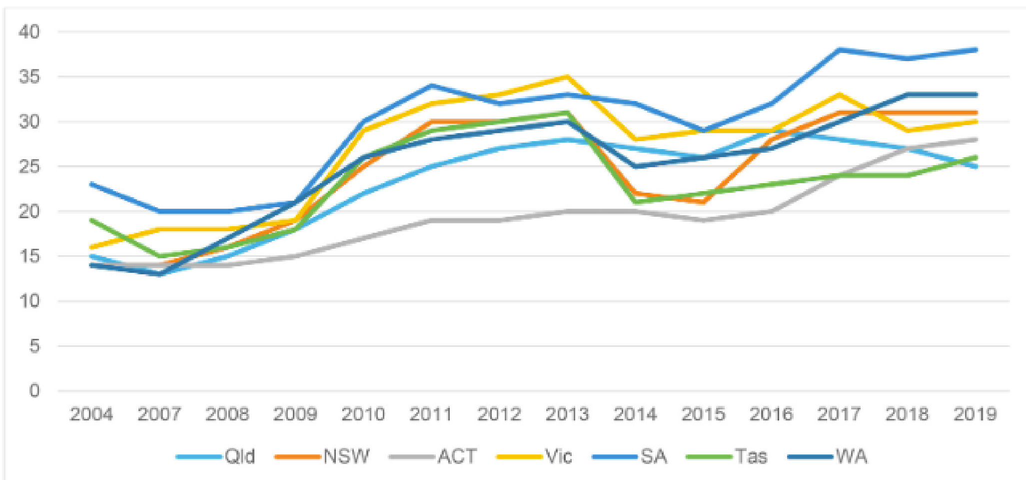

Fig. 4. Retail price cents/Kwh 2004–19 (AEMC, 2011–2019).

Figure 8: Retail Electricity Price in Each State

Source: Dr Michael Greevey, Colin MacDougall, Dr Matt Fisher, Mark Henley, Fran Baum.[45]

State government supply contracts also supported renewable energy projects in the state. For example, the SA government's desalination plant contracted with the gentailer AGL in 2009 to be powered by South Australian renewable energy projects[46] and in 2020, the SA government signed a 10-year supply contract for the government's energy needs for 280MW from the Cultana solar farm and 100MW from the Playford Utility battery.[47]

By 2016, all coal generators in SA had been phased out. Playford B (240MW) was mothballed in 2012 then Northern Power Station (520MW) was retired by Alinta

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[42] OpenNEM.
[43] Ibid.
[44] Government of South Australia. Solar feed-in payments. 27 November 2018. (Table O).
[45] Dr Michael Greevey, Colin MacDougall, Dr Matt Fisher, Mark Henley, Fran Baum. Expediting a renewable energy transition in a privatised market via public policy: The case of south Australia 2004-18. January 2021.
[46] AGL. South Australian desalination renewable energy contract underlines strength of AGL's renewable energy position. 10 September 2009.
[47] PV Magazine. SA Government contracts for energy to advance Cultana Solar Farm and Playford Utility Battery. 2 November 2020.

Energy in 2016.[48] Both plants, prior to ceasing generation, were operating primarily in the summer to meet peaks in electricity demand.[49,50] Wind generation increases along with reduced demand had made coal plants unprofitable to run around-the-clock in winter.[51]

In 2015 Alinta Energy offered to keep Northern station running for another 3 years for a $24 million payment, but the South Australian government refused.[52] Both coal plants were then closed in 2016. The reason for retirement of the coal plants, according to Alinta, was that operations had become "increasingly uneconomic" due to a decline in energy demand in SA (as the number of industrial customers had fallen and households had become more efficient), and that there was an excess supply of generation, putting downward pressure on wholesale prices and making them "unable to generate enough revenue to support the cost structure of the business".[53]

Though not stated explicitly by Alinta, the increasing supply of wind and rooftop solar and a national oversupply of largely coal-generated wholesale electricity made it difficult for the ageing SA coal plants to compete.[54] The increasing amounts of renewables were complemented by storage or responsive generation (like peaking gas-fired power plants, which remains in the SA grid to this day), rather than the inflexible coal plants.

Before closing the last remaining coal plants in 2016, SA had the highest wholesale electricity prices in the mainland NEM.[55] The closure of the Northern plant led to a temporary wholesale price rise of 7.7%.[56] Since 2017 wholesale electricity prices have reduced by 65% (2017 - 2021 YTD) and the contribution of renewables to demand has grown from 43% to 60% (2017 - 2020). [57]

This shows that closing unprofitable, expensive coal plants and installing large amounts of renewables can reduce electricity prices. The SA government, in refusing to subsidise the ageing and unprofitable Northern (coal-fired) Power Station,

[48] Global Energy Monitor. Northern Augusta Power Station. 25 December 2019.
[49] Ibid.
[50] Global Energy Monitor. Playford power station. 25 December 2019.
[51] Dr Michael Greevey, Colin MacDougall, Dr Matt Fisher, Mark Henley, Fran Baum. Expediting a renewable energy transition in a privatised market via public policy: The case of south Australia 2004-18. January 2021.
[52] Dr Michael Greevey, Colin MacDougall, Dr Matt Fisher, Mark Henley, Fran Baum. Expediting a renewable energy transition in a privatised market via public policy: The case of south Australia 2004-18. January 2021.
[53] ABC News. Alinta Energy to close power stations at Port Augusta and coal mine at Leigh Creek. 11 June 2015.
[54] Dr Michael Greevey, Colin MacDougall, Dr Matt Fisher, Mark Henley, Fran Baum. Expediting a renewable energy transition in a privatised market via public policy: The case of south Australia 2004-18. January 2021.
[55] Australian Energy Regulator (AER).
[56] ABC News. South Australian power bills to increase by $115 after Hazelwood power station closure. 14 Dec 2016.
[57] OpenNEM (AEMO data).

enabled the transition to a renewables dominated grid to occur sooner than it would have otherwise.

The SA example shows:

- **Financially backed government policies (e.g. the RET, the state feed-in tariff, government supply contracts) can drive renewables installations.**

- **Allowing unprofitable fossil fuel plants to close as dictated by market conditions, rather than providing them with subsidies to stay open for longer, can lead to increase renewables uptake and reduction in wholesale electricity prices in the medium term.**

Lesson 3: Ambitious Renewables Plans (500%) Can Drive Economic Growth

While SA is likely to reach net 100% renewables by 2025[58], the SA government now has an aim to reach 500% renewables by 2050, exporting surplus renewable energy to other states and internationally through green hydrogen and other low emission products. This is expected to drive economic growth in the region.

> *"South Australia's transition to a net zero emissions economy and a national and international exporter of clean energy could mean achieving a level of renewable energy that is more than 500 per cent of current local grid demand by 2050."*
>
> - SA Government Climate Change Action Plan[59]

Reaching the 500% renewables goal will require investment in new transmission projects. Across the NEM there are plans for new Renewable Energy Zones (REZs) in areas with high wind and/or solar potential, and for transmission lines to connect the REZs to load centres. A new interconnector to enhance energy supply demand balancing between SA and NSW has been identified as a high priority project. Transmission line augmentations between Adelaide and high wind potential areas are also being explored for feasibility (Figure 10).

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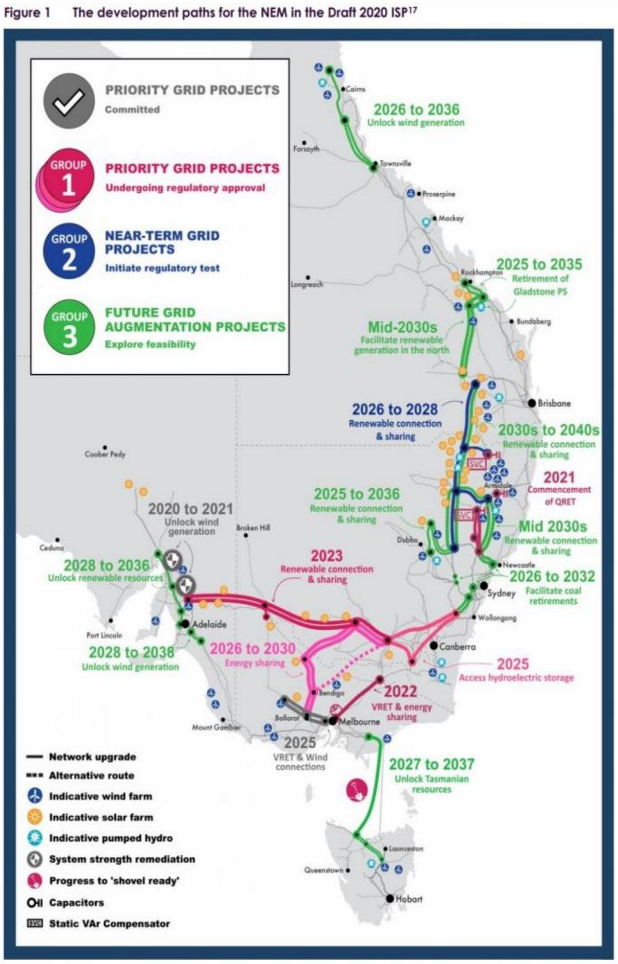
[58] RenewEconomy. South Australia could meet state Liberals' 100 pct renewables target 5 years early. 22 April 2020.
[59] Government of South Australia. Climate Change Action Plan 2021–2025. 2020-21.

Figure 10: Planned ISP Projects



Source: AEMO.

The ambitious SA aim to reach 500% renewables is being backed by government investment in decarbonization initiatives. This is creating an environment which is attracting international investment and creating local jobs.

At present, SA has many state government programs supporting the transition including:

- $100 million Home Battery Scheme[60]
- $50 million Grid Scale Storage Fund

[60] This scheme gives all grid-connected South Australians access to state government subsidies and low-interest loans provided by the Clean Energy Finance Corporation to help pay for home battery systems and new solar if required. It is driving increasing battery installations in SA, increasing investment and adding local jobs. See Government of South Australia. Benefits of Home Battery Scheme shining through. October 2019.

- $150 million Renewable Technology Fund[61]
- $2 million grant plus $20 million loan for a Virtual Power Plant[62], and
- $18.3 million Electric Vehicle Action Plan.[63]

Furthermore, the federal and state government have, together, committed to $1 billion in funding for hydrogen, carbon capture and storage (CCS), electric vehicles and gas.[64] While CCS has been criticised for its high cost[65], and gas for its high emissions, green hydrogen and electric vehicles are expected to be key enablers of a low emissions grid.

The state government Home Battery Scheme has driven an uptick in battery equipment demand. The number of behind-the-meter batteries in SA is currently estimated at 17,000 units (2019-20) and is forecast to almost triple in the next 5 years. This will represent 20% of all batteries in the NEM by 2025.[66] The high demand for batteries has resulted in international battery manufacturers Sonnen and Alpha-ESS establishing local manufacturing and assembly facilities in the state and creating local jobs. More than one hundred local system providers are now qualified to sell and install batteries under the scheme. [67]

To reach 500% renewables, additional investment will be required in new renewable energy generation projects, green hydrogen facilities and local low-emission product manufacturing capability. This is expected to drive significant economic growth and jobs creation.

The SA example shows that:

- **There is potential to drive significant economic growth through state-based decarbonisation policies and programs.**

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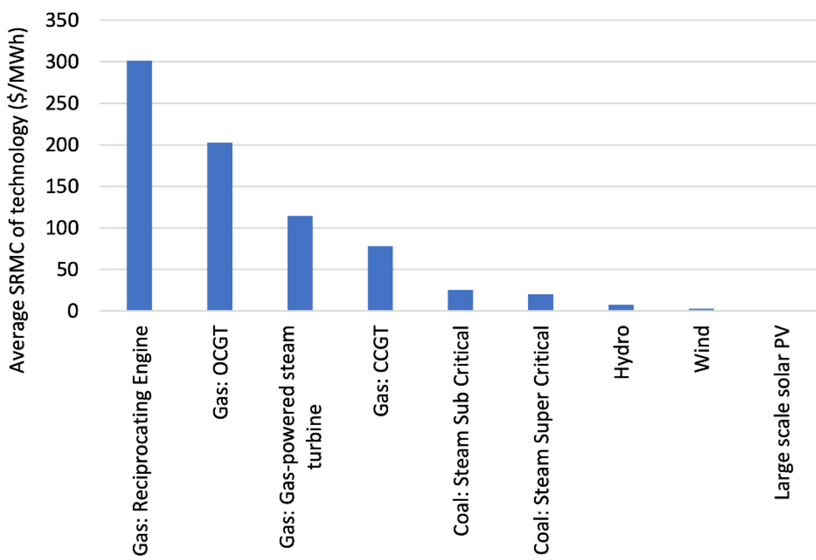
[61] Government of South Australia Department for Energy and Mining. Growth and low carbon. 2021.
[62] Government of South Australia Department for Energy and Mining. South Australia's Virtual Power Plant. 2021.
[63] Government of South Australia Department for Energy and Mining. Electric vehicles. 2021.
[64] ABC. Scott Morrison reveals $1bn energy deal with South Australian government. 18 April 2021.
[65] RenewEconomy. Carbon capture could be six times more costly than wind and storage, analysis shows. 9 December 2020.
[66] Australia Energy Market Operator. South Australian Electricity Report. November 2020.
[67] This scheme gives all grid-connected South Australians access to state government subsidies and low-interest loans provided by the Clean Energy Finance Corporation to help pay for home battery systems and new solar if required. It is driving increasing battery installations in SA, increasing investment and adding local jobs. Source: Government of South Australia. Benefits of Home Battery Scheme shining through. October 2019.

Lesson 4: Wind and Solar Bring Down Wholesale Electricity Prices

The increasing amount of renewables in SA and the NEM are bringing down wholesale electricity spot prices. Wind and solar have the lowest short-run marginal cost (SRMC) of key generators in the NEM. This is mainly due to their zero-fuel cost and low operation and maintenance costs (Figure 11).

Figure 11: SRMC of Each Technology in the NEM ($/MWh)

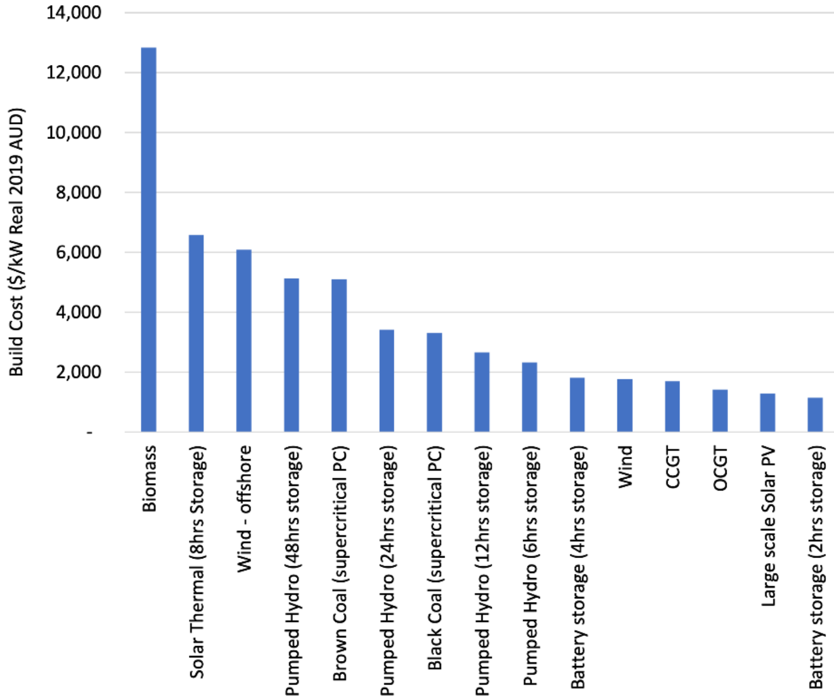


Source: AEMO.[68]

Battery storage and large-scale solar PV also have the lowest new build cost of all energy generating technologies in the NEM (Figure 12).

[68] AEMO. 2019 Input and Assumptions workbook. 5 July 2020. Tab: Generator Summary - Existing, Committed and Anticipated Generators.

Figure 12: Build Costs for Generation Technologies 2020-2021



Source: AEMO – Original Source CSIRO GenCost 2020 and Entura 2018.[69]

The marginal cost of solar and wind plants is so low they usually bid into the market at low, zero or even slightly negative prices. The bidding behaviour of 7 example renewable generators is shown in Table 1, with the amount of time they bid at zero or below at 99%. Note this refers to spot market bid behaviour, however many energy generation projects will also be contracted via PPA or other contracts.

Table 1: Bidding Behaviour of Sample of Wind and Solar Plants

Plant Name	Technology	<$0	$0-5000	>$5000	% Time Less Than Zero
Bannerton Solar Park	Solar	853	0	10	99%
Beryl Solar Farms, Units 1-60	Solar	591	1	5	99%
Broken Hill Solar Plant	Solar	1875	0	26	99%
Ararat Wind Farm	Wind	1557	0	42	97%
Bald Hills Wind Farm	Wind	2077	2	18	99%
Boco Rock Wind Farm	Wind	2132	2	23	99%
Bodangora Wind Farm	Wind	848	0	13	98%
Average					**99%**

Source: VEPC NEM Data Dashboard.

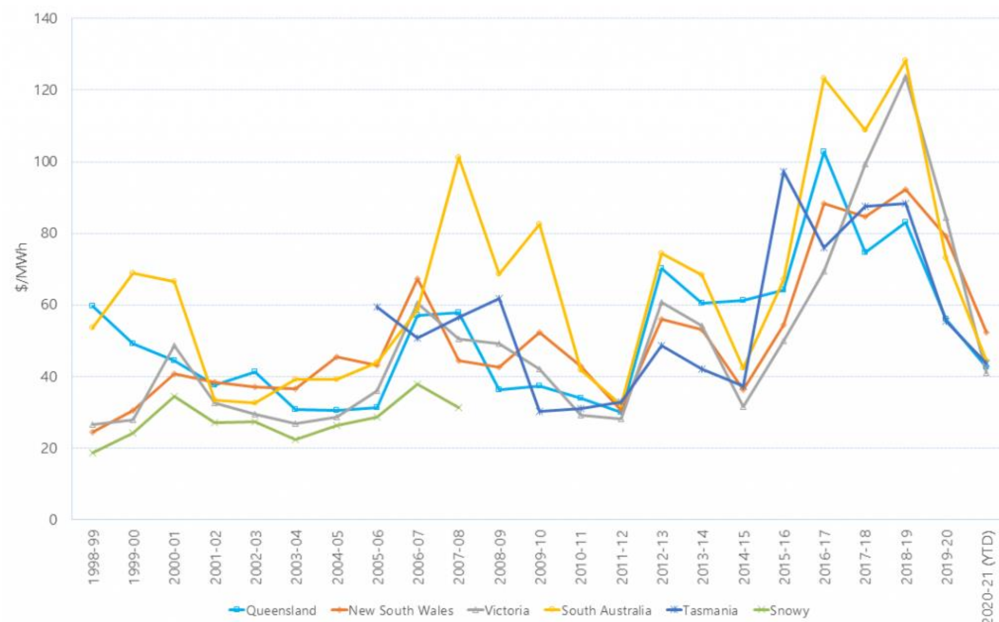
[69] AEMO. 2019 Input and Assumptions workbook. 5 July 2020.

It has been seen in the NEM that, as low cost wind and solar are integrated into the market, prices are decreasing in line with the merit order effect. Wind and solar bid into the market at such low prices that it puts downward pressure on wholesale electricity spot prices. The downward pressure on prices is also exacerbated by negative to low demand growth.

Wholesale electricity prices peaked NEM-wide in 2017. In this period, prices across the NEM were $103/MWh and in SA were $126/MWh. In 2021 year-to-date (YTD), prices in the NEM were $40 and in SA $44. The NEM has experienced a drop of 61% and SA a drop of 65% (2017 - 2021 YTD).[70]

These major wholesale electricity price reductions are indicative of increasing amounts of renewables in the system, with SA experiencing a higher reduction than the NEM overall. SA prices are now at their lowest levels since 2015-16 (Figure 13).[71] Furthermore SA was the Australian state that recorded the lowest wholesale prices in the NEM in the last four months of 2020.[72] Low prices in SA (and NEM-wide) are indicative of increasing amounts of renewables in the system driving down prices.

Figure 13: Annual Volume Weighted Average Wholesale Spot Prices - Regions



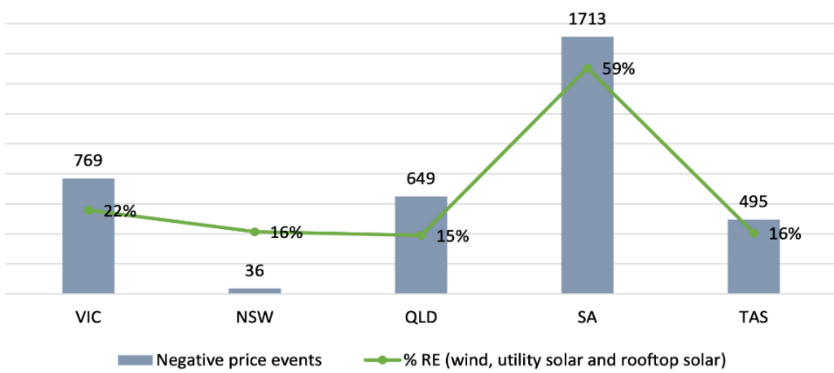
Source: AER.[73]

Negative prices are becoming more frequent due to lower daytime demand (driven primarily by increasing rooftop solar PV uptake), increased interconnector

[70] OpenNEM.
[71] AEMO. South Australian Electricity Report. November 2020.
[72] AEMO. Quarterly Energy Dynamics Q4 2020. 29 January 2021.
[73] Australian Energy Regulator. Annual volume weighted average spot prices – regions. 2021.

constraints and large amounts of renewable generation supplied to the market at low prices. SA had the highest number of negative price instances in 2020 (1,713) (Figure 14). In Q1 of 2021, SA had negative spot prices for 17% of the time and the average spot price during peak solar production (10am-3.30pm) was *negative* $12/MWh.[74]

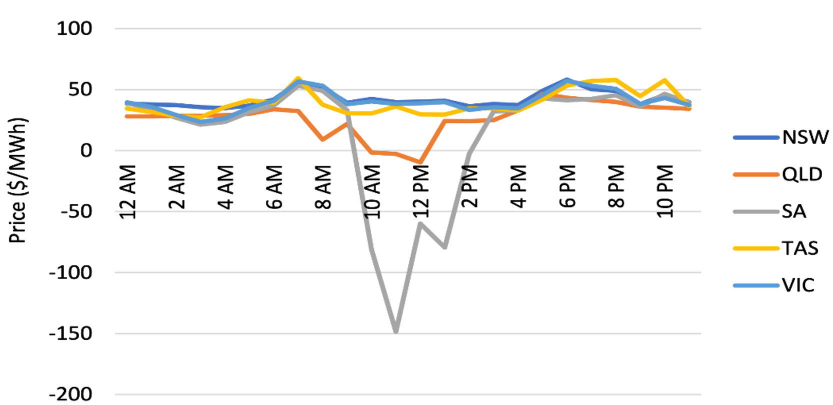
Figure 14: Negative Price Instances vs VRE Penetration 2020 in South Australia (% RE Indicates Wind, Solar and Rooftop PV)



Source: AEMO data. % RE indicates wind, solar and rooftop PV as a proportion of total generation mix (i.e. variable renewable energy). Generation figures are post auxiliary and transmission losses.

Prices are moving into negative territory in the middle of the day, in the maximum solar insolation period, when supply is offered at negative prices as generators compete with one another to stay online. An example day in SA (18 September 2020) had prices reaching -$150 in the middle of the day (Figure 15).

Figure 15: Negative Price Example in South Australia - 18 September 2020

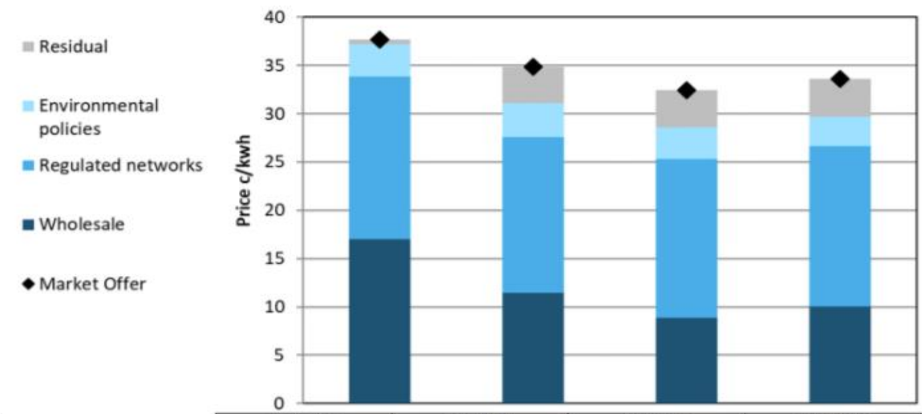


Source: AEMO data.

[74] AEMO. Quarterly Energy Dynamics Q1 2021. April 2021.

The cost of actually generating electricity makes up around 39% of the average residential consumer's bill – the remainder comes from transmission, distribution, retail and other fees.[75] Therefore, while these reduced wholesale electricity spot prices will drive reductions in consumer bills, it is not the full picture. In SA, residential electricity bills are expected to reduce by 10.8% from 2019/20 - 2022/23 (Figure 16) driven by reductions in wholesale prices (largely due to increasing solar PV penetration, evidenced in negative daytime prices) and reductions in regulated network and environmental costs.[76]

Figure 16: Trends in South Australian Supply Chain Components in Residential Electricity Bills



	2019/20 Base Year		2020/21 Current Year		2021/22		2022/23	
	c/kwh	$/year	c/kwh	$/year	c/kwh	$/year	c/kwh	$/year
Environmental policies	**3.37**	**$169**	**3.46**	**$173**	**3.32**	**$166**	**3.07**	**$154**
LRET - LGC cost	0.81	$40	0.79	$39	0.64	$32	0.45	$22
SRES - STC cost	0.86	$43	0.96	$48	0.97	$48	0.91	$46
Feed-in Tariff Schemes	1.45	$73	1.46	$73	1.46	$73	1.46	$73
REES	0.25	$13	0.25	$13	0.25	$13	0.25	$13
Regulated networks	**16.82**	**$841**	**16.18**	**$809**	**16.39**	**$819**	**16.60**	**$830**
Transmission	3.25	$163	3.39	$170	3.54	$177	3.70	$185
Distribution	12.89	$645	12.33	$617	12.39	$619	12.44	$622
ACS Metering	0.68	$34	0.46	$23	0.46	$23	0.46	$23
Wholesale	**17.02**	**$851**	**11.44**	**$572**	**8.89**	**$445**	**10.04**	**$502**
Residual	**0.46**	**$23**	**3.76**	**$188**	**3.83**	**$191**	**3.89**	**$195**
Market Offer	**37.68**	**$1,884**	**34.84**	**$1,742**	**32.42**	**$1,621**	**33.61**	**$1,680**

Source: AEMC analysis
Note: All figures are exclusive of GST.

Source: AEMC.[77]

The SA example shows:

- **Increasing amounts of variable renewable energy generation results in lower wholesale electricity prices, especially in the middle of the day when there are large amounts of solar PV generation. This is filtered through to retail electricity savings for consumers.**

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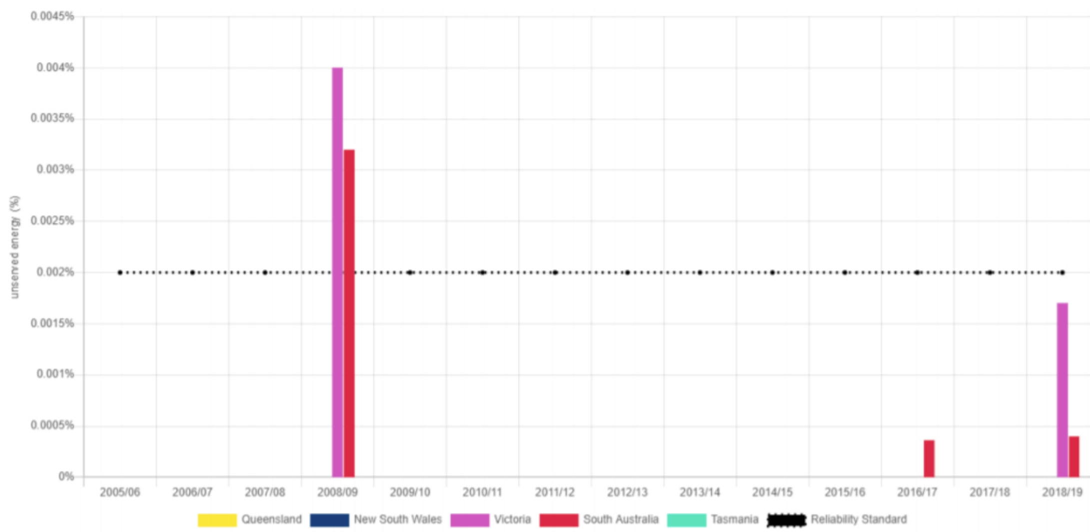
[75] Clean Energy Council. How much does electricity cost. 2018.
[76] AEMC. Final Report Residential Electricity Price Trends 2020. 21 December 2020.
[77] Ibid.

Lesson 5: System Reliability and Security Can Be Maintained in a High Renewables Grid

SA is experiencing a transition challenge: how to integrate large amounts of variable renewable energy, and increasingly distributed energy resources, while maintaining grid reliability and security. It has so far been successful in maintaining reliability and is implementing and exploring various mechanisms to better manage security.

Australia has a very high reliability standard of 99.998% of consumer demand being met each year (i.e. maximum of 0.002% of unserved energy (USE) occurring in a given year). SA has met its reliability standard for the past 15 years (Figure 17) except for 2008-09 when extreme temperatures in Victoria and SA reduced the availability of the interconnector, and Victorian generators contributed to 0.004% and 0.0032% unserved energy respectively.[78] This shows that even in a region with high VRE penetration, reliability can be maintained at extremely high levels.

Figure 17: Unserved Energy in the NEM



Source: AEMC.[79]

The changing dynamics of demand and supply in SA are creating operational and planning challenges within AEMO about how to manage the grid when demand on the grid is extremely low – related to "security of the grid, managing voltage, and having enough system strength and inertia".[80] So-called 'minimum operational demand' is reaching record lows in SA, most recently on 11 October 2020 at 1pm which had a record-low minimum operational demand of 290MW. AEMO expects minimum demand to continue to decline and potentially approach zero by 2024-25.[81] It should be noted that as a term "minimum demand" is a poor proxy for some

[78] AEMC. Information Paper – The Reliability Standard. March 2020.
[79] Ibid.
[80] Australia Energy Market Operator. South Australian Electricity Report. November 2020.
[81] Ibid.

real challenges, such as voltage and fault current at a local level, frequency and inertia at a regional level.

Increasingly the operator has had to intervene in the market and direct synchronous generators to operate in a particular way in order to maintain system strength. The operator issued 253 directions in 2019-20 to ensure the correct level of fault current was always maintained, an increase of 65% compared to 2018-19.[82] This was in part due to very low demand in the grid, such that gas generators were required to generate to maintain system strength, however with wholesale prices being so low in those given periods the gas generators had not bid into the wholesale market and therefore had to be contracted outside of the wholesale market. In Q1 of 2021, AEMO directed SA's gas powered generators (GPGs) for a record 70% of the quarter due to persistently low electricity prices below their cost of generation.[83]

There is still considerable work to do to automate control systems and improve system and market mechanisms to deliver the required system security and strength, to prevent AEMO from needing to direct generators on a case-by-case basis (which is proving costly for consumers[84]).

SA is exploring and advancing various technology solutions to support system security and increase consumer value, including:

- installing four synchronous condensers (procured by Electranet at a cost to SA customers of $166m over the next 40 years) [85]
- improving interconnection with neighbouring states to increase import and export capability,
- obtaining contingency frequency reserves from renewable generation and large-scale battery storage, and
- implementing fast-start and rapid-response technologies.[86]

Regulatory solutions are also being explored or introduced in SA and the wider NEM to support system security, including:

- introducing a mandatory requirement for generators to activate any existing capability to provide primary frequency response,
- revision of inverter requirements standards for smaller distribution-connected generation to "optimise and support a secure power system

[82] AEMO. South Australian Electricity Report. November 2020.
[83] AEMO. Quarterly Energy Dynamics Q1 2021. April 2021.
[84] AEMC. Summary of submissions to AEMC investigation into intervention mechanisms and system strength. June 2019.
[85] VEPC. System Security Report. March 2021.
[86] Australia Energy Market Operator. South Australian Electricity Report. November 2020.

under high levels of DER penetration, support energy affordability and allow consumers to pursue individualised services."

- introducing a wholesale demand response mechanism in the NEM (commencing 2022), "to allow consumers to sell demand response in the wholesale market directly or through aggregators" and
- limiting imports into SA when SA's Under Frequency Load Shedding schemes are "not effective to prevent cascading failures and potential system black".[87]

The Energy Security Board (ESB) is also exploring other potential electricity market reform options including mechanisms for: resource adequacy, managing ageing thermal generator retirement, procuring essential system services (including introducing a spot market for inertia), integrating distributed energy resources and demand side participation, and managing transmission and access.

Many of these regulations and market mechanisms will help drive system security and help consumers realise value from their DER resources.

However, all planning must be targeted at a zero-emissions future to prevent investment in stranded assets or unnecessary regulations that look beneficial in the short term, but may not be required in the long term.

A recent IEEFA report stated that:

> *"Large-scale inertia infrastructure, such as synchronous condensers, developed for the purpose of providing system security, will be superfluous in a future post-transition grid that has little or no synchronous inertia, and can be managed entirely with power electronics and low-latency digital communications."* [88]

Furthermore, NSW transmission business TransGrid has suggested grid-forming batteries can provide inertia for "a small fraction of the cost" of synchronous condensers.[89]

The IEEFA report stated that the investments in synchronous condensers, and the development of a market to procure inertia, should be scrutinized, as they will be superfluous in a post-transition grid. The energy industry should be planning for a zero-inertia, zero-emissions future dominated by inverter-based resources (IBRs), to prevent investment in assets that may be obsolete in the future.[90]

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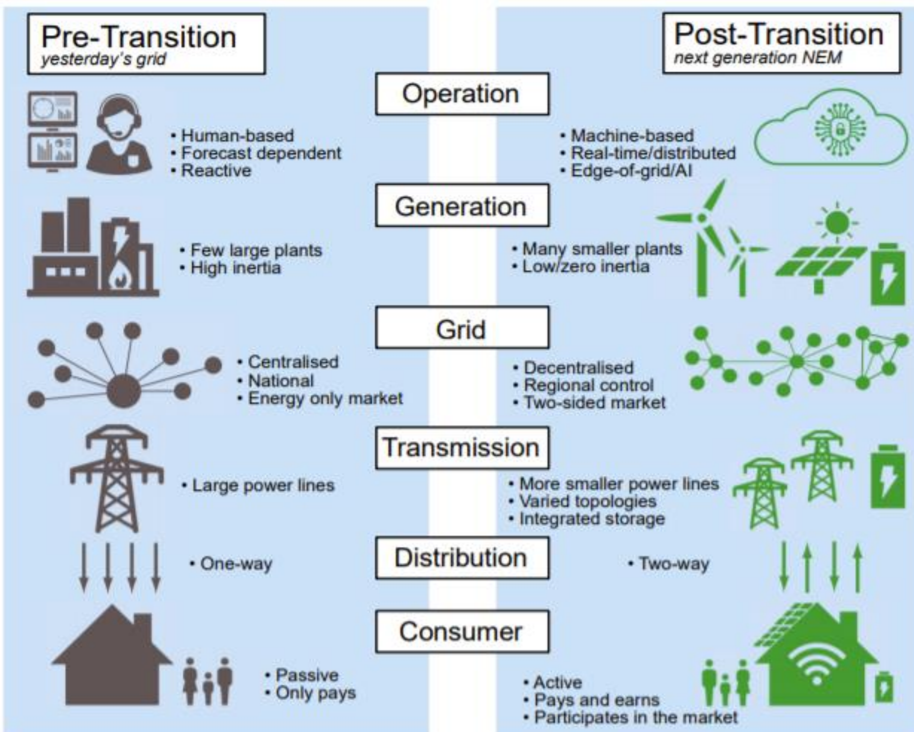
[87] Australia Energy Market Operator. South Australian Electricity Report. November 2020.
[88] IEEFA. Australia's Opportunity To Plan Ahead for a Secure Zero-Emissions Electricity Grid. March 2021.
[89] The Australia Institute and VEPC. Inertia and System Strength in the National Electricity Market. March 2021.
[90] IEEFA. Australia's Opportunity To Plan Ahead for a Secure Zero-Emissions Electricity Grid. March 2021.

The focus should be on developing the digital systems needed to manage an increasingly complex electricity system. The future grid control system will need to be more dynamic and flexible to cope with an increasing number of variable and distributed energy resources. Generation, storage and load would be optimally controlled via low-latency digital communications networks, with edge-of-grid regional control methods and real-time distributed computing, all orchestrated with artificial intelligence. This will require digital and data systems to be developed in tandem with energy systems, starting now.[91]

Figure 19: Difference Between Yesterday's Grid and the Next



Source: Tim Finnigan.[92]

The SA example shows:

- **Reliability and system security can be maintained in a high renewables grid through the implementation of various mechanisms.**

- **Planning for a digitalized, zero-inertia, zero-emissions future grid is vital to prevent investment in assets, markets or regulations that might prove obsolete, and to set up the digital systems required for intelligent operation of the future grid.**

[91] IEEFA. Australia's Opportunity To Plan Ahead for a Secure Zero-Emissions Electricity Grid. March 2021.
[92] Ibid.

Lesson 6: Batteries Can Help Maintain System Reliability and Security

In 2017, after several power cuts in SA, Tesla CEO Elon Musk made a bet that if his company could not build a battery to reduce the risk of future blackouts in 100 days, he would provide one for free. Musk won his bet, installing the Hornsdale Power Reserve battery in the short timeframe, together with Neoen.[93] It has been a successful project, saving SA consumers more than $150m in the first two years of operation.[94]

At 100MW/129MWh, the Hornsdale Power Reserve was the largest lithium-ion battery in the world at the time of commissioning.[95] A 50MW/64.5MWh expansion of the battery was finalised in 2020.[96] [97] The battery is co-located with the Hornsdale Wind Farm.

Hornsdale has proved profitable through the provision of FCAS services and energy arbitrage, recovering its capital costs in a little over two years.[98] The battery's fast response times are helping to manage frequency deviations in the market. It has played a critical role in ensuring reliability and security by reacting quickly to disturbances and fluctuations in the frequency of the grid that may have caused outages.[99]

The Hornsdale battery provides the following services:

- **high-quality regulation FCAS services:** Hornsdale provides a rapid and precise response to regulation FCAS signals. It assists in maintaining

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[93] The Financial Times. Batteries charge up Australia's efforts to shift away from coal. April 2021.
[94] Hornsdale Power Reserve. South Australia's Big Battery. 2021.
[95] Ibid.
[96] Ibid.
[97] PV Magazine. Neoen completes Hornsdale big battery expansion. 3 September 2020.
[98] RenewEconomy. Tesla big battery recoups cost of construction in little over two years. 15 May 2020.
Examples of how the battery has performed include:

- In February of 2020 tornadoes tore down the interconnector between Victoria and South Australia, leaving South Australia operating as an energy island for more than 2 weeks. Hornsdale and the other big batteries in SA played a key role in providing frequency services and maintaining reliable energy supply in this time. For the 2 weeks SA operated as an island, it had on average more than 50% renewables, and had a lower cost of power than coal-dominated NSW.
- Hornsdale intervened rapidly to help reduce dangerous changes in frequency changes when a major coal generator, Loy Yang (560MW), tripped nearly 1000km away, causing a large, sudden loss of power. Hornsdale injected 7.3MW into the network to help increase frequency which had fallen below 49.8Hz, helping the system to stabilise.[99]
- On 16 November 2019 there was a failure of the interconnector between South Australia and neighbouring state Victoria, due to spurious signals from telecommunications equipment that caused the maloperation of protection equipment. This islanded South Australia, and caused frequency rise and wholesale electricity spot price rise. The battery helped the grid return to a normal frequency within minutes, saving consumers approximately $14m.

network frequency within a 50 ± 0.15 Hz normal operating range.[100] Hornsdale has reduced the average regulation FCAS costs by more than 90% in SA.[101]

- **premium contingency FCAS services through Fast Frequency Response:** Hornsdale participates in all six of the existing contingency FCAS markets in the NEM. It has a fast response time of 100ms compared to the minimum required 6 second response time.[102]

- **participates in the wholesale energy market, earning revenue through energy arbitrage**

- **participates in the System Integrity Protection Scheme (SIPS):** SIPs is a scheme designed to prevent the interconnector between SA and Victoria from tripping due to extreme import flows.[103] SIPS identifies conditions that could result in loss of synchronism between SA and Victoria and corrects these conditions by injecting power from batteries or shedding load to rebalance supply and demand in SA. It prevents unstable power swings on the SA-Victoria interconnector.[104] Hornsdale can discharge up to 100MW of reserve capacity in less than 150ms when it receives a signal from the local transmission company to do so.[105] While the SA Government sponsors Hornsdale to participate in the SIPS scheme, no "direct" revenue streams are available to battery projects to provide this service.[106]

- **provides a backup reliability measure:** If there is a need for backup generation, under arrangements with the SA government 70MW of reserve capacity is offered into the NEM at the Market Price Cap (ensuring this energy will not be dispatched ahead of other generation in SA).[107]

- **provision of inertia - under trial** (through 50MW expansion): The Hornsdale battery is undergoing a trial via a 50MW expansion to provide inertia to slow down the rate of change of frequency (RoCoF) when required, and to provide system strength. This might provide a direct revenue stream in the future.[108]

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[100] Aurecon. Hornsdale Power Reserve Year 1 Technical and Market Impact Case Study. 2018.
[101] Hornsdale Power Reserve. South Australia's Big Battery. 2021.
[102] Aurecon. Hornsdale Power Reserve Year 1 Technical and Market Impact Case Study. 2018.
[103] Note this scheme is also used in other states. For example, on the VNI interconnector between NSW and VIC.
[104] AEMC. Consultation paper. Request for declaration of protected event. 13 December 2018
[105] Aurecon. Hornsdale Power Reserve Year 1 Technical and Market Impact Case Study. 2018.
[106] ARENA. Large-Scale Battery Storage Knowledge Sharing Report. November 2019.
[107] AEMO. Initial Operation of the Hornsdale Power Reserve Battery Energy Storage System. April 2018.
[108] RenewEconomy. Tesla big battery expansion gets regulatory nod, testing to begin soon. 18 June 2020.

Figure 20: Hornsdale Power Reserve Project Structure and Objectives

HPR 100MW, 129MWh	Battery Capacity	Project Objectives	Services Provided
SA Government Reserved Capacity	70MW, 10MWh	• Improved System Security for SA network • Downward pressure on ancillary services prices • Improved reliability of supply	• Participation in System Integrity Protection Scheme (SIPS) • Fast Frequency Response • Contingency FCAS • Regulation FCAS • Back-up reliability measure
Neoen Market Capacity	30MW, Balance of energy	• Commercial market participation • Optimised bidding across energy and all eight FCAS markets	• Energy Arbitrage • Regulation FCAS • Contingency FCAS

Source: Aurecon 2018.[109]

Other large-scale batteries in Australia have followed in the footsteps of the Hornsdale battery. South Australia now has four large scale batteries. [110]

Distributed batteries can also be implemented to provide services in the NEM. Virtual Power Plants (VPPs) aggregate distributed batteries (or other DERs) to provide contingency frequency control ancillary services (FCAS) and energy market services. AEMO, together with Tesla, is undertaking a VPP trial in SA to inform how VPPs can be best integrated into the NEM.[111] The trial plans to connect 50,000 SA homes into the VPP scheme.

The SA example shows:

- **Batteries are a key technology for maintaining system security and reliability in a grid with more variable renewable generation.**

Lesson 7: High Penetrations of Rooftop Solar Can Be Managed with Distribution Network Innovation

High Penetration of Rooftop Solar Can Be Reached

The SA government introduced the first subsidised solar feed-in tariff in Australia which ran for systems installed from 2008 - 2013 (with some of those tariffs still being honoured). This early government support enabled a rooftop solar industry to be established, creating jobs and an industry that continues to grow.

Australia has the largest amount of utility and rooftop solar Watts per capita in the world (786W per person as at the end of 2020).[112] Australia now has over 2.7m

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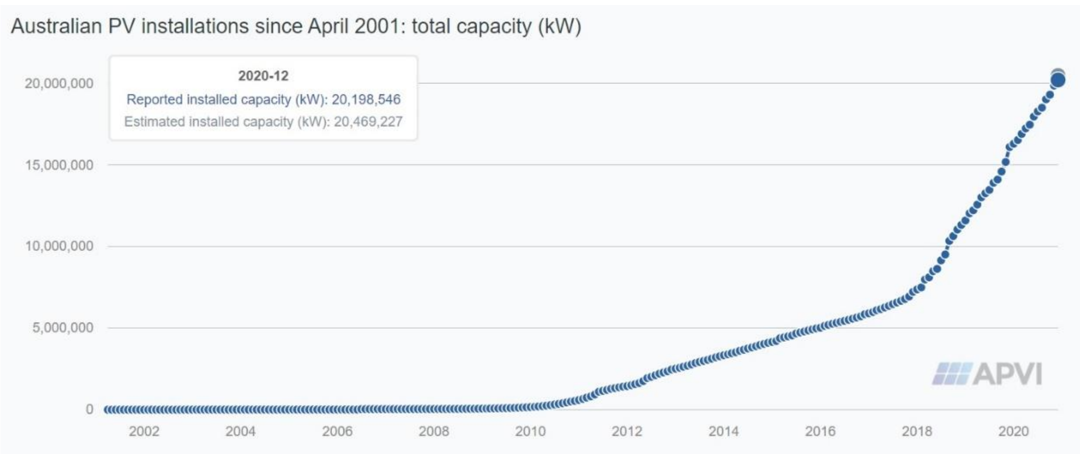
[109] Aurecon. Hornsdale Power Reserve Year 1 Technical and Market Impact Case Study. 2018.
[110] Dan Van Holst Pellekaan – SA Energy Minister. ABC Four Corners Fired Up. 12 April 2020.
[111] Australia Energy Market Operator. South Australian Electricity Report. November 2020.
[112] IEEFA calculation based on Clean Energy Regulator data for Dec 2020 has 20,198,546 kW installed solar PV and Australian Bureau of Statistics at 30 June 2020 Australia's population was 25,687,041 people.

household rooftop solar systems with a combined capacity of over 13GW (out of a total PV capacity of over 20GW as shown in Figure 21). There was a record rate of 3GW installs in the calendar year 2020 which was a 39% increase on a year-on-year (yoy) basis and the highest per capita install rate ever in the world.[113]

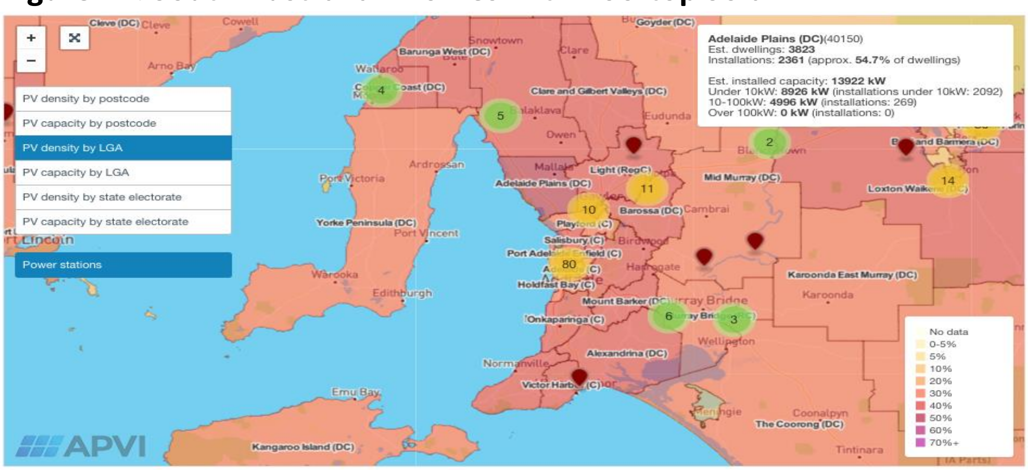
Figure 21: The Extraordinary Growth in Australian Solar Installations



Source: Australian Photovoltaic Institute (APVI).

SA has the largest amount of generation provided by rooftop solar of all NEM regions, with 13% of 2020's total generation coming from rooftop solar.[114] On average by local government areas (LGAs), 40% of SA homes have rooftop solar (some LGAs have even higher amounts). For example, the map in Figure 22 shows 55% rooftop penetration in the Adelaide Plains LGA.

Figure 22: South Australian Homes with Rooftop Solar



Source: APVI.

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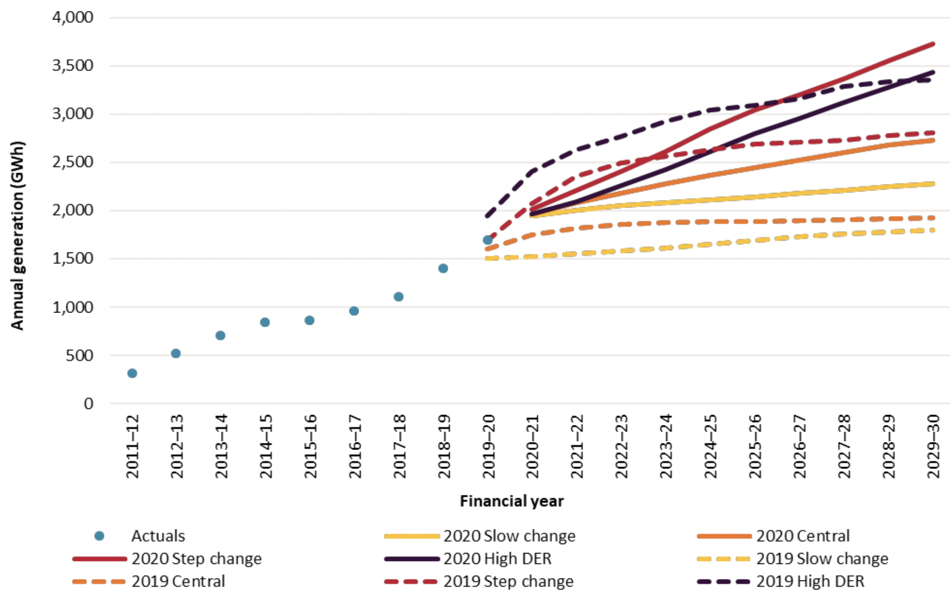
[113] Renew Economy. Rooftop solar market ends tricky 2020 by smashing records, surpassing 13GW total capacity. 11 January 2021.
[114] OpenNEM.

Not only does residential rooftop solar continue to grow, but PV systems between 100kW and 30MW, known as PV Non-Scheduled Generation (PVNSG) which are typically installed on commercial and industrial (C&I) rooftops and small solar farms (including on agricultural properties), have experienced rapid growth since 2015, and a 79% increase in capacity since 2018-19 to 129MW on 30 June 2020. AEMO's forecast in Figure 23 shows that both small and mid-sized rooftop solar will continue to grow.

Figure 23: South Australian Rooftop PV Generation Forecasts to 2029-30



Source: AEMO.

The SA example shows:

- **Rooftop solar PV generation can be incorporated into the grid at penetration of over 40% of households.**
- **It is key to plan for high penetrations of rooftop solar and multi-way flows within distribution networks.**

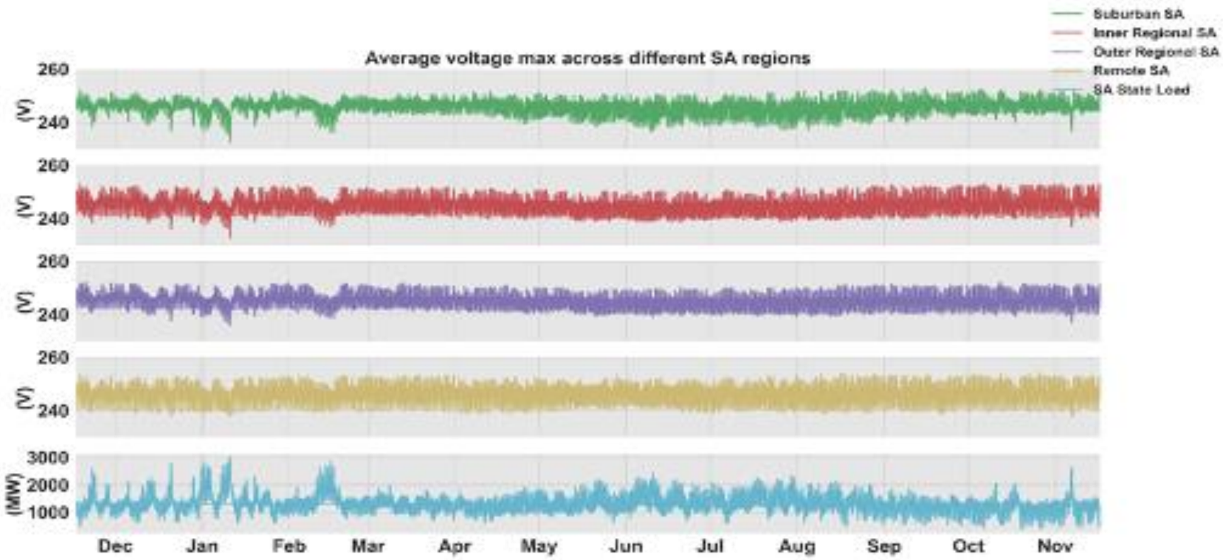
Voltage Rise Risk Was Exaggerated – Leading to Potentially Questionable Investments and Regulations

Concerns have been raised suggesting high levels of rooftop solar penetration has the potential to cause voltage rise in the grid. This can occur when rooftop solar exports feed-in to distribution networks.

We would argue that the more important question is, to what extent is this a significant issue to be managed and critically, what is the current state of voltage and voltage management on distribution networks across the NEM?

The ESB commissioned a study by the University of NSW (UNSW) to examine the state of voltage across the NEM.[115] The study determined that even in the absence of rooftop solar, there are existing high voltages across the NEM and SA. (Figure 24)

Figure 24: Samples of Average Suburban Voltages in South Australian Regions



Source: UNSW.[116]

The NEM's nominal voltage standard is 230V with a maximum limit of 253V. In SA the average maximum voltages are often close to the upper bound of 253V over the whole year. High voltage in the distribution network can be primarily attributed to the historic 240V nominal voltage standard from which distribution networks are still adjusting, and voltage management decisions made to support additional air conditioning loads installed over the last two decades.

SA's average maximum voltages are generally highest in autumn and spring when demand is usually lower and rooftop solar performance is strong. Rooftop solar does contribute somewhat towards voltage rise, but is a minor contribution compared to the challenges of existing high voltage levels. The ESB/UNSW[117] analysis found many sites experience higher voltages during the night when solar PV is not operational. These findings show that the operation of distribution networks is causing voltage rise, and while rooftop solar can contribute to this, the contribution is not significant at this point.

It is hard to tell if voltage rise from rooftop solar exports will become a significant issue in SA in the future. A number of policies and regulations being put in place will impact flows from rooftop solar exports. In 2020 regulations were brought in stating that SA inverters must be able to be remotely disconnected when directed by

[115] See Energy Ministers: LV Voltage Report.
[116] Ibid.
[117] Ibid.

the system operator. This 'solar cut-off' regulation unjustifiably defines distributed PV as a ‘problem’, especially when SA is islanded. A recent IEEFA report described the solar cut-off as a blunt instrument, suggesting Dynamic Operating Envelopes (DOEs) could instead be used to address issues in distribution networks while enhancing system security.[118]

A ‘solar sponge’ network tariff was also introduced on 1 July 2020. From 10am to 3pm, electricity network charges are now 25% of the standard rate (3.6c/kWh vs 18c/kWh peak). This should encourage increased demand in the middle of the day when there is plenty of solar generation. However, results are yet to be seen and ongoing challenges include that the ‘solar sponge’ tariff applies every day, regardless of sunshine; and how much load is easily able to be shifted is not yet clear.

We expect the adoption of batteries and especially EVs to have the largest impact on rooftop PV exports, potentially significantly decreasing the volume of solar flowing back into the grid and over the longer term, thereby all but eliminating any problematic distributed solar-related voltage rises.

The SA example shows:

- **Concerns about the voltage rise impact of Distributed Energy Resources (DER) on the grid can be exaggerated, and solid data and trials are needed to ensure risks are not overstated, and to prevent investment in unnecessary solutions.**

More Effective Options to Manage Rooftop Solar Include Voltage Monitoring, Tap Changes on Transformers and DOEs

In order to manage pre-existing issues in the SA distribution network, there needs to be improved voltage monitoring. This is an inherent feature of smart meters (which have been rolled out in Victoria but only partially in other Australian states).

SA Power Networks are installing and commissioning permanent remote monitoring at a sample set of approximately 1,300 multi-customer Low Voltage (LV) distribution transformers in the Adelaide metropolitan area. The plan is to improve capacity planning in its LV network at a net cost of about $4.5m over five years.[119]

The next step is using voltage information to adjust transformer settings. This is a legacy challenge as the majority of SA Power Network’s 70,000 low voltage transformers have limited, if any, capacity to have their taps changed, and transformer upgrades are generally costly.[120] It will take time for distribution

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[118] Gabrielle Kuiper & Steve Blume, Blunt Instrument: Uncompensated Solar Cut-Off Isn’t the Only Solution to the Minimum Demand ‘Problem’, IEEFA April 2020.
[119] SA Power Networks, LV Transformer Monitoring Business Case, 10 December 2019.
[120] Richard Chirgwin, Grid Voltage Rise Is Getting Worse And That’s A Problem For Solar Owners, Solar Quotes Blog, August 2019.

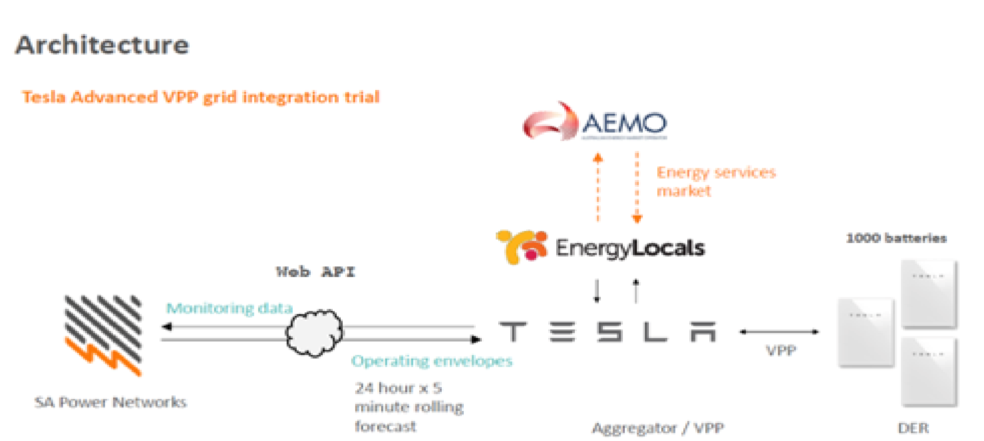
networks to adjust to managing multi-way flows and finding cost-effective solutions to do so.

Probably the most important innovation in managing DER in Australian distribution networks has been the development of dynamic operating envelopes (DOEs), sometimes known as dynamic connection agreements or 'flexible export limits'. DOEs vary import and export limits by location and time depending on the available capacity of local network or power system as a whole.

To date distribution companies have imposed static export limits (usually 5kW for households). While useful for incentivising self-consumption, static limits restrict return on investment and can result in inefficient solar spillage for larger rooftop solar systems.

SA Power Networks' DOEs are set dynamically at five-minute intervals, 24 hours in advance for each connection point (see Figure 25). In a Virtual Power Plant (VPP) trial across 1,000 batteries, this has enabled the 5MW capacity to be increased to a possible 10MW while keeping the network operating safely and securely.[121]

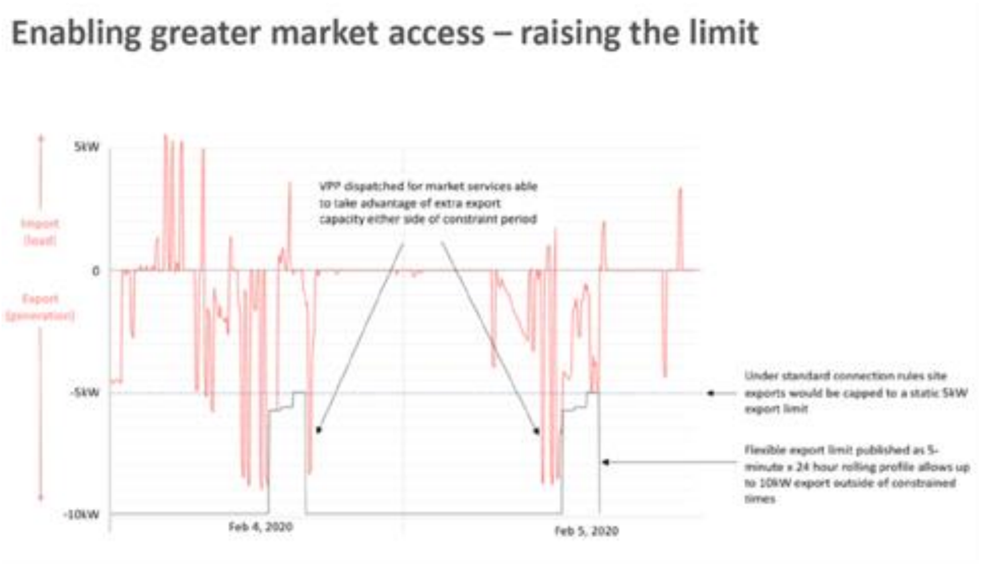
Figure 25: Architecture of South Australia Power Networks Operating Envelopes and VPP Trial



Source: SA Power Networks.

[121] See ARENA. Advanced VPP Grid Integration.

Figure 26: How Dynamic Operating Envelopes Can Increase Exports Within Network Constraints



Source: SA Power Networks.

The SA example shows:

- **Distribution networks should plan for high levels of solar PV penetration when constructing or upgrading the network and network management systems.** This should include planning to increase network visibility, smart management systems and software to create dynamic operating envelopes.

- **DOEs can manage exports to operate within distribution network limits.**

- **DOEs can also be used to address system operator concerns about minimum demand,** although that functionality has not yet been used in SA.

Managing Rooftop Solar Is Not Expensive: It Currently Costs Less Than 1% of Network Revenue in SA

As is often the case with new technology, rooftop solar has been characterised as a risk to the grid, but SA Power Networks is managing 40% rooftop penetration with less than 1% of its regulated network revenue.[122]

The Australian Energy Regulator (AER) granted SA Power Networks $3,914m in revenue from its customers for the period 1 July 2020 to 30 June 2025. Of this almost $4b total, SA Power Networks will spend an estimated $32m of capex to

[122] Australian Energy Regulator. SA Power Networks - Determination 2020-25. June 2020.

build capabilities to roll out DOEs as a standard connection service.

Dr Bryn Williams from SA Power Networks told us:

> *"The cost for any given (distribution business) is likely to be different from any other, depending on their specific circumstances and their starting point in terms of existing systems and capabilities. In SA Power Network's case this involves significant investment in:*
>
> - *New IT systems to receive and process high volumes of telemetry data from smart meters and other data sources across our LV network, whereas the Victorian distribution businesses have built this kind of data platform for their AMI (Advanced Metering Infrastructure) rollouts.*
> - *Building our LV hosting capacity model, which includes the cost of field audits on a sample basis to improve the quality of data we have on the physical assets we have in the field for our LV network, as our records and data quality in this area are poor*
> - *The cost of establishing a DER database and associated business processes."*

The available figures for other Australian network businesses are similar - that is, less than 5% of revenue being spent to create the smarts to manage rooftop solar, at least for the next five years.

There has been no indication from Australian distribution companies that future rooftop solar integration costs will rise significantly. Indeed, Energy Networks Australia's (ENA) Electricity Network Transformation Roadmap[123] modelled that a renewables-only NEM could save $16bn in infrastructure costs by 2050, and reduce average household bills by $414 every year, a reduction of around 30% on 2017 charges.

The SA example shows:

- **It is not expensive to manage rooftop solar PV.**

[123] Energy Networks Australia. Electricity Network Transformation Roadmap. April 2017.

About IEEFA

The Institute for Energy Economics and Financial Analysis (IEEFA) examines issues related to energy markets, trends and policies. The Institute's mission is to accelerate the transition to a diverse, sustainable and profitable energy economy. www.ieefa.org

About the Authors

Johanna Bowyer

Lead Research Analyst for Australian Electricity Johanna Bowyer has previously worked for CSIRO, Solar Analytics and Suntech and as a management consultant at Kearney. Johanna has research experience in microgrids, energy tariffs and distribution networks. She has a degree in Photovoltaics and Solar Energy Engineering from UNSW.

Gabrielle Kuiper

DER Specialist and Guest Contributor, Dr Gabrielle Kuiper is an energy, sustainability and climate change professional with over twenty years' experience in the corporate world, government and non-government organisations and academia. Most recently she was the DER Strategy Specialist with Australia's Energy Security Board. Prior to that Dr Kuiper held senior executive or senior advisory energy-related positions in the Office of the Australian Prime Minister, at the Public Interest Advocacy Centre (PIAC) and in the NSW Government.