IES 2022

Overview

Australia's two main electricity systems provide the world with a useful test-case in the technical challenges and opportunities of relying upon intermittent renewable generation as the primary source of electricity generation in large scale grids. Australia is large, sunny, windy and mostly empty. Its southern coastline abuts the roaring forties, a constant source of high-quality wind energy. Australia is blessed with high solar irradiation across most of the continent and the capacity for almost limitless deploy of solar PV. A solar and wind-based electricity system is theoretically possible. The plan in Australia is to be the first to find out if this can be achieved in practice.

The new Federal (national) Government has committed to a 43 per cent emissions reduction target based on 2005 levels by 2030. Given limited abatement opportunities in most other major sectors, the government's own modelling suggests this will require 82 per cent of Australian's electricity coming from renewables by 2030. In other words, it assumes Australia's two main electricity grids will be regularly running on 100 per cent renewable (intermittent wind and solar PV) generation within eight years.

It's a big ambition. Australia's two main grids – the east coast National Electricity Market (NEM) (204 TWh per annum) and the Perth region Wholesale Electricity Market (WEM) (20 TWh) – are completely isolated. Each is totally self-reliant and cannot import or export power. A renewables-based electricity system will require each to develop a complementary system of dynamic fast start short and longer-term firming.

This technical challenge is exacerbated because Australia's current primary source of electricity is coal-fired generation. Australia's 18 coal generators still supply around 60 per cent of the nation's electricity. Operationally coal generators are increasingly incompatible with the constantly varying generation supplied from renewables. The transition from coal to renewables will therefore require new transmission and new gas and other firming technologies that can respond to the high variability of large-scale renewables.

Scaling up renewable generation in Australia is also likely to be constrained by the pace of new transmission infrastructure which will be needed to connect Renewable Energy Zones (REZ) to major load centres.

The changes in generation have required a more centrally planned approach to future grid design and possible modifications to the energy-only, gross pool market used in the NEM, in particular the potential for a mechanism to pay for capacity.

Background

Australia is a large island continent between the Pacific and Indian Oceans in the southern hemisphere. It is similar in size to western Europe or continental USA, and yet has a population of only 25 million people. Around 20 million of these live along the coast in south-eastern Australia (Sydney, Melbourne, Brisbane and Adelaide). Despite the popular notion of Australians living in "the outback", Australia is a highly urbanised economy: about 90 per cent of the population live in cities or regional centres.

The temperate climate in south-east and south-western Australia means residential demand for electricity is mild for most of the year. Residential electricity demand peaks in winter and during

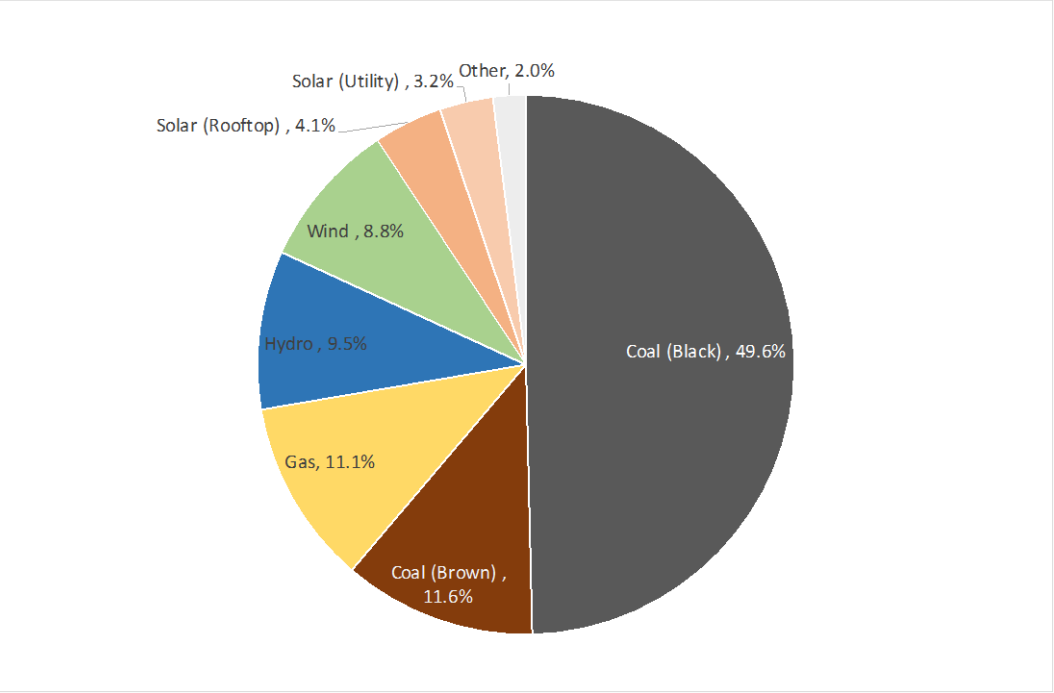
summer heatwaves. Residential demand accounts for about 30 per cent of total electricity consumption.

Australia has high quality wind and solar resources. It enjoys average wind speeds across southern Australia of more than 8 m/s and solar irradiation of more than 20 MJ/m2 a year across central and northern Australia.

Australia's industrial economy reflects its resources industry. Australia is a net energy exporter, with abundant reserves of black and brown (lignite) coal along the east coast, conventional gas fields in the south-east and north-west, and unconventional gas fields scattered across the north of the continent. It is the world's third largest uranium exporter, and holds world class reserves of key energy-related minerals like lithium, cobalt and nickel.

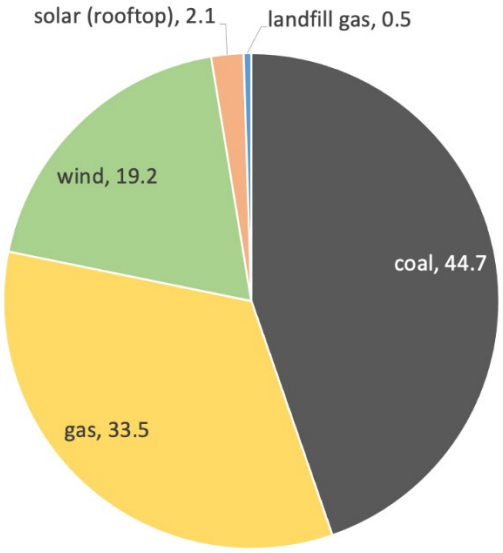
Government support for renewable investment over the past decade has driven a growing share of electricity generation. In the year to August 2022 Australia's largest grid, the National Electricity Market, derived 49.6 per cent of its electricity from black coal, 11.6 per cent from brown coal (lignite), 11.1 per cent from gas, 9.5 per cent from hydro, 8.8 per cent from wind, 4.1 per cent from rooftop solar PV and 3.2 per cent from utility solar PV. Intermittent renewables supply around 16 per cent of total electricity in the NEM, and 22 per cent in the WEM.

Electricity generation by fuel type, NEM, August 2021-22



Source: OpenNEM

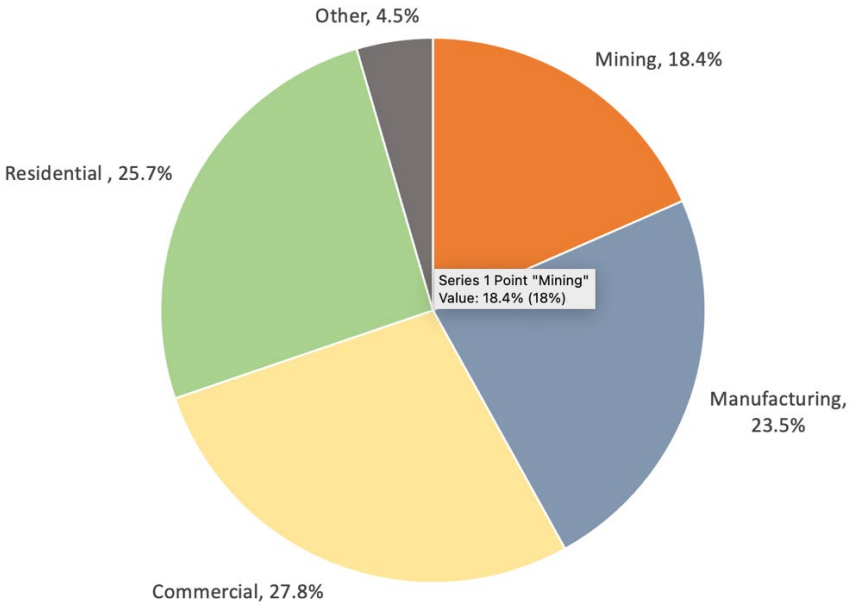
Electricity generation by fuel type, WEM 2021



Source: AEMO

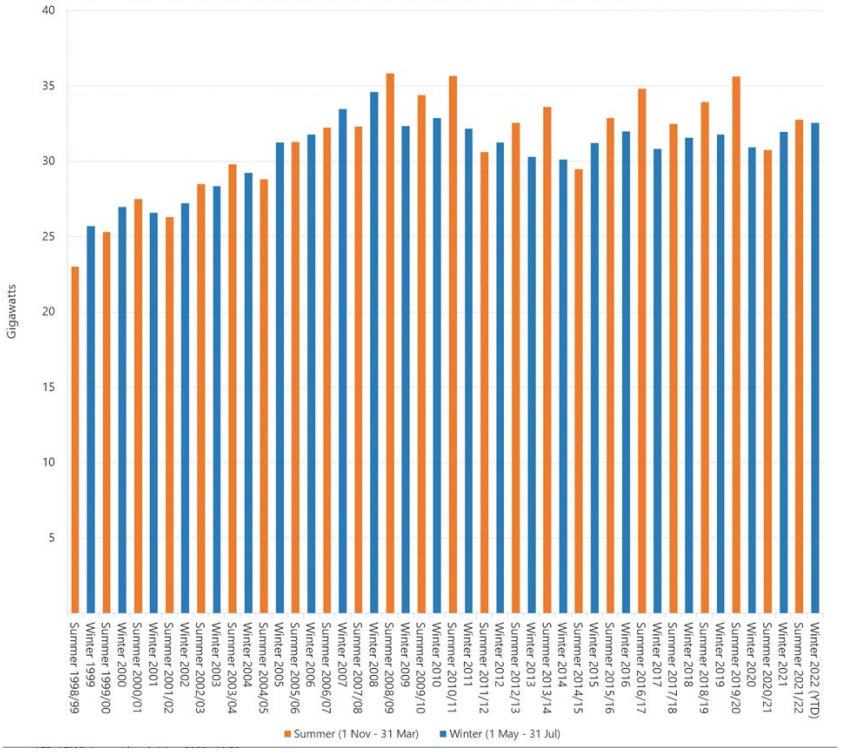
Australian electricity demand is relatively volatile/peaky, driven by a relatively high proportion of residential demand. Household demand for electricity typically peaks in the evening, with seasonal peaks in demand during summer heatwaves and in winter.

Electricity demand by sector, 2021



Source: Australian Energy Statistics

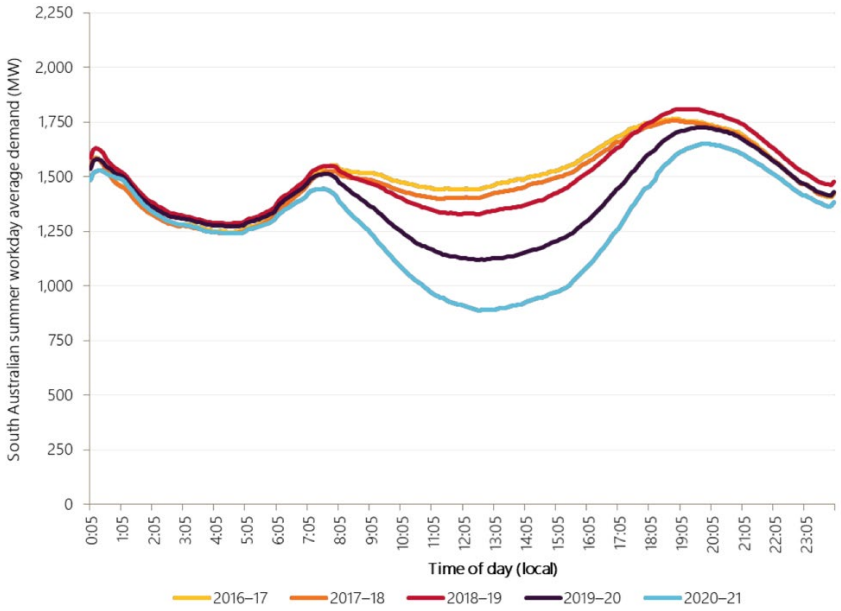
National Electricity Market summer and winter peaks 1999-2022, GW



Source: Australian Energy Regulator

Household electricity demand is being further impacted by continued uptake of rooftop solar PV systems. There are now more than 3.1 million rooftop solar PV installations in Australia, with around 8.5 million dwellings able to host solar systems. This is the highest rate of rooftop solar PV in the world.

South Australian summer workday average demand by time of day (MW), 2021



High solar PV uptake is driving an increasingly steep "duck curve" in electricity demand as increased residential solar PV generation reduces electricity demand during the day, then demand ramps up to conventional evening peaks as the sun sets.

The implicit strategy for Australian electricity markets is to encourage more renewable generation and managing the gradual closing of Australia's 18 remaining coal fired generators. This will require new transmission infrastructure to connect renewables to markets, along with investment in storage and firming technologies.

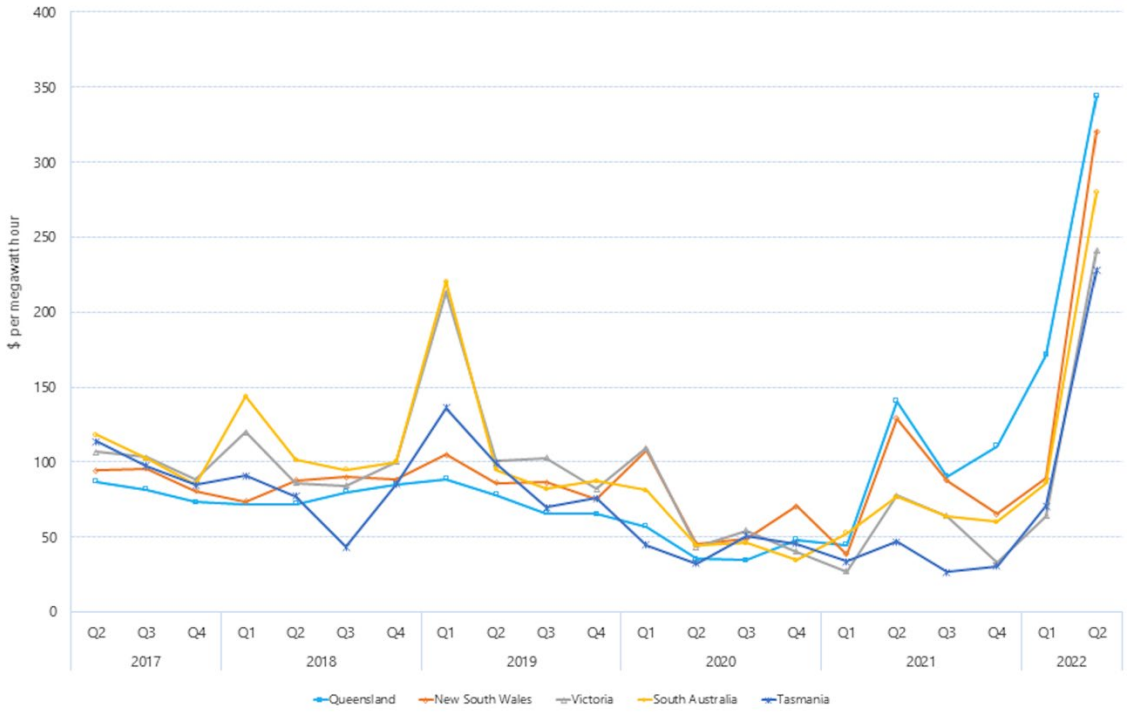
The greatest barrier to these objectives is the physical limitations of the existing transmission network and the speed at which new transmission can be completed. There is also a level of technical uncertainty about the real-world firming requirements of renewables at such large scale in completely isolated electricity systems and the cost and availability of batteries and related technologies at the scale required.

Electricity systems

Australia has two main electricity markets – the National Electricity Market (NEM) with annual total demand of 204 TWh. It supplies the eastern states including Sydney, Melbourne, Brisbane and Adelaide and the Wholesale Electricity Market (20 TWh) which operates around the city of Perth. The Australian Energy Market Operator (AEMO) oversees trading and market operations in both markets.

The NEM was created in 1999 by linking the independent state electricity grids of the five eastern states – New South Wales, Victoria, Queensland, South Australia and Tasmania. The significant distances between state networks and Australia's relatively low population density make the NEM one of the largest interconnected AC systems in the world.

Quarterly VWA spot electricity prices, NEM, 2017-22



Source: AER

It is an energy-only mandatory gross pool market with a high Value of Lost Load (VoLL) of $15,500 per MWh, encouraging active trading in forward contract markets to hedge price and volume risk. The liquidity of trading these derivatives (mostly swaps and caps) has been a key feature of the market. The provision of caps (insurance against wholesale prices exceeding $300 MWh) have acted as a form of

capacity payment, creating a revenue stream for peaking capacity. The Wholesale Electricity Market (WEM) is a capacity market, reflecting increased self-reliance on generation given the isolated nature of that grid.

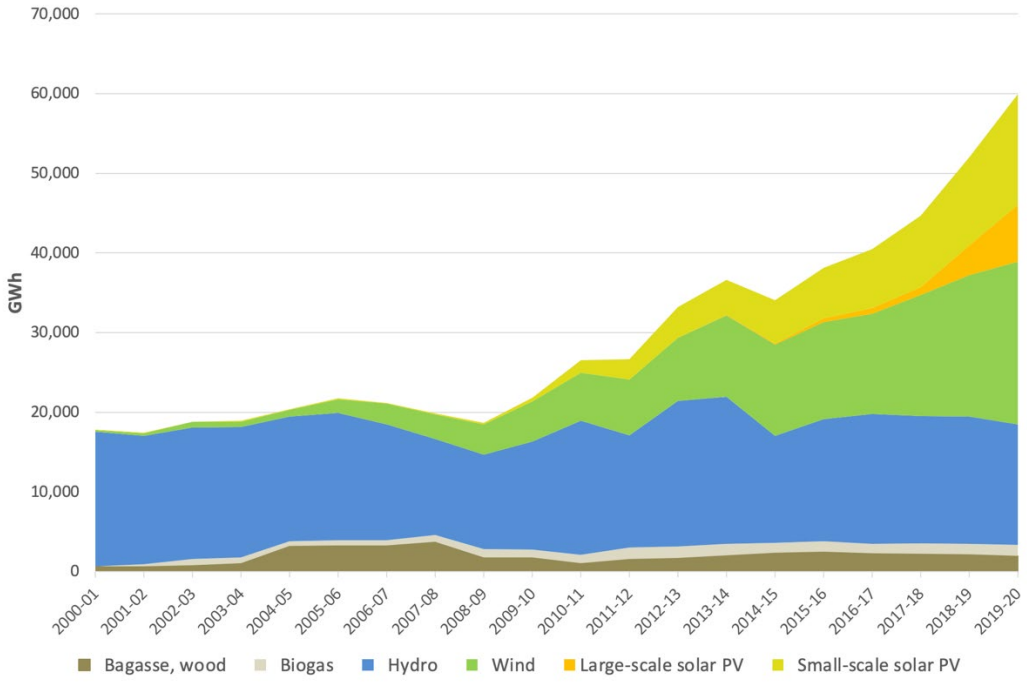
Electricity prices typically are highest during summer and had been softening at the end of last decade as increased renewables investment and no major retirements led to an oversupplied market. This was exacerbated by weaker electricity demand during the peak of the COVID-19 pandemic. Wholesale prices have increased sharply in 2022, impacted by higher global prices for gas and coal.

Renewables

Renewable generation supplies around 25 per cent of Australia's electricity supply. This share has been growing over the past decade, driven by two national subsidies: the Renewable Energy Target (RET) for large scale renewables and the Small-scale Renewable Energy Scheme (SRES) for household solar PV. As at June 2022 Australia had 8.1GW of installed hydro, 8.3GW of wind and 6.3GW of solar PV.

The growth in renewable generation has been predominantly in wind and solar PV. Like most developed economies, there is little capacity for new hydro. Hydro generation is largely determined by rainfall patterns. The popularity of rooftop solar PV has slowed utility scale solar development, with increasingly soft spot electricity prices during the middle of the day.

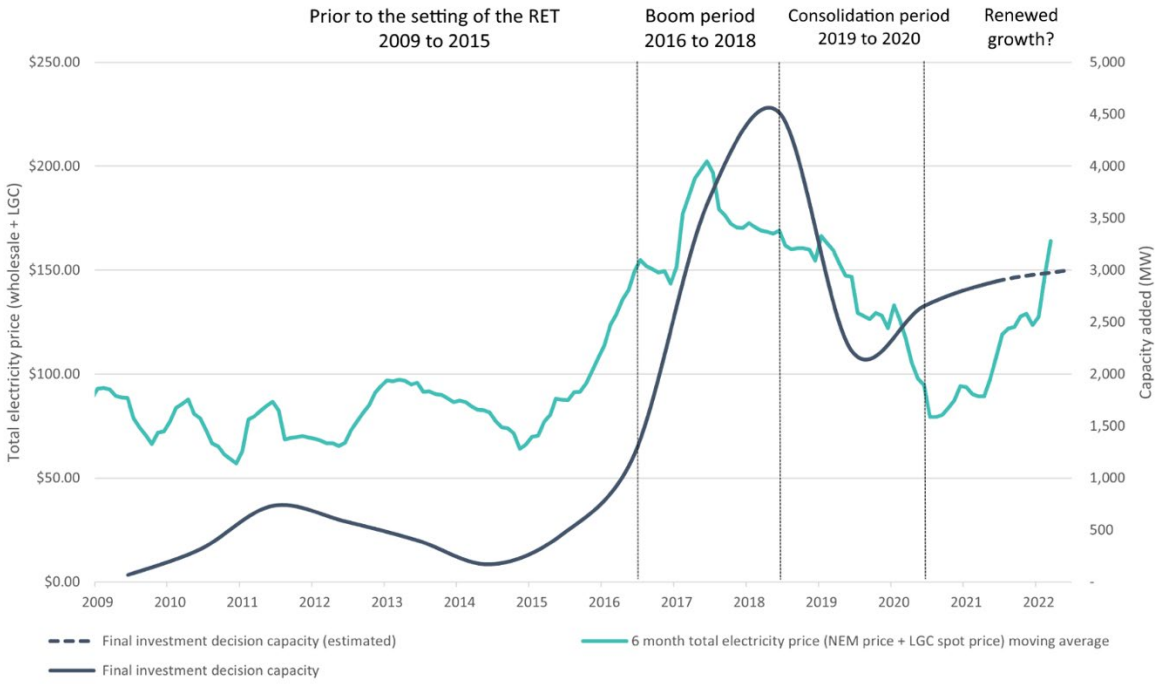
Annual renewable generation by type, 2000-20, GWh



Source: Australian energy statistics

The pace of large-scale renewable development in Australia appears to be influenced by electricity price trends. Increases in wholesale electricity prices (and the value of the renewables subsidy) result in increases in renewables investment. If this thesis persists then Australia should expect increased investment in renewables projects driven by high global prices for fossil fuels.

Final renewables investment decision and electricity prices over time, 2009-22



Source: Clean Energy Regulator

Planning and market structure

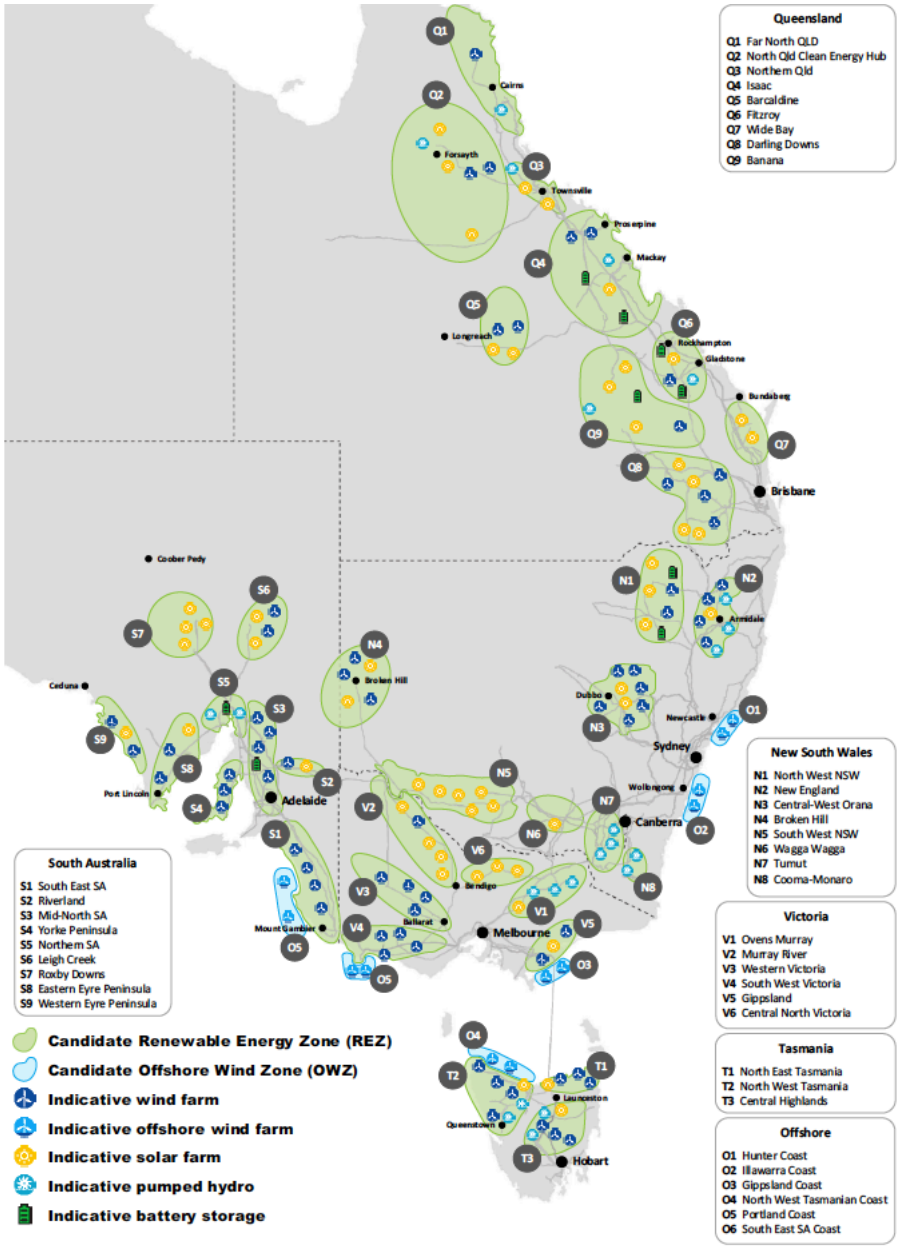
The challenge of decarbonising electricity supply and developing a renewables-based electricity system has resulted in a shift away from market-led reforms towards greater central planning. This was reflected in the replacement of transmission planning with system planning in 2018. These Integrated System Plans (ISP) are produced by the Australian Energy Market Operator (AEMO) and to date have identified 41 Renewable Energy Zones (REZ) to host wind (in the south) and solar generation (in the central and northern zones) and transmission infrastructure needed to move the electricity to load centres.

The national electricity market has been created by connecting state-based grids which typically radiate outwards from the capital city. While Australia has abundant open space to develop large scale renewables, there is little or transmission infrastructure in most of these new regions. This will need to be built to enable continued development of renewables.

A series of market reforms have also been proposed by electricity market agencies to augment existing energy-only market arrangements and maintain adequate supply given the inherent uncertainties during the transition. These reforms include:

- Introduction of a capacity mechanism to ensure there is enough dispatchable generation as more renewables enter the market.
- Active and more nuanced procurement of system services like inertia, fast frequency control, system strength and operating reserves needed as conventional generators exit the market.
- Improved co-ordination of distributed energy resources (DER) – to optimise existing and future residential solar and batteries, load shifting, monitoring, aggregation and provision of services.
- Transmission access reform to enable new generators and storage to access the grid at the lowest cost and to improve management of congestion.
- Data reforms to improve access and sharing of data produced by digital metering and related technologies.

Map of 41 Renewable Energy Zones, 2022



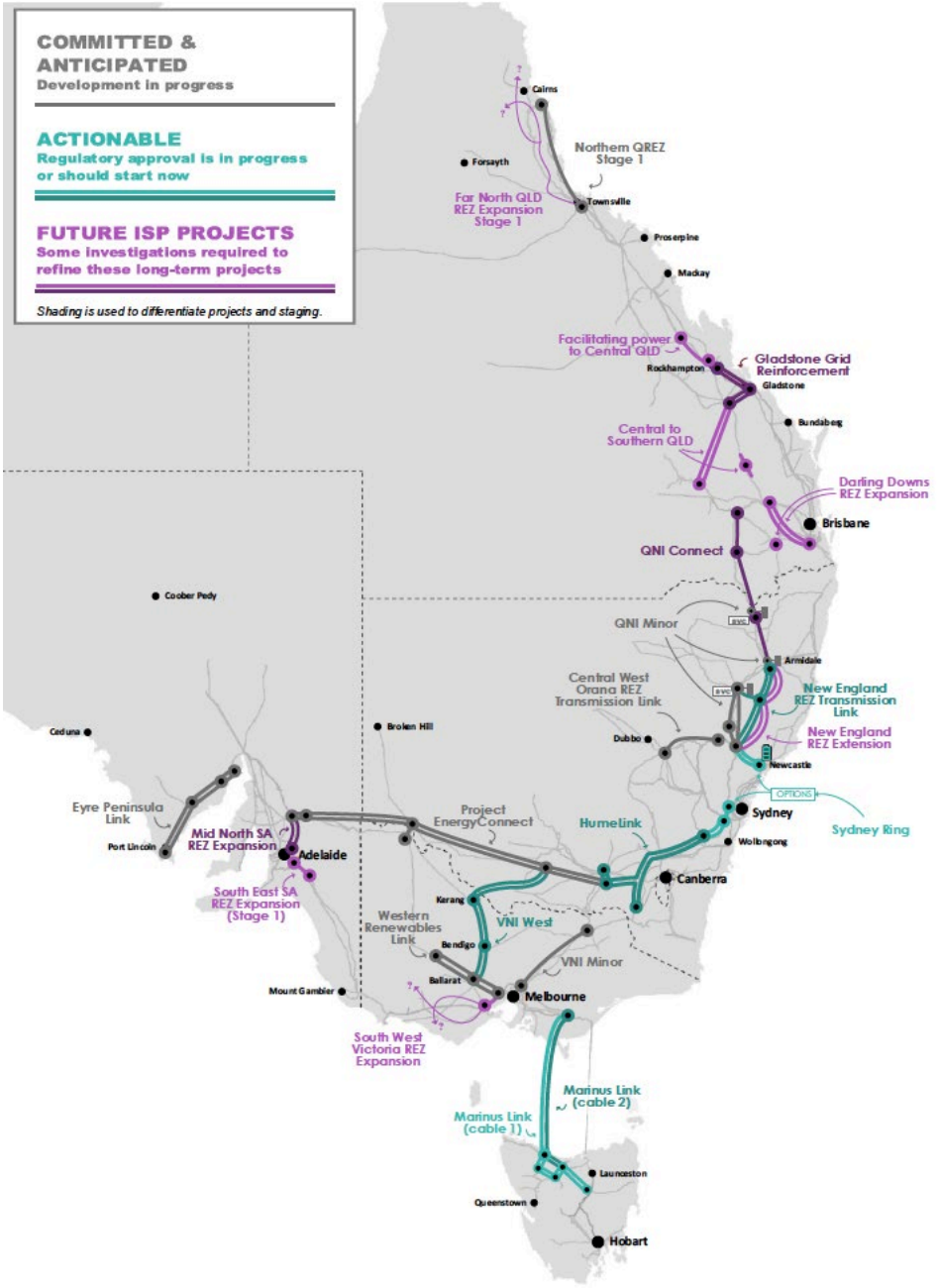
Source: AEMO

Transmission

The most critical infrastructure in the execution of the Integrated System Plan is the construction of up to 22 new transmission lines or upgrades. There are needed to connect the expanded renewables generation to market and augment interstate and inter-regional transmission links.

The scale of this is challenging for the transmission industry, given almost no major transmission infrastructure has been built for 30 years. There is more than 10,000 kilometres of new transmission required in the NEM, but supply constraints and labour shortages mean the ability to construct it when required is questionable. This means the pace of renewables integration is likely to be slowed by transmission constraints.

New transmission projects, National Electricity Market, ISP 2022



Source: AEMO

Storage

The development of big renewables will need supporting investment in storage technologies. The ISP estimates the NEM will require 46GW/640GWh of dispatchable storage by 2050. This includes utility scale batteries, pumped hydro storage, aggregated residential batteries and vehicle to grid batteries from EVs. Currently the NEM has around 46GW of firming capacity, much of it coal.

There are currently three pumped hydro storage facilities operating in Australia with a combined capacity of 2.6GW. All are in the NEM. Another two projects are under construction: a 250MW facility in north Queensland and the 2GW Snowy 2.0 project in NSW. This multi-billion dollar retrofit of the existing Snowy Mountains hydro scheme is likely to be completed towards the end of the decade. All existing and under construction pumped hydro projects have been heavily underwritten by

governments.

There is around 750W of battery storage installed in the NEM and another 800MW under construction. Almost all battery storage has been either underwritten by governments or built as augmentations to regulated transmission infrastructure. There is 16GW of battery projects proposed for the NEM. Existing batteries can augment spot market arbitrage income by selling frequency control services. Further battery investment will need to rely more on price arbitrage. Given challenges in sourcing batteries, the high cost of batteries and the size of the spread needed to earn a return, getting to financial close remains challenging without significant government support.

In the smaller and more isolated WA market there is a 100MW battery under construction in the WEM and the WA Government is investigating potential pumped hydro projects.

Coal exit

At its peak, coal supplied almost 90 per cent of Australia's electricity. Coal still supplies more than half of Australia's electricity supply but continues to decline as generators are replaced with renewables and related firming capacity. There are 19 coal generators still operating in Australia: 16 in the NEM and three in the WEM. The closure date for many coal generators has been brought forward over the past two years.

Coal fired power station closure schedule, Australia

State	Name	Fuel	Commissioned	Closure	Capacity (MW)
NSW	Liddell	Black coal	1971-73	2023	2,000
NSW	Eraring	Black coal	1982-84	2025	2,880
WA (W)	Collie	Black coal	1999	2027	340
VIC	Yallourn W	Brown coal	1975, 1982	2028	1,480
NSW	Vales Point B	Black coal	1978	2028	1,320
QLD	Callide C	Black coal	2001	2028	810
QLD	Callide B	Black coal	1989	2028	700
WA (W)	Muja	Black coal	1981, 1986	2029	1,070
NSW	Bayswater	Black coal	1982-84	2033	2,640
QLD	Gladstone	Black coal	1976-82	2035	1,680
QLD	Tarong	Black coal	1984-86	2036	1,400
QLD	Tarong North	Black coal	2002	2037	443
NSW	Mt Piper	Black coal	1993	2040	1,400
QLD	Kogan Creek	Black coal	2007	2042	750
QLD	Stanwell	Black coal	1993-96	2045	1,460
VIC	Loy Yang A	Brown coal	1984-87	2045	2,210
VIC	Loy Yang B	Brown coal	1993-96	2046	1,026
QLD	Millmerran	Black coal	2002	2051	851
WA (W)	Bluewaters	Black coal	2010	NA	416

Source: companies

The rate at which coal generators are being closed is a function of age, coal contracts, local mine depletion, ash dam replacement and challenges of operating baseload generation in an increasingly volatile renewable system. Some generators are exploring "snap freezing" units: injecting nitrogen into boilers and closing capacity with the ability for it to be "stored" and brought back into service in the event it is needed in the future. Coal generators are now required to give a minimum 3-year notice period before they close to allow replacement capacity to be installed in time.

System extremes: South Australia and Western Australia

The impact of system transformation is experienced differently in each Australian state. Large states like New South Wales (Sydney), Victoria (Melbourne) and Queensland (Brisbane) still retain most of their coal generators and are relatively interconnected to other large states. Tasmania (Hobart) is a small state, but is mostly self-reliant for electricity due to its large hydroelectricity resources. The two states that are experiencing the "leading edge" of big renewables integration are South Australia (Adelaide) and Western Australia (Perth).

South Australia sources around 68 per cent of its electricity from intermittent renewables (wind and solar). It is the leading large-scale grid for renewables integration in the world. It relies heavily on balancing from indigenous gas generators, some battery storage and imports from neighbouring Victoria. A second major 800MW transmission line is being constructed to connect the state to NSW to reduce risk and allow more renewables to feed into larger markets.

Western Australia hosts a relatively small (6GW), isolated grid around Perth. This system is operating with high and increasing levels of rooftop solar PV and wind energy. In the year to August 2022, it sourced 29 per cent of its electricity from wind and solar. To achieve this, the WA government-owned coal generators operate non-commercially to ensure reliable supply.

1. Distributed rooftop solar and minimum demand – Perth

The isolated grid around Perth has a capacity of around 6GW, with total rooftop solar PV capacity approaching 1.5GW. Rooftop solar PV is, by capacity, the largest generator in the system. This poses technical problems on mild, sunny afternoons on weekends in spring when demand is low and rooftop PV output is high.

A record low operational demand of 765MW was set in November 2021 and is expected to fall this year below the system security threshold of 700MW. This is the minimum amount of dispatchable generation needed to supply adequate ancillary services. This minimum demand event would equate to around 62 per cent of supply on these afternoons being met by distributed solar PV.

These low operational demand levels force minimum baseload generation below their minimum output levels. They are then unavailable in the evening peak when demand increases and solar generation is zero. On current trend minimum operational demand could reach zero by 2026-27. Coal generators may need to be constrained-on during these future low demand events to supply ancillary services and be available for evening peaks and measures are being taken to curtail rooftop solar PV to maintain a minimum demand threshold.

2. Islanding of a high renewables grid – South Australia

Industry and market operators have been successfully managing to integrate increasing levels of intermittent renewable generation into the South Australian grid over the past decade. The upgrading of a 650MW interconnector to neighbouring Victoria has been crucial in maintaining reliable supply given the increased generation volatility that accompanies high intermittent renewables.

The last coal generator exited the South Australian market in early 2016 as it was unable to operate commercially given the price impact of large zero marginal cost renewable generation. South Australia then experienced a system black event in September 2016 when a large storm took out intrastate transmission lines connecting wind generators in the mid-north of the state to the main load centre in Adelaide. The subsequent collapse in voltage tripped the interstate transmission line and the entire state was blacked out.

South Australia was islanded for 18 days in February 2020 following a major fault on the interconnector to Victoria. Another system black was narrowly avoided when the tripped, and South Australia ran on a 50:50 gas and renewables mix while islanded. Blackouts were avoided partly thanks to mild summer weather containing demand. The islanding exposed a shortage of frequency control services in the state, with ancillary services costs almost three times the cost of energy during the event.

Since 2016 there have been major changes in the operation of the South Australia grid:

- Firm generation: another 710MW of peaking and fast start reciprocating engine generation has been added in South Australia, while 1280MW of old gas-fuelled steam turbines have closed.
- Batteries: 180MW of batteries have been installed and another 300MW are under construction.
- Transmission: a second 800MW transmission line linking South Australia to NSW is scheduled to be completed in 2023. This will reduce transmission risk and enable even more renewable generation in the state.
- Synchronous condensers: four synchronous condensers have been installed to provide more system strength and inertia in the north of the state, reducing the need for gas fired units to be directed on to provide these services.

Electrification of Transport

Australia may be an early adopter of solar PV as a consumer good, but it has been a slow follower of electric vehicles, with EVs comprising just 1.8 per cent of new passenger car sales in 2020. This compares to 75 per cent of new car sales in Norway, 32 per cent in Sweden, 25 per cent in the Netherlands, 13.5 per cent in Germany or 11 per cent in the UK. This is not the result of a lack of consumer interest. EVs are popular and seen as highly desirable in the Australian market.

The Australian car market is small and far from most major car manufacturers. Australian consumers only have access to a limited range of passenger vehicles, partly due to Australia being right-side drive.

Governments have elected not to subsidise EVs and, so far, have been reluctant to introduce meaningful fuel efficiency standards that encourage EV uptake.

While electric cars adoption will continue to grow, it is unlikely to drive a significant change in electricity demand in the short term. Nevertheless, the electricity sector is examining what policies are required to ensure the coming growth in residential demand is managed well. Key focus areas have been 1) ensure capability for control of residential chargers and 2) tariff reform to encourage charging outside peak times.