100% Renewable grid by 2030

Discussion Paper

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1. Document information

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The ATA is a not-for-profit organisation that enables, represents and inspires people to live sustainably in their homes and communities.

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2. Executive summary

Australia should transition quickly to a 100% renewable electricity grid, as it is cheaper and less risky than the alternative of building new coal-fired power stations. This can be achieved by 2030.

The Alternative Technology Association (ATA) is a not-for-profit organisation that enables, represents and inspires people to live sustainably in their homes and communities. Established in 1980, the ATA provides expert, independent advice on sustainable solutions for the home to households, government, industry and corporate clients.

Based on recent research by the Australian National University (ANU), we forecast likely progress towards a fully-renewable grid in the National Electricity Market (NEM). We considered recent trends and developments in projects such as Snowy Hydro 2.0.

Fully-renewable operation of the National Electricity Market requires 93,300 megawatts (MW) of renewable generation capacity, according to the ANU. If construction of wind and solar generation continues at the 2017 rate, this level will be attained in 2040. To reach this milestone by 2030 would require an acceleration of 80% from the 2017 rate. This is illustrated in the following chart.

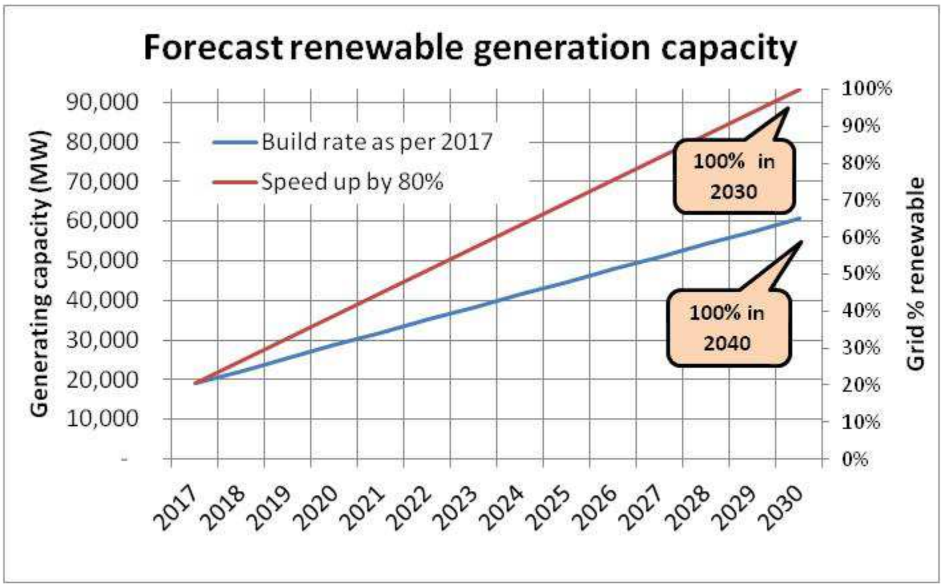

Figure 1: Forecast renewable generation capacity.

The following chart forecasts the construction of energy storage facilities by project category in the National Electricity Market. Energy storage capacity is shown in megawatt-hours (MWh), and also as a percentage of the 490,000 MWh required for a 100% renewable grid. “PH” is an abbreviation for “pumped hydro”. The category “Other” includes Cultana, Kidston, Aurora and the Jamestown and Vic batteries. “Hilltop PH” represents 21 small, off-river facilities as proposed by the ANU.

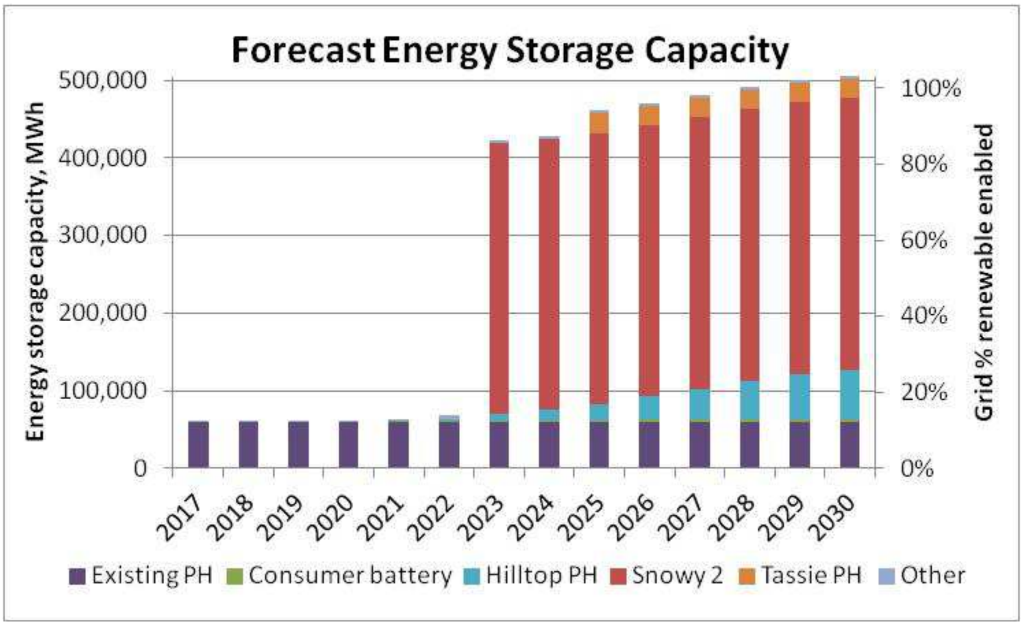

Figure 2: Forecast energy storage capacity

Based on this forecast, energy storage will be sufficient to support a fully-renewable grid by 2030.

Electricity from new-build coal-fired power stations would likely cost between $81 and $182 per MWh. This becomes a range of $102 to $203 once we allow for hidden health impacts ($13/MWh) and climate impacts ($8/MWh). In a fully-renewable electricity grid, electricity would cost about $93 per MWh. This includes the cost of building energy storage and extra transmission to manage intermittency.

The cost of renewable electricity is already in the lower range of the cost estimates for new-build coal-fired generation, even if coal's hidden costs are ignored. And renewable costs will fall further in the future.

Retail electricity prices from the 1990s are unlikely to return, regardless of the option chosen. Consumers are advised to shop around for a good deal, work on reducing their energy consumption and install rooftop solar if possible. Energy efficiency must not be neglected. Although this paper's focus is on electricity generation, Australia has massive opportunities to save money and help the environment by getting smarter about how we use energy.

Australia should prepare a proper plan for 100% renewable energy, and implement it. Decisions should not be left to separate companies driven by short-term profits, as this may lead to a poor overall system. Until Snowy Hydro 2.0 is built, wind and solar should focus on NSW and QLD as their total level of renewables is low, so they can easily accommodate more. This will avoid the operational problems that see the market operator ordering South Australian wind farms to reduce their output, burning expensive gas instead of using free wind. Authorities should also address how to manage a high-renewable grid – the energy market must ensure that energy stores can be conserved for use at the end of a cloudy, calm week.

3. Introduction

Australia is in a transition, as the ageing coal-fired power stations are reaching end-of-life and being retired.

So what should we replace them with? New-build generation since 2012 has been dominated by wind farms and solar panels. If we continue this path to its conclusion, what does our country's final electricity grid look like? How close are we to that future? What might it mean for electricity prices? We explore these issues, drawing on recent research and developments.

The Alternative Technology Association (ATA) is a not-for-profit organisation that enables, represents and inspires people to live sustainably in their homes and communities. Established in 1980, the ATA provides expert, independent advice on sustainable solutions for the home to households, government, industry and corporate clients.

This document aims to inform Australian households and policymakers. It builds on our paper published in December 2016, "100% Renewable Grid – Feasible?"[1], which explained that a fully-renewable grid:

- is feasible and economic in the long-term
- would be a big project, but achievable
- is a major step to meeting Australia's climate commitments.

Energy efficiency must not be neglected. Although this paper's focus is on electricity generation, Australia has massive opportunities to save money and help the environment by getting smarter about how we use energy.

3.1 Recent developments in the grid

The last year has seen much action in the electricity grid, both announced and commenced.

It's become clear that the electricity grid's transition is well underway, as coal-fired power stations are being replaced by renewables.

However, poor planning and coordination has caused problems such as curtailment of wind generation in South Australia (see Section 3.1.4 below).

3.1.1. Generator construction and retirement

The following chart from the Australian Energy Regulator shows historical construction and retirement of large generators. Generating capacity is noted in megawatts (MW) of rated power. Retirement of generators is indicated as negative capacity. New generation is dominated by renewables (mostly wind farms) while coal-fired power stations have been closing. The chart's timeline ends before closure of the coal-fired Hazelwood Power Station in March 2017. That power station's capacity was 1,600 MW.

[1] http://www.ata.org.au/wp-content/general/One_Hundred_Percent_Renewable_Grid.pdf

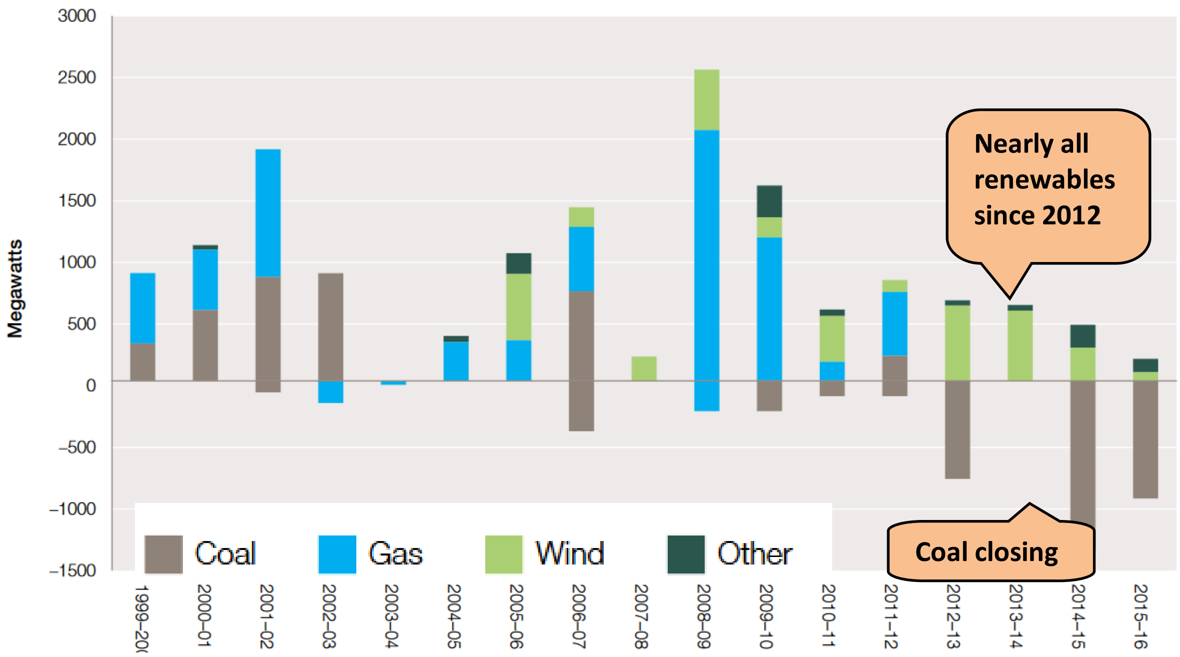

Figure 3: Investment in new generation, and plant retirements[2]

The above chart also does not include rooftop solar panels, because these are installed on customer premises and are largely invisible to organisations managing the grid.

The following chart shows the uptake of rooftop solar. The rated capacity of rooftop solar systems reached 6,000 MW in 2017 and is increasing by about 1,000 MW per year. This exceeds the annual build in large generator capacity in any year from 2009 to 2016.

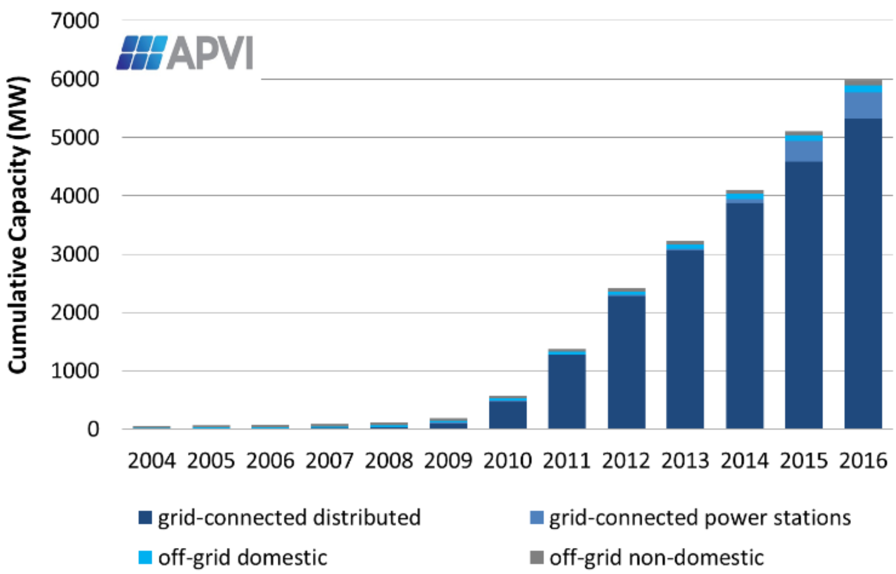

Figure 4: Installed capacity of solar PV generation by year[3]

[2] State of the Energy Market, May 2017, Australian Energy Regulator. Page 38. https://www.aer.gov.au/system/files/AER%20State%20of%20the%20energy%20market%202017%20-%20A4.pdf

[3] Australian PV Institute press release 31 July 2017. http://apvi.org.au/wp-content/uploads/2017/07/APVI-Press-201707_PV-in-Australia-Report.pdf

As of September 2017, investors were very keen to build new renewable generators. According to the CEO of the Australian Energy Market Operator in September:
"We have 21,000 megawatts of connection requests, all solar and wind." [4]

On the other hand, investors are not keen to build new coal-fired power stations. This is seen clearly in statements by AGL, Australia's largest owner of coal-fired electricity generation. For example, according to CEO Andy Vesey,
"Technology is driving this — we don't see any baseload other than renewables."[5]

3.1.2. Electricity energy generation

Of the grid's total generating capacity, newly-built renewable generating capacity still only accounts for a small fraction. The National Electricity Market (which excludes WA and NT) has a total generating capacity of 48,000 MW.[6] The blue bars in the following chart show the proportion of electrical energy generation contributed by each type of generator. It's clear that fossil fuels still dominate our electricity generation.

The grey bar shows each generation type's proportion of rated capacity. For coal-fired power stations the blue bar is larger than the grey one, indicating a high level of energy generation compared to their rated capacity. This is because coal-fired power stations tend to run most of the time. The situation is reversed for gas-powered stations – they are usually left idle until really needed because their fuel is expensive. Due to night-time, clouds etc, rooftop solar systems also have relatively low energy generation compared to their rated capacity.

Note that the chart dates to FY 15–16 so it doesn't reflect developments since July 2017.

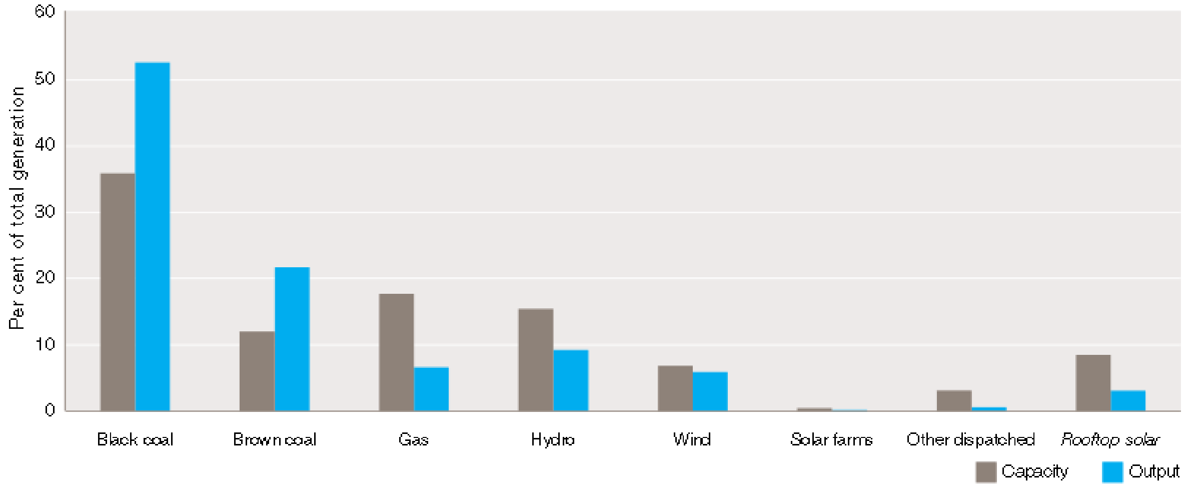

Figure 5: Generation in the NEM by fuel source 2015-16[7]

[4] Audrey Zibelman speaking at ATA event at Melbourne University, 20 Sept 2017. 19 minutes 40 seconds into the file, https://archive.org/details/SecuringAustraliasEnergyFutureSeptember202017
[5] The Australian, 21 June 2017. http://www.theaustralian.com.au/business/mining-energy/coal-cant-compete-with-renewables-agl-chief-andy-vesey/news-story/8f488b5adbf61735ea85e01c267aad36
[6] AEMO generator registration list, accessed 18/10/17, type "generator".
[7] State of the Energy Market, May 2017, Australian Energy Regulator. Page 30. https://www.aer.gov.au/system/files/AER%20State%20of%20the%20energy%20market%202017%20-%20A4.pdf

3.1.3. Recent developments

2017 has seen many innovative developments and proposals in our electricity grid. Interestingly, many of these were foreshadowed by our paper last year. Here are some of the highlights.

Jamestown Tesla battery

Contracted by the South Australian government in July 2017, the Tesla company has already built part of a large grid-connected battery in Jamestown, and switched it on.[8] Compared to other grid infrastructure, this construction is blindingly fast! When fully complete by 1 December 2017, the battery will have a rated capacity of 100 MW and an energy storage capacity of 129 megawatt-hours (MWh). This means that when full, it can discharge at full power for one-and-a-bit hours before it's depleted. The battery will be used to stabilise the SA grid, jumping in quickly to counteract disturbances in voltage and frequency. It will also store electricity generated by the adjacent Hornsdale Wind Farm, helping to buffer its output that naturally varies with wind conditions.

Figure 6: Jamestown Tesla battery

Demand response

Occasional periods of peak demand drive much of the cost in our electricity system. Rather than building expensive generators or batteries that sit idle most of the time, it makes sense to instead reduce demand at these critical times. Typically, large consumers are paid to switch off equipment. Australia's grid makes little use of this method, unlike other countries.[9] Rule changes to facilitate it have been refused.[10]

In October 2017 a new initiative was announced to deliver demand response.[11] Run by the Australian Energy Market Operator (AEMO) and the Australian Renewable Energy Agency (ARENA), this trial will deliver 143 MW of capacity for this summer.

[8] http://www.abc.net.au/news/2017-09-29/elon-musk-tesla-world-biggest-battery-reaches-halfway-mark/9001542

[9] "Re-Powering Markets", International Energy Agency 2015, page 161.
https://www.iea.org/publications/freepublications/publication/REPOWERINGMARKETS.PDF
https://arena.gov.au/blog/demand-response-2/

[10] http://www.aemc.gov.au/Rule-Changes/Demand-Response-Mechanism/Final/AEMC-Documents/Information-sheet-%E2%80%93-Final-determination.aspx

[11] https://arena.gov.au/funding/programs/advancing-renewables-program/demand-response/

Victorian batteries in western Victoria
To strengthen the electricity grid in western Victoria, the state government will build a battery with a power of 40 MW and energy storage of 100 MWh.[12]

Port Augusta concentrating solar thermal generator, "Aurora"
Concentrating solar thermal (CST) facilities use mirrors to reflect and concentrate sunlight, creating temperatures up to 300 – 1000 degrees Celsius. Heated fluid is stored in an insulated tank; when required its heat boils water into steam to spin an electric generator.

In August 2017 the South Australian government announced that it will build a CST generator at Port Augusta with a power of 150 MW, able to store 1,200 MWh of energy.[13] It will begin construction in 2018 and is estimated to be completed in 2020.

Figure 7: Concentrating solar thermal power station.
Photo courtesy Solar Reserve

Cultana seawater pumped hydro
Pumped hydroelectricity is a method of storing energy and works like a big battery. To store energy, an electric pump pushes water up a pipe to a high dam. To discharge energy, the water is allowed to flow down again, spinning the pump in reverse to generate electricity.

In 2017, a feasibility study was published for a pumped hydro facility at Cultana in South Australia. The plan is to pump seawater from the Spencer Gulf up to a new hilltop dam on land owned by the Department of Defence. Its power will be 225 MW and energy storage 1,770 MWh.

Results are promising; through buying and selling electricity in the normal wholesale market, the facility is expected to earn an 8% to 12% rate of return. The study was undertaken by EnergyAustralia, Arup and the University of Melbourne's Melbourne Energy Institute (MEI), with support from ARENA.[14]

[12] https://www.energy.vic.gov.au/batteries-and-energy-storage
[13] https://www.premier.sa.gov.au/index.php/jay-weatherill-news-releases/7896-port-augusta-solar-thermal-to-boost-competition-and-create-jobs
[14] https://arena.gov.au/assets/2017/09/Cultana-Pumped-Hydro-Project-_Public-FINAL-150917.pdf

Kidston pumped hydro

This planned project will use two existing pits in a disused gold mine in north Queensland as upper and lower dams for pumped hydroelectricity. The feasibility study is complete, and the company Genex Power is negotiating transmission connections. It's expected to be operational in 2019, with a power of 250 MW and energy storage of 1,500 MWh.[15]

Figure 8: Disused pits at Kidston gold mine in north Queensland

Image source: https://arena.gov.au/projects/kidston-pumped-storage-project/

Hydro Tasmania "Battery of the nation"

Tasmania already has a lot of hydroelectric generation. The state's rainwater dams and lakes already store huge amounts of potential energy, ready to be released through electricity-generating turbines before flowing down-river to the sea.

The existing system has its limitations. Water release must consider other stakeholders, e.g. irrigation. And Tassie dams cannot store energy generated elsewhere, e.g. by a wind farm. To operate like a proper battery, Tassie needs the addition of pumped hydro.

In April 2017, a study was announced into the feasibility of adding 13 pumped hydro facilities in Tasmania, mostly connecting existing dams.[16,17]
The power expected by these projects is 2500 MW, but energy storage in MWh has not been stated.

Snowy Hydro 2.0

This is a proposal to develop pumped hydro energy storage in the Snowy Mountains.[18] The idea is to periodically pump water uphill between existing water reservoirs (Talbingo and Tantangara), and then release the water back downhill to generate electricity. It will act to store electricity like an enormous battery. Proposed generating capacity is 2,000 MW of power, and energy storage capacity is 350,000 megawatt-hours (MWh). This means that if the top dam is full, Snowy 2.0 could generate at full power for a whole week before it was depleted. The feasibility study is due in December 2017, and the project might take 6 years to complete.[19]

Other projects

In addition there are many renewable projects planned by large industrial companies. For example, Arrium plans to construct a pumped hydro facility sized at 120 MW / 600 MWh, a battery sized at 100 MW / 100 MWh and many hundred megawatts of renewable generation capacity.[20]

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[15] http://www.genexpower.com.au/the-kidston-pumped-storage-hydro-project-250mw.html
[16] https://www.hydro.com.au/about-us/news/2017-04/talking-point-let%E2%80%99s-be-battery-nation
[17] http://www.themercury.com.au/news/tasmania/can-tasmania-be-the-battery-of-the-nation/news-story/145ab43ec960aff34d07ce1250112509
[18] http://www.snowyhydro.com.au/our-scheme/snowy20/
[19] http://www.news.com.au/technology/innovation/snowy-hydro-20-to-get-funding-boost/news-story/63d905fa328b7fe5d0ef1ef5f8bc7a4f
[20] http://www.afr.com/news/sanjeev-guptas-700-million-solarbatteryhydro-bet-to-power-whyalla-steel-20171029-gzaqfe

3.1.4. Curtailment of South Australian wind farms

At first glance it seems there shouldn't be any trouble using all of SA's wind generation. However, in the interests of system security AEMO has ordered wind farms to reduce (curtail) output many times in 2017. Expensive gas has been burnt instead of using free wind power.

SA's wind generation capacity has already grown to 1,700 MW[21], with investors attracted by SA's historically high electricity prices, excellent wind resource and federally-administered incentives. SA's record minimum electricity demand is 834 MW[22], and SA can also export up to 790 MW to Victoria. Adding these two numbers, the grid can always use at least 1,624 MW of power from generators in SA. Since it's highly unlikely for all of SA's wind turbines to simultaneously spin at full capacity, there seems to be no problem.

However, running totally on wind can create problems for the state's current electricity grid.[23] AEMO has been studying this situation for many years.[24]

In April 2017 AEMO decided to run some gas-fired power generation at all times to ensure grid stability and security. [25] These gas generators supply some of SA's electricity demand, reducing the outlet available to wind farms. If wind farms are generating more power than can be absorbed by the grid then AEMO instructs them to reduce power. Wind farms may have had around 6% of their generation curtailed in the period from 19 July to 13 September 2017.[26] As new additional wind farms are built, curtailment will increase.

AEMO's specific reason for always requiring some gas generation is to maintain system strength. If a transmission line touches the ground (for example), we actually want a strong grid to push a momentary, massive current into the ground, because then the grid's big safety switches will switch off as they'll register the high current as a fault. Successful disconnection of the faulty power line helps stabilise the rest of the grid and allows safe restoration works.

Current wind turbines don't provide this system strength, so the grid may not push enough current into the fault for the safety switches to operate correctly. Gas generators are currently the only equipment in South Australia that can provide sufficient system strength.

This appears to be a failure in planning. With some foresight and coordination, the coal-fired Northern Power Station's decommissioned turbines could have been re-purposed as synchronous condensers which provide system strength without burning fuel.[27] In future, this service could be provided by other renewable solutions such as concentrating solar thermal or pumped hydro energy storage. These two technologies naturally provide system strength and inertia because they include heavy, spinning machinery.

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[21] AEMO NEM registration list, accessed 28/10/17.
[22] AEMO South Australian Electricity Report 2016, page 23. http://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/SA_Advisory/2016/2016_SAER.pdf
[23] For example, the grid's inertia drops to a low level, meaning any grid disturbance that happens will unfold more rapidly and be hard to control For more info please see ATA's paper "100% renewable grid: feasible?".
[24] https://www.aemo.com.au/Datasource/Archives/Archive1365
[25] https://www.aemo.com.au/-/media/Files/Electricity/NEM/Market_Notices_and_Events/Power_System_Incident_Reports/2016/Power-System-Operations-Incident-Report_SA13Nov16.pdf
[26] http://www.wattclarity.com.au/2017/09/how-much-wind-powered-electricity-production-has-been-curtailed-in-sa-since-these-new-constraints-were-invoked/
[27] Electranet, Page 32, "Northern South Australia Region Voltage Control" https://www.electranet.com.au/wp-content/uploads/resource/2016/08/20160803-Report-NorthernSARegionVoltageControlPSCR.pdf

4. Where is this grid transition taking us?

At the completion of this transition, we expect that Australia's electricity grid will be powered completely or almost completely by renewable energy.

Some progress has already been achieved in solar and wind generation.

However, there's been little progress on energy storage and strengthening the transmission system. In a grid dominated by wind and solar, energy storage is essential to get through a calm, cloudy week. And extra transmission lines are needed to transport electricity from areas experiencing sunshine and wind to the rest of the country.

4.1 How is the grid planned now?

Most of Australia's current power stations were constructed in the 1970s and 80s by state-based electricity bodies such as ETSA in South Australia. These were integrated organisations controlling the entire supply chain from generation through to customer billing. They managed their generator fleets carefully, planning new power stations to take over from those nearing end-of-life.

In the current system there is no such plan. In the 1990s the state-based bodies were mostly split up and privatised, and superseded by the new National Electricity Market.[28] Generators compete against each other, may close without notice and have a business incentive to conceal their future intentions.

There is no guarantee that new power stations will be built – the system expects that investors will foresee a shortfall, identify a profit and construct the needed infrastructure. To assist investors, the market operator (AEMO) annually produces the Electricity Statement Of Opportunities report[29] attempting to identify future shortfalls. This document only looks ahead 10 years, and doesn't consider scenarios such as 100% renewables. AEMO also a transmission report[30], which looks ahead 20 years but has a relatively narrow focus on transmission lines and related assets.

In hindsight this system has a clear flaw. If investors fail to act in time, generating capacity may be insufficient to meet demand. It takes several years to build a new power station, but an old one can be closed very quickly – Hazelwood's owners provided only 5 months' notice.[31] Individual asset owners have no responsibility for the overall system's reliability. This is why interventions in the market have been required in 2017, including the South Australian government's Energy Plan[32] and the federal government's efforts to dissuade AGL's plans to close Liddell power station in 2022.[33] The market is now facing its first major refresh of the generation fleet, as end-of-life approaches for the old generators constructed prior to the market's commencement.

The current system also relies heavily on clear, long-term government policy to guide investors. Without such policy, investors face the risk that their newly-built asset might have to contend with unexpected new incentives, rules and regulations.

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[28] http://www.aemc.gov.au/Australias-Energy-Market/Markets-Overview/National-electricity-market
[29] "ESOO": https://www.aemo.com.au/Media-Centre/2017-Electricity-Statement-of-Opportunities
[30] "NTNDP": http://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/NTNDP/2016/Dec/2016-NATIONAL-TRANSMISSION-NETWORK-DEVELOPMENT-PLAN.pdf
[31] http://www.abc.net.au/news/2017-03-24/hazelwood-latrobe-valley-not-the-first-or-the-last-to-close/8380760
[32] http://ourenergyplan.sa.gov.au/
[33] http://www.sbs.com.au/news/article/2017/09/11/agl-consider-extending-life-liddell-power-station

4.2 What kind of planning do we need?

As the grid transitions to a high level of renewables, good long-term planning is required.

If the grid's current planning arrangements continue unchanged, decisions and investments will be uncoordinated. They may make sense for the short-term profits of individual companies, but may not lead to a well-designed overall system.

The Chief Scientist considered this, and recommended an "integrated grid plan" by AEMO.[34]

4.3 The best plan so far

In the absence of long-range planning by authorities for a high-renewable grid, the best studies have come from universities.[35] In February 2017, the ANU published a clear vision for our future grid.[36] Its researchers found the most economic combination for a fully-renewable grid comprises:

- wind farms (45,000 MW)
- solar farms (23,000 MW)
- rooftop solar (17,000 MW)
- existing hydroelectric and biomass generators (10,800 MW)[37]
- pumped hydro energy storage
- extra transmission lines.

Total generation capacity is 93,300 MW, nearly double our grid's generation capacity of 48,000 MW[38] in 2017. This is due to "over-building" wind and solar to cater for their intermittent nature. Generators are spread widely to ensure that some of them are always generating well regardless of weather conditions, as the whole continent is never calm and cloudy simultaneously.

To transport electricity around the NEM, the ANU proposes a new transmission "backbone", roughly following the Great Dividing Range and onward into South Australia and Tassie. The ANU's study only considered the National Electricity Market, so the separate grids in WA and NT were excluded.

Energy storage requirements are relatively modest – enough to supply average grid demand for 30 hours without any generation. Off-grid households know this concept as "days of autonomy". Such families typically have batteries large enough to supply 3 to 5 days of average electricity demand with no generation. An off-grid house requires a relatively large amount of storage because it can harvest solar and wind energy from only a single location, so it's vulnerable to localised stretches of cloudy, calm weather.

Detailed simulations determined that this combination of generation and energy storage keeps the grid reliable even under rare weather conditions. This includes supplying heavy industry such as smelters. Existing hydroelectric power stations (e.g. the Snowy hydro scheme) and existing biomass generation (e.g. burning sugar cane residue) are used when the weather is particularly unfavourable.

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[34] Independent Review into the Future Security of the National Electricity Market, June 2017, Alan Finkel. Recommendations 5.1 and 5.2. http://www.environment.gov.au/system/files/resources/1d6b0464-6162-4223-ac08-3395a6b1c7fa/files/electricity-market-review-final-report.pdf

[35] For a list of previous studies, refer to ATA's paper "100% renewable electricity grid – feasible?"

[36] "100% renewable electricity in Australia", Andrew Blakers, Bin Lu and Matthew Stocks, Australian National University. http://energy.anu.edu.au/files/100%25%20renewable%20electricity%20in%20Australia.pdf

[37] AEMO generator registration list, accessed 18/10/17, type "generator".

[38] Ibid

4.3.1. Off-river pumped hydro dams

The ANU found that the most economical form of energy storage is pumped hydro. They propose earthen constructions like oversized farm dams, built on hilltops. A second similar dam sits at the bottom of each hill. The upper dam is 300 to 900 metres higher than the lower one. When solar and wind power are plentiful in the grid, water is pumped up a pipe to the top dam. When power is required, water is allowed to flow down the pipe, spinning the pump in reverse to generate electricity. The same water is recycled so the only losses are due to evaporation, and are very small compared to other demands on Australian water.[39] River flows are not affected.

High pressure due to the upper dam's height enables large amounts of energy to be stored with a relatively small area. For example, an upper dam might cover 10 hectares to a depth of 20 metres. On a 700m tall hill, it can generate 500 MW of power for six hours, for a total energy storage of 3,000 MWh.[40] Round-trip efficiency is 80%.

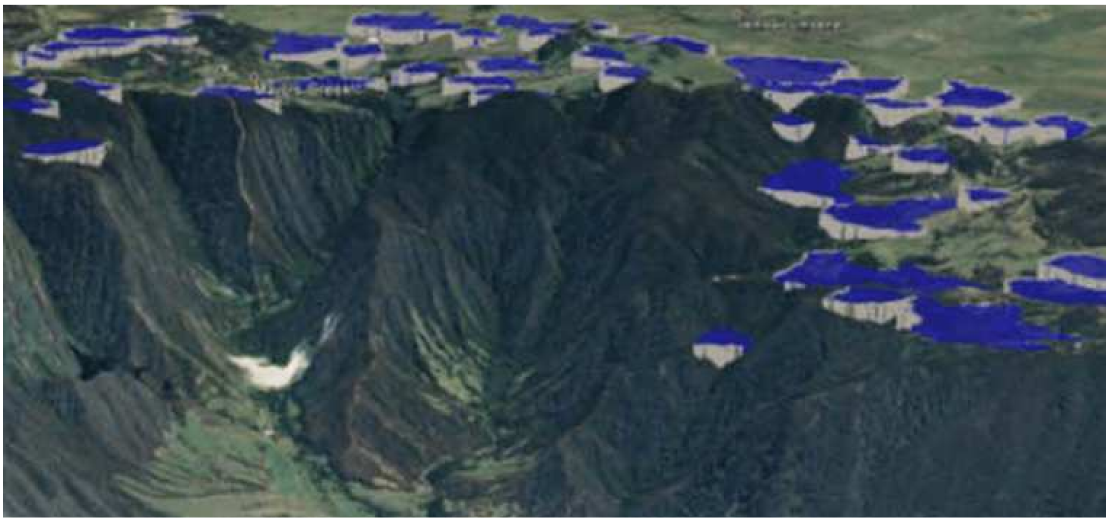

Figure 9: A plentiful choice of upper dam sites near Araluen, ACT. Topography exaggerated[41].

In the absence of any other energy storage, the ANU's plan requires about 160 such facilities, with energy storage totalling 490,000 MWh. Total power capacity is 16,000 MW, and total inundated area is 36 square kilometres.

Potential sites are plentiful – a topological search found 22,000 suitable locations away from national parks and urban areas.[42] This leaves plenty of scope to pick sites with easy access, cooperative landowners, simple construction and minimal environmental impact. Most sites are close to the Great Dividing Range, within easy reach of the ANU's proposed new transmission backbone.

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[39] Presentation by Bin Lu, "100% renewable electricity", slide 15. https://www.google.com.au/url?sa=t&rct=j&q=&esrc=s&source=web&cd=19&cad=rja&uact=8&ved=0ahUKEwip3ZL61pLXAhVFkZQKHX6eDVw4ChAWCE0wCA&url=http%3A%2F%2Fwww.cleanenergysummit.com.au%2Fdam%2Fclean-energy-summit%2Fagenda%2Faces-2017-presentations%2FTransitioning-the-generation-fleet%2FBIN-LU-UPDATED%2FBIN%2520LU%2520UPDATED.pdf&usg=AOvVaw3t_X71AHXPbeS5YmKXell

[40] Page 11, "100% renewable energy in Australia", February 2017. http://energy.anu.edu.au/files/100%25%20renewable%20electricity%20in%20Australia.pdf

[41] Page 18, An atlas of pumped hydro energy storage, Andrew Blakers et al, ANU, 21st September 2017. https://www.dropbox.com/s/5s5cbwcw32ge18p/170919%20PHES%20Atlas.pdf?dl=0

[42] An Atlas of pumped hydro energy storage, Andrew Blakers et al, ANU, 21st Sept 2017. https://www.dropbox.com/s/5s5cbwcw32ge18p/170919%20PHES%20Atlas.pdf?dl=0

4.3.2. Wind and solar

A 100% renewable grid will involve large areas of wind and solar farms.

Wind farms totalling 45,000 MW would comprise 15,000 turbines, assuming each turbine is 3 MW in size. They would use an area about one-quarter as large as Anna Creek Station, Australia's largest cattle station.[43]

As with existing wind farms, agriculture continues unimpeded underneath, and the landowner receives royalty payments. Australia currently hosts about 3,000 wind turbines.[44] Here's a fun fact – each blade on a modern wind turbine is about as long as the leaning tower of Pisa!

Figure 10: General Electric wind turbine used in the 453 MW Coopers Gap wind farm (Qld). [45]

Solar farms totalling 23,000 MW would require about 70 million panels. This is a large number, but it's clearly achievable since by December 2015 Aussies had already installed more than 23 million panels on rooftops.[46] For the ANU's plan, solar farms would cover about 230 square kilometres.[47] This is about 1.8 times as large as Australia's largest irrigated area, which is on Cubbie station.

Solar farms can coexist well with sheep, as space is normally left between rows to avoid self-shading.

Figure 11: Sheep grazing at University of Queensland's solar research facility – ABC news.

[43] Extrapolating from the existing Macarthur Wind Farm. https://en.wikipedia.org/wiki/List_of_the_largest_stations_in_Australia, https://www.agl.com.au/about-agl/how-we-source-energy/renewable-energy/macarthur-wind-farm

[44] AEMO generator registration list, accessed 15/11/17, fuel "wind", assume turbine size 3 MW.

[45] http://www.ecogeneration.com.au/ge-and-agl-team-up-for-453mw-qld-wind-farm-australias-largest/

[46] http://www.sunwiz.com.au/index.php/2012-06-26-00-47-40/73-newsletter/384-australian-solar-industry-celebrates-the-new-year-by-ticking-over-1-5m-pv-systems.html

[47] Each panel's rated power is 320W and its area is $1.6m^2$. Assumes 50% empty space so rows of panels don't shade each other.

5. Cost of electricity generation

Electricity from a 100% renewable grid would cost about $93/MWh, based on the ANU plan. This is cheap compared to a new ultra-supercritical coal-fired power station, which would likely cost between $81 and $182 per MWh, or $102 to $203 once we allow for the hidden health and climate impacts. This reinforces the message from several previous studies[48] which found that a 100% renewable grid is economically competitive with other newly-built generators.

5.1 Levelised cost of energy

The average cost of generating energy over a power station's lifespan is called the levelised cost of energy, or LCOE. This is the sum of all costs including construction, operation and fuel divided by total electricity generated. It also includes a discount rate to allow for the decreasing value of money over time.[49] With wind and solar, the cost is mostly incurred during construction – after that the fuel is free. Conversely with fossil fuels the cost is spread out more evenly over the power station's lifespan.

5.1.1. Cost of coal-fired generation

A new, like-for-like replacement coal-fired power station could generate electricity for around $75-$80 per MWh.[50],[51] However, proposals for new projects use the slightly less polluting ultra-supercritical coal-burning technology. This has not yet been proven in Australia so costing is uncertain, but estimates range from $81[52] to $182[53] per MWh once market financing costs are included. These figures assume no carbon capture technology, which further increases costs to prohibitive levels.[54] It also excludes decommissioning and remediation costs, which can be large.

Coal-burning emits into the atmosphere particles and gases that reduce air quality and impact people's health. The cost of this health burden has been estimated at $13 per MWh in Australia.[55] Also, each MWh generated in current Australian coal-fired power stations emits on average about 1 tonne of carbon dioxide gas[56], which imposes current and future costs on Australia due to climate

[48] For a list, see ATA's paper "100% renewable grid – feasible"?
[49] https://en.wikipedia.org/wiki/Cost_of_electricity_by_source#Levelized_cost_of_electricity
[50] Page iii, Australian Power Generation Technology Report, CO2CRC, 2016. http://www.co2crc.com.au/wp-content/uploads/2016/04/LCOE_Report_final_web.pdf
[51] Page 201, Independent Review into the Future Security of the National Electricity Market, June 2017, Alan Finkel, Chief Scentist of Australia. http://www.environment.gov.au/system/files/resources/1d6b0464-6162-4223-ac08-3395a6b1c7fa/files/electricity-market-review-final-report.pdf
[52] Ibid
[53] Australian Financial Review, 3 February 2017 "Clean coal sounds good, but the numbers weigh against it". http://www.afr.com/business/mining/coal/clean-coal-sounds-good-but-the-numbers-weigh-against-it-20170202-gu4220
[54] Page iii, Australian Power Generation Technology Report, CO2CRC, 2016. http://www.co2crc.com.au/wp-content/uploads/2016/04/LCOE_Report_final_web.pdf
[55] Page "ii", The Australian Academy of Technological Sciences and Engineering, "The Hidden Costs of Electricity", 2009: https://www.scribd.com/document/36842518/ATSE-Hidden-Costs-Electricity-report
[56] Clean Energy Regulator, "Australia's largest electricity generators" http://www.cleanenergyregulator.gov.au/DocumentAssets/Documents/Australia%E2%80%99s%20largest%20electricity%20generators%20factsheet.pdf

change.[57] Fairly attributing the climate cost is difficult, so we use the results of the federal government's latest Emission Reduction Fund auction, $11.82 per tonne.[58] A new ultra-supercritical coal-fired power station might emit 0.7 tonnes of carbon dioxide per MWh of electricity generated.[59] On these assumptions, coal's hidden climate cost would be $8 per MWh (rounded to the dollar).

5.1.2. Cost of wind and solar generation

The Chief Scientist's report this year estimates that wind and solar farms built today can generate electricity for $91 to $92 per MWh over their lifespan.[60] However this looks too high, as recent long-term contracts have been below $60.[61,62] These contracts do attribute some value for Renewable Energy Certificates (a federally-administered subsidy scheme), but on the other hand RECs may not be a major factor, as they're unlikely to deliver much value past 2020. Low REC value is even more likely now that the government has announced that it will not implement a Clean Energy Target.

Another estimate comes from AGL Energy, Australia's largest owner of coal-fired generation. AGL says the cost of energy from wind and solar farms in 2017 is $64 and $75 per MWh respectively.[63] Global levelised costs for wind and solar farms are USD $30–60 and USD$43–53 respectively per MWh, according to Lazard (a leading financial advisory and asset management firm).[64]

In the ANU's proposed 100% renewable electricity grid, the average cost of energy generation across all sources is $65 per MWh.

5.1.3. Overall cost of renewable energy

Since wind and solar are intermittent generators, we must also consider the cost to integrate them into a reliable grid. This includes energy storage and extra transmission lines, as noted above.

These costs are large, but work out to a surprisingly small figure when spread out over total grid electricity consumption. The ANU calls this the "levelised cost of balancing", and estimates it at $28 per MWh. Adding this to the cost of energy generation, the total levelised cost of energy for a 100% renewable electricity grid is around $93 per MWh.[65]

[57] CSIRO "What are the impacts of climate change?": https://www.csiro.au/en/Research/OandA/Areas/Assessing-our-climate/Climate-change-QA/Impacts
[58] http://www.cleanenergyregulator.gov.au/ERF/Auctions-results/april-2017
[59] [59] Page 203, Independent Review into the Future Security of the National Electricity Market, June 2017, Alan Finkel, Chief Scientist of Australia. http://www.environment.gov.au/system/files/resources/1d6b0464-6162-4223-ac08-3395a6b1c7fa/files/electricity-market-review-final-report.pdf
[60] Finkel Independent Review, page 201.
[61] ASX & Media Release by Origin Energy, 8 May 2017 for Stockyard Hill Wind Farm. "Below $60/MWh". https://static1.squarespace.com/static/594b52ed37c581fa1843961b/t/5951b00378d171b90598308e/1498525701119/OEL+Media+release+SHWF+sale+20170508.pdf
[62] ASX & Media Release by AGL Energy, 17 August 2017 for Coopers Gap Wind Farm. "less than $60/MWh". http://www.asx.com.au/asxpdf/20170817/pdf/43lh4k5zfz162v.pdf
[63] Slide 6, "A future of storable renewable energy", AGL. https://www.agl.com.au/-/media/DLS/About-AGL/Documents/Investor-Centre/Presentation-and-speech----A-future-of-storable-renewable-energy.pdf
[64] Lazard's Levelized Cost of Energy Analysis version 11, November 2017, page 2. https://www.lazard.com/media/450337/lazard-levelized-cost-of-energy-version-110.pdf
[65] Page 1, "100% renewable electricity in Australia", ANU.

5.2 Costs: renewables vs coal

As noted above, electricity from new-build coal-fired power stations would likely cost between $81 and $182 per MWh. This becomes a range of $102 to $203 once we allow for the hidden health impacts ($13/MWh) and climate impacts ($8/MWh).

In a fully-renewable electricity grid, electricity would cost about $93 per MWh. This is in the lower range of the cost estimates for new-build coal-fired generation, even if coal's hidden costs are ignored. If coal's hidden costs are included, a renewables grid becomes cheaper than even the lower estimate for coal.

5.2.1. Future cost trends

The cost to install solar panels and wind turbines has dropped dramatically over the past decade, and this trend is expected to continue. For example, between 2015 and 2025 the International Renewable Energy Agency expects a 42% reduction in the cost of solar panels and a 26% drop in the cost of electricity from wind turbines.[66]

On the other hand, costs for coal-fired power stations are not reducing. Old coal-fired generators have been able to supply cheap electricity primarily because their financing was paid off decades ago, and cheap coal supplies had been available. A new coal-fired power station would have neither of these advantages. It would also have to contend with modern labour costs and regulations.

Future trends affect decisions being made today. Approving, designing and building a coal-fired power station would take many years. By the time it opened it would be competing against the next generation of cheaper wind and solar.

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http://energy.anu.edu.au/files/100%25%20renewable%20electricity%20in%20Australia.pdf

[66] International Renewable Energy Agency, "The Power to Change: Solar and wind cost reduction potential to 2025", June 2016, pages 44 and 67.
http://www.irena.org/DocumentDownloads/Publications/IRENA_Power_to_Change_2016.pdf

6. When can we have a 100% renewable grid?

Using the ANU plan as a target, we examine our progress towards a 100% renewable grid.

If Australia commences a proper effort in early 2018, ATA analysis shows that a fully-renewable electricity grid is achievable by 2030. This 12-year timeframe allows for the renewable industry to ramp up its capacity prior to a full-speed rollout in the final decade.

Constructing wind and solar generators at the rate seen in 2017, a fully-renewable grid will be achieved in 2040. If this is accelerated by 80%, full renewable operation can occur a decade earlier, in 2030.

The speed of transition is determined by wind and solar generation capacity, as energy storage requirements can be largely covered by 2025. This assumes the construction of new, large pumped hydro facilities in the Snowy Hydro scheme and in Tasmania, utilising existing dams.

6.1 Renewable generation capacity

Current solar and wind generation capacity is relatively small, only amounting to 16% and 10% respectively of the levels required to fulfil the ANU plan.[67] If we also include existing hydroelectric and biomass generators, total renewable generation capacity in the National Electricity Market is 19,100 MW, which is 20% of the amount required for a fully-renewable grid. Most existing solar panels are on rooftops, bought by householders assisted by government incentives.

In 2017, construction of wind and solar farms has reached a rate of around 2,200 MW of new generating capacity per year.[68,69] The pipeline is strong – AEMO has a big backlog of requests to connect proposed new generators to the grid. This totals 21,000 MW, and all the generators on AEMO's list are renewable.[70]

Adding 1,000 MW of rooftop solar per year (see Section 3.1) gives a total of 3,200 MW per year.

Fully-renewable operation of the National Electricity Market requires 93,300 MW of renewable generation capacity, according to the ANU.[71] If construction of wind and solar generation continues at the 2017 rate, this level will be attained in 2040. To reach this milestone by 2030 would require an acceleration of 80% from the 2017 rate.

The following chart forecasts renewable generation capacity in megawatts (MW) and as a percentage of 93,300 MW.

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[67] AEMO generator registration list, accessed 18/10/17, type "generator", APVI Market Analyses http://pv-map.apvi.org.au/analyses

[68] https://www.cleanenergycouncil.org.au/news/2017/February/2017-renewable-energy-projects-snowy-hydro.html

[69] http://www.afr.com/news/agl-energy-wind-farm-helps-turn-clean-energy-wave-into-tsunami-20170818-gxzbmm

[70] Audrey Zibelman speaking at ATA event at Melbourne University, 20 September 2017. 19 minutes 40 seconds into the file, https://archive.org/details/SecuringAustraliasEnergyFutureSeptember202017

[71] Page 16 & 17, "100% renewable electricity in Aus.", ANU. Also added 8,300 MWh for existing hydro & bio. http://energy.anu.edu.au/files/100%25%20renewable%20electricity%20in%20Australia.pdf

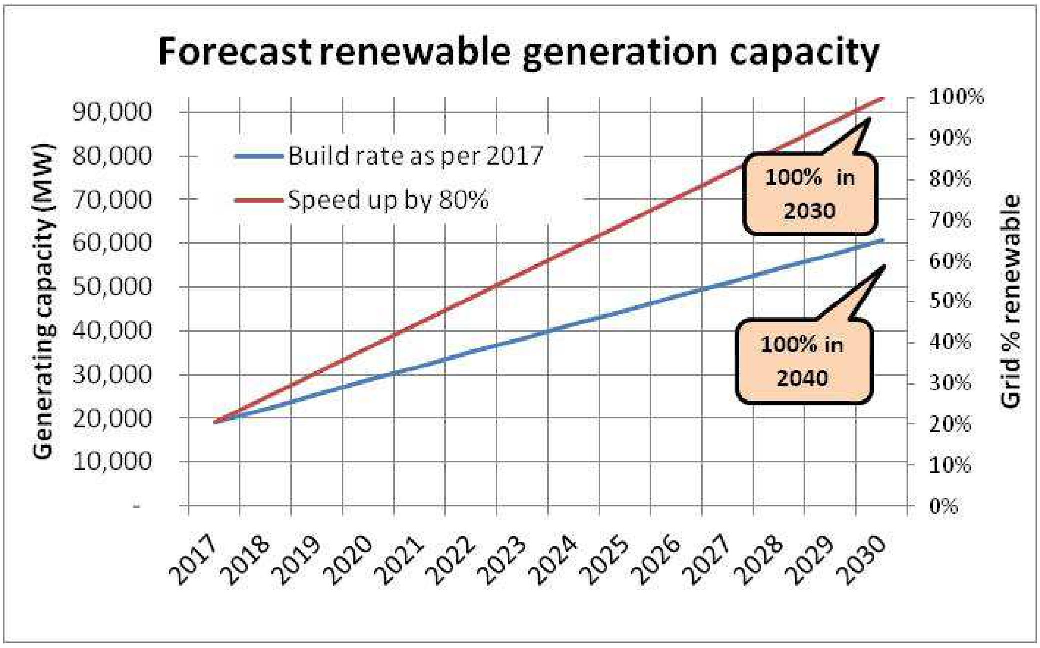

Figure 12: Forecast renewable generation capacity.

6.2 Energy storage

Energy storage in 2017 is dominated by the pumped hydro facilities at Tumut 3 (Snowy Mountains), Kangaroo Valley (near Shoalhaven) and Wivenhoe (near Brisbane). These can generate at a total power of 2,240 MW and can store energy totalling nearly 60,000 MWh. Operation of these dams is constrained by water flows, as they are part of other systems such as rivers.

A 100% renewable grid requires energy storage to supply about 30 hours of average demand, according to the ANU. This equates to 490,000 MWh of energy storage.[72]

Many new energy storage projects are proposed – see Section 3.1.3 for details. We've assumed the following projects will proceed.

- Jamestown battery (Tesla)
- Snowy Hydro 2.0
- Hydro Tasmania upgrades: "Battery of the nation"[73]
- Cultana and Kidston pumped hydro
- Big battery in Western Victoria
- "Aurora" concentrating solar thermal generator in Port Augusta
- 21 hilltop pumped hydro dams, following ANU example specifications noted in Section 4.3.1.

Completion year is estimated from public documents, except for the hilltop pumped hydro facilities. The first of these is assumed to be built in 2022, with a rollout accelerating to a peak in 2027 and then easing off to 2030. We haven't included projects by industrial companies, such as the one announced by Arrium.

[72] Ibid.
[73] Assumed 10 hours of energy storage, as the energy storage in GWh has not been announced.

Homes and businesses are also installing batteries; we've followed the latest AEMO forecast.[74] This is conservative, as it only considers batteries included with new solar systems, not batteries retrofitted to existing solar systems.

The following chart forecasts the construction of energy storage facilities by project category in the National Electricity Market. Energy storage capacity is shown in megawatt-hours (MWh), and also as a percentage of the 490,000 MWh required for a 100% renewable grid. "PH" is an abbreviation for "pumped hydro". The category "Other" includes Cultana, Kidston, Aurora and the Jamestown and Victorian batteries.

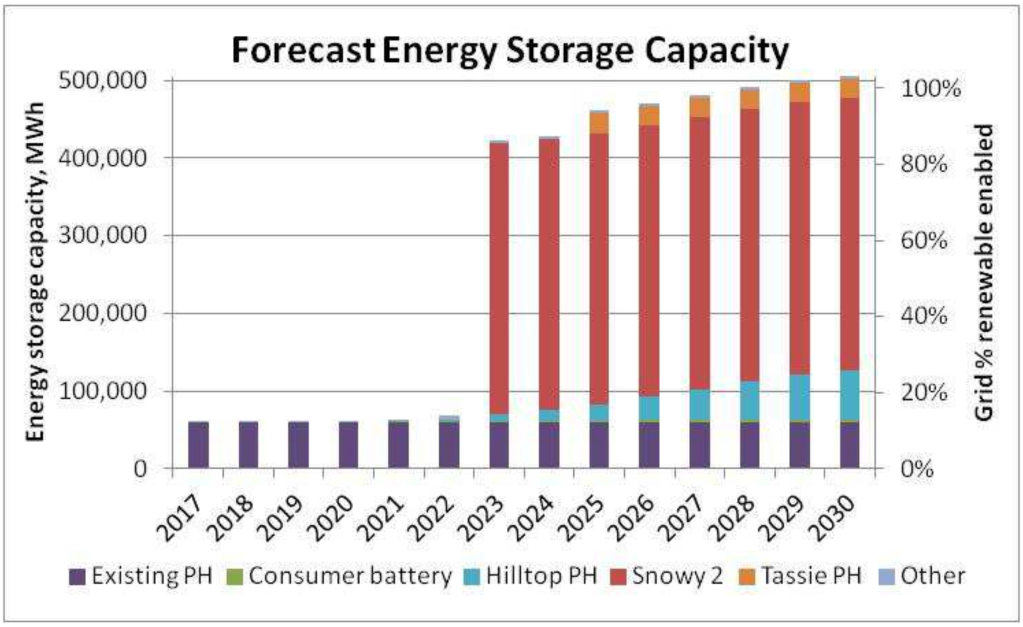

Figure 13: Forecast energy storage capacity

Based on this forecast, energy storage will be sufficient to support a fully-renewable grid by 2030.

Pumped hydro projects dominate the chart. When Snowy 2.0 is constructed (estimated 2023), the grid will already have 80% of the storage required for fully-renewable operation. By 2025 this level has risen to 94%.

6.2.1. Energy storage: power

The previous section considered the amount of energy stored in each facility. This is the key attribute to support a fully-renewable grid through a cloudy, calm week, as capacity is gradually discharged to meet demand.

In a high-renewable future, energy storage facilities will also be called upon to rapidly discharge to supply peaks in demand. Here the key measure is power delivery, measured in megawatts (MW). The ANU found that a fully-renewable grid requires energy storage capable of discharging at a total power level of 18,200 MW.[75]

[74] AEMO National Electricity Forecasting Report 2016, pages 29 & 31. Averaged the forecasts for 20-21 and 25-26. Assumed 1.56 hours to discharge, consistent with numbers for 2035-36.
[75] Page 17, "100% renewable electricity in Australia", ANU. Also added 2,240 MW for existing hydro & bio.

The following chart forecasts the power of energy storage in the National Electricity Market, by category. "PH" is an abbreviation for "pumped hydro". The category "Other" includes Cultana, Kidston, Aurora and the Jamestown and Vic batteries.

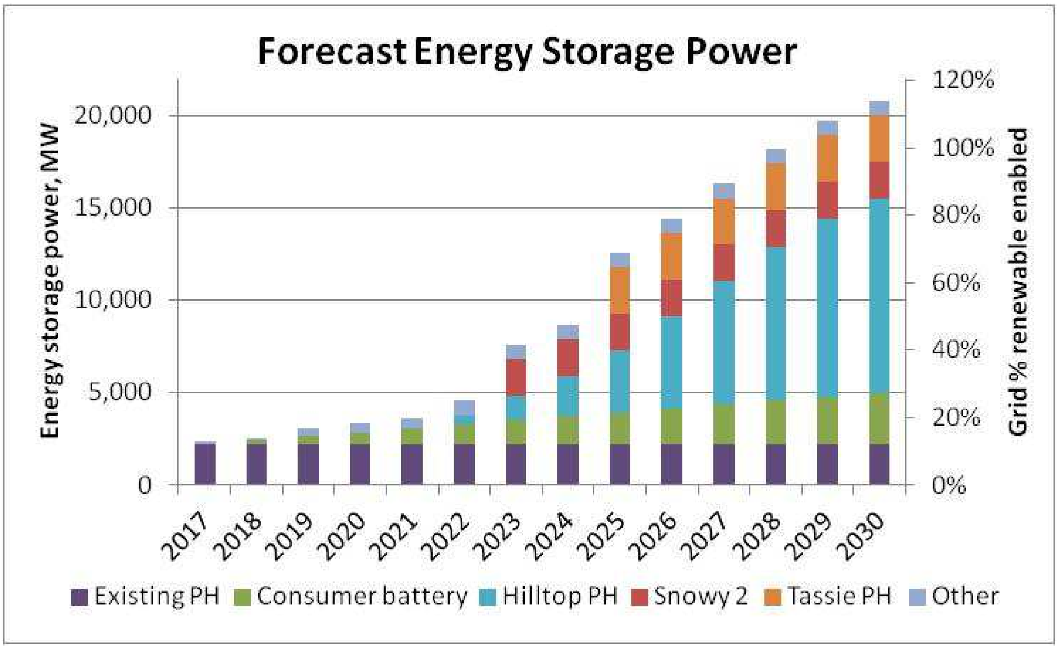

Figure 14: Forecast energy storage power

Based on this forecast, by 2029 the grid will have energy storage with sufficient power to support fully-renewable operation. Hilltop pumped hydro is the most important category for power delivery. Consumer batteries and Tasmanian pumped hydro are also significant.

Currently, periods of peak demand in the grid are commonly supplied by open-cycle gas turbines and diesel generators known as "peaking plants". These are relatively cheap to build, but costly to run as they have low efficiency and expensive fuel. These generators sit idle most of the time. Their total generating capacity is around 7,800 MW.[76]

During the transition to 100% renewables, these peaking plants will be available to help backup wind and solar generation, temporarily supplementing energy storage facilities. Using this method, by 2025 the grid will have sufficient energy storage power for fully renewable operation, with the exception of brief periods running these fossil-fuel peaking plants. Four years later the peaking plants could be decommissioned as the energy storage projects are completed.

http://energy.anu.edu.au/files/100%25%20renewable%20electricity%20in%20Australia.pdf

[76] AEMO generator registration list, accessed 16/11/17, technology "OCGT" or fuel "diesel" or "kerosene".

6.1 Targets by political parties

For reference, the following chart shows an indicative path to 2030, accompanied by targets contained in policies of three federal political parties as at 3/11/17.[77]

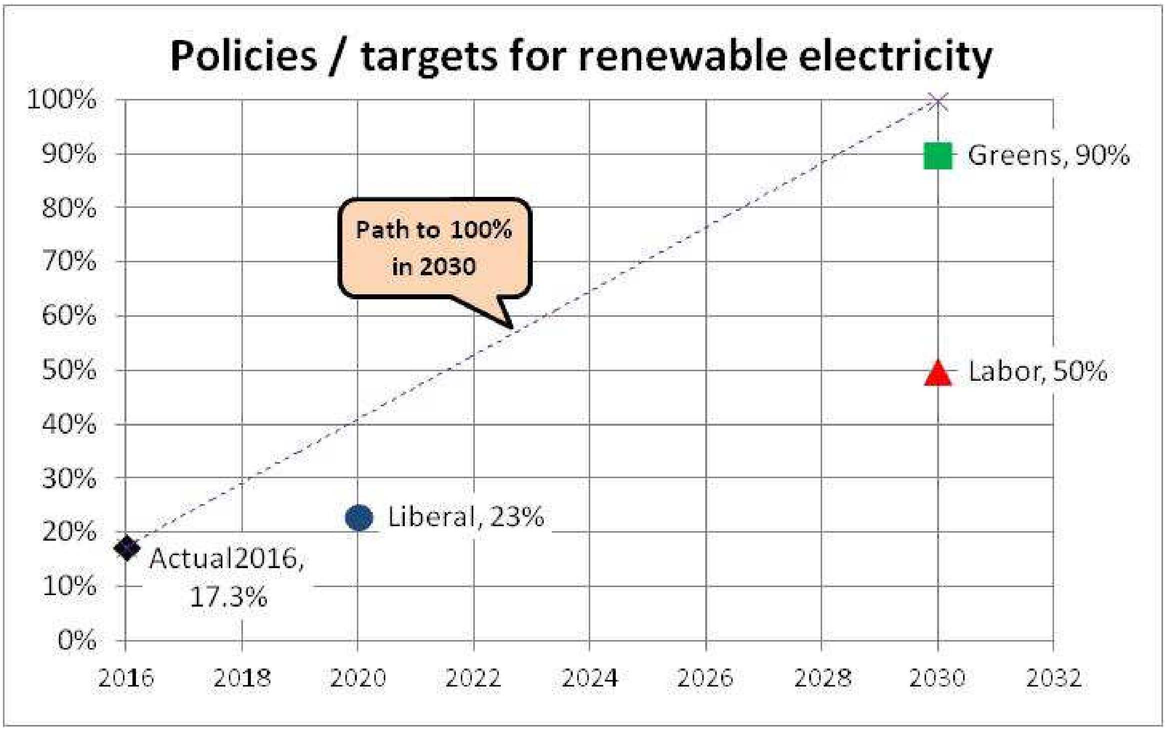

Figure 15: Political policies/targets for renewable electricity

Please note that this chart forecasts electrical energy generated by year. This doesn't directly correspond to the other forecast charts as they show generating capacity instead. Nevertheless it provides a useful comparison.

[77] https://www.liberal.org.au/our-plan/protecting-our-environment, http://www.alp.org.au/renewableenergy, https://greens.org.au/sites/greens.org.au/files/2015_11_Renew_Australia.pdf

6.2 Transmission – work required

Extra transmission to share renewable energy around the grid needs planning and coordination.

Long-distance transmission has recently become cheap, using very high voltage electricity. For example, China is constructing a power line that can transmit 12,000 MW of power 3,400 km.[78]

The ANU proposes a new transmission "backbone" for the National Electricity Market roughly following the great dividing range and extending onward to South Australia and Tassie. They found that this would cost about half as much as the required new energy storage.[79] These costs are included in estimates for the overall cost of electricity from a 100% renewable grid.

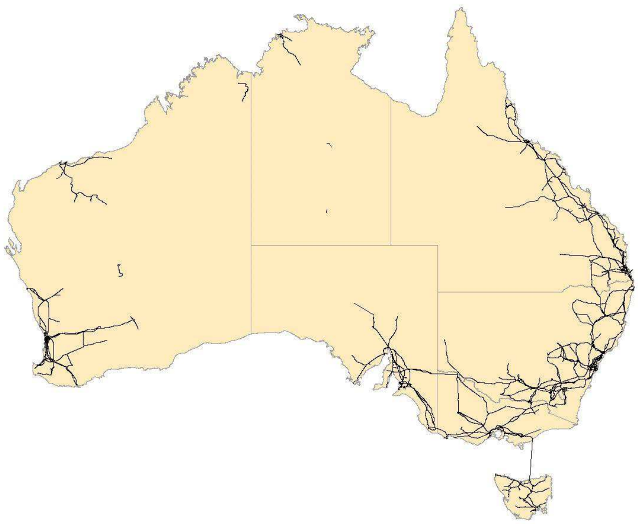

Figure 16: Map of existing transmission lines.
Source: Commonwealth of Australia (Geoscience Australia) 2015

Forecasting the construction of new transmission lines by year is beyond the scope of this paper.

AEMO is due to release a new National Transmission Network Development Plan by the end of 2017; hopefully this will expand and clarify the ANU's research in this area.

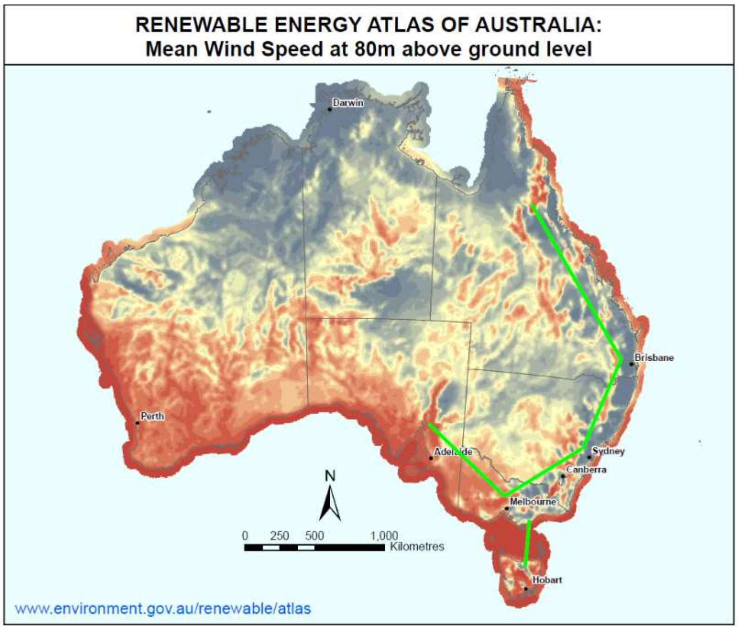

Figure 17: ANU's proposed transmission "backbone" shown in green

[78] http://www.afr.com/business/energy/electricity/acdc-and-supergrid--not-bands-a-new-way-to-export-electricity-20170112-gtqmr7
[79] Page 7, "100% renewable electricity in Australia", ANU. http://energy.anu.edu.au/files/100%25%20renewable%20electricity%20in%20Australia.pdf

6.3 Renewable generation by state

Once the big energy storage and transmission projects are complete, there will be no problem accommodating intermittent renewable generation. Until then, their rollout must be managed to avoid local issues such as wind curtailment in South Australia (see Section 3.1.4 above).

Currently, wind and solar farms are not distributed evenly among the states. The following chart shows the total registered generating capacity of wind and solar capacity, as a proportion of total capacity in each state in the National Electricity Market.[80,81]

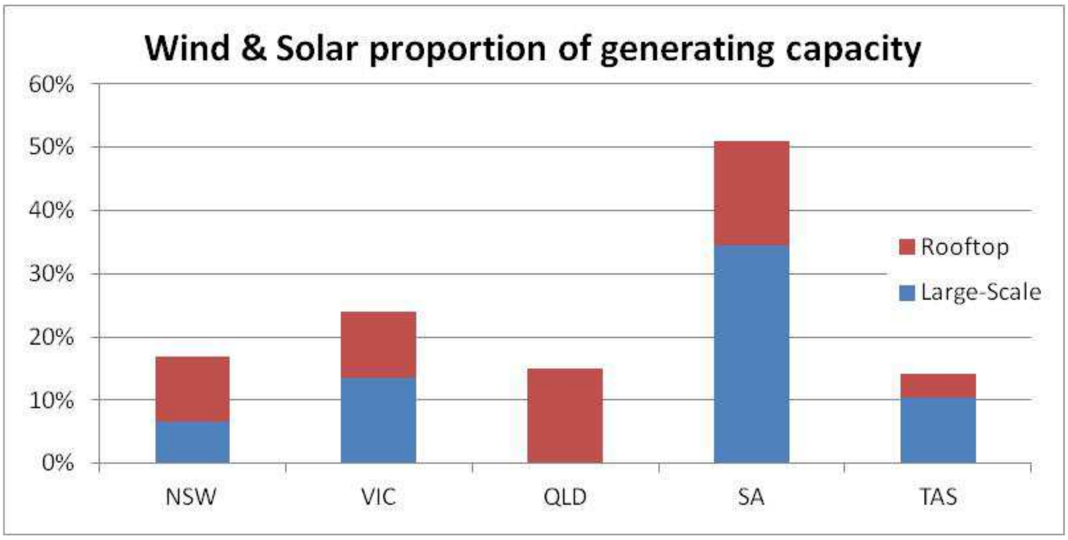

Figure 18: Proportion of generating capacity from intermittent renewables, by state

States having a low value in this chart such as NSW and QLD can easily accommodate the construction of more wind and solar farms. Their existing fossil fuel generation can supply demand during poor weather and also supply other needs such as system strength.

There is no need to slow down Australia's current rate of renewable generation; it just needs geographic re-balancing.

[80] AEMO generator registration list, accessed 1/11/17, type "generator", fuel "solar" or "wind".
[81] http://pv-map.apvi.org.au, accessed 16/11/17, NSW includes ACT too.

7. Alternative options

A feature of the plan described above is that it largely relies only on proven, well-understood technology: wind farms, solar panels and pumped hydro energy storage. Hydroelectric pumps and generators are heavy spinning machines, so as well as energy they also naturally provide all the other services of fossil fuel generators such as inertia and system strength.

There are other ways Australia could achieve a fully-renewable grid. More energy could be provided by concentrating solar thermal generators such as the "Aurora" project described in Section 3.1.3 above. This integrates into a single facility both energy generation and storage, and can also provide inertia and system strength. Batteries could potentially play a bigger role, reducing the amount of pumped hydro required. Breakthroughs could occur with currently immature technologies such as wave energy or geothermal energy (using underground heat via deep bores).

We support a flexible approach to take advantage of new opportunities arising during the transition. We don't support a "wait and see" attitude. Wind, solar and pumped hydro should be built straight away as they are already economic, and their clean energy, storage and other services will make an important contribution regardless of future developments.

7.1 Future electricity consumption

Plans for a fully-renewable grid aim to supply the same amount of electricity as our current grid. However, future demand may be different. Australia has massive opportunities to improve energy efficiency[82], for example by improving building insulation. This directly lowers consumers' bills, improves comfort and also reduces the investment required to replace ageing fossil-fuel generators. In the future, our nation's total electricity demand could be much lower than now. For example, Australia consumes 44% more electricity per capita than Germany, a country with high industrial output and a more severe climate.[83] Beyond Zero Emissions estimated that Australia's total energy consumption could be halved.[84]

On the other hand, electricity consumption could rise as people install efficient electric appliances to replace their old gas ones.[85] Similarly, electricity may displace fossil fuels for transport.

These two trends tend to cancel each other out, but their magnitude is uncertain. It seems sensible to plan the grid to supply current demand.

Excluding these two trends, electricity consumption is not expected to change much to 2030, as its growth largely halted in 2009.[86]

[82] Also known as energy productivity.
[83] United Nations World Development Indicators, annual kWh per capita, 2013. Aus 10,134, Germany 7,019. http://data.un.org/Data.aspx?d=WDI&f=Indicator_Code%3AEG.USE.ELEC.KH.PC
[84] page 13, Beyond Zero Emissions, "Zero Carbon Australia 2020 Stationary Energy Plan" 2010. http://media.bze.org.au/ZCA2020_Stationary_Energy_Report_v1.pdf
[85] ATA, "Are we still cooking with gas?", http://www.ata.org.au/wp-content/projects/CAP_Gas_Research_Final_Report_251114_v2.0.pdf
[86] https://www.aer.gov.au/wholesale-markets/wholesale-statistics/national-electricity-market-electricity-consumption

7.1 Less-connected options

Our future electricity grid described above has multiple strong connections within and between states. Sharing electricity around the country minimises total investment in wind and solar farms.

It may be possible for each state to autonomously achieve a fully-renewable electricity grid. However, this would require a much larger investment to retain the current level of service. For example, to supply itself through a cloudy, calm winter week, Victoria would need to build a very large amount of generation and/or energy storage.

Similarly, self-sufficiency for individual towns and cities would be an expensive proposition. We believe cities and large industrial sites should retain a grid connection. Ideally they will generate much of their own electricity, but the grid allows surpluses and shortfalls to be balanced.

An exception is small, remote towns and properties connected to the grid with long, expensive lines. In these cases self-sufficiency may be the best option, as the savings in line maintenance often outweigh the extra investment required in local generation and storage. The off-grid option is also likely to be more reliable than a long power line through the bush.[87]

8. How will we manage energy storage?

In a high-renewable grid the key challenge is to get through a cloudy, calm week. This is a familiar concept to families living in off-grid houses – battery energy must be conserved for the week's end.

In the National Electricity Market, assets are controlled by their owners who operate them to maximise individual profits. Owners of energy storage will be tempted to discharge whenever the electricity spot price is high, rather than conserving energy for later. If they control newly-built energy storage, market traders will gain even more scope to "game" the market.

To ensure that energy storage can be managed effectively in the future, authorities should review the relevant market rules. Perhaps AEMO should control large-scale energy storage and operate it according to well-defined, transparent rules. This energy storage would act to smooth out demand for electricity, discharging at times of peak demand and charging at other times. By including energy storage in their published short-term electricity forecasts, AEMO would provide a more stable load against which generators could bid. This would reduce market volatility and consumer costs.

A precedent is Hydro Tasmania, which manages all the hydroelectric generation in Tasmania cooperatively, conserving energy to meet future electricity demand.

Under this approach, energy storage could be owned by private companies. AEMO would contract companies to construct and operate the facilities, and would pay them an agreed annual fee for this service. AEMO would recover its costs through market fees as usual. The companies could be selected via tender. A precedent is AEMO's existing contracts for "black start" services.

[87] Rule change submission by Energy Networks Australia, ATA and PIAC, 8/11/17: https://www.ata.org.au/news/moving-beyond-poles-and-wires-2

9. What does all this mean for consumers?

9.1 Electricity prices

One way or another, money must be spent to refresh Australia's ageing fleet of power stations. Unfortunately, none of the replacement options is likely to generate electricity as cheaply as the old, paid-off coal-fired power stations. The wholesale electricity price is unlikely to return to the abnormally low levels of the 1990s and 2000s.

On the other hand, electricity generation only makes up about a third of household electricity bills.[88] The bulk of our bills go to maintaining electricity distribution "poles and wires", retailer call centres, profits etc. All these components have good scope for reduction, as found recently by the ACCC.[89]

Electricity prices are notoriously hard to predict. We recommend that households expect continuing volatility. Consumers should shop around for a good deal on their electricity.

9.2 Energy efficiency

The total bill is what matters to a consumer. Even if electricity tariffs rise, smarter use of energy can see the total bill fall.

The ATA recommends that consumers understand their energy consumption and take steps to manage and reduce it. Most households have opportunities such as:

- turning off lights and appliances that aren't in use
- draught sealing, e.g. around windows and doors
- insulation and window shading
- LED lights and efficient appliances.

9.3 Rooftop solar

A well-planned solar system pays for itself quickly these days. Equipment prices have dropped rapidly, and feed-in tariffs are now decent in most locations. However, adding a battery is generally not yet economic since its additional bill savings are small compared to its additional upfront cost. For a quick, easy indication of bill savings from solar and batteries in your household, please refer to www.ata.org.au/ata-solar-advice.

Renters and apartment-dwellers can find solar tricky to install. Solutions exist, such as devices to cleverly share a solar system's generation among apartments[90], and smart financing such as Environmental Upgrade Agreements.[91] Policymakers should remove barriers to their uptake.

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[88] Page 27, "Retail electricity price history and projected trends", Jacobs for AEMO, http://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/EFI/Jacobs-Retail-electricity-price-history-and-projections_Final-Public-Report-June-2017.pdf

[89] Retail Electricity Pricing Inquiry, Prelim. Report 22 September 2017. Aust. Competition & Consumer Commission. https://www.accc.gov.au/system/files/ACCC%20Retail%20Electricity%20Pricing%20Inquiry%20-%20Preliminary%20Report%20-%2022%20September%202017.pdf

[90] Eg Allume Energy, http://www.afr.com/leadership/entrepreneur/startup-allume-lets-solar-panels-be-shared-by-strata-dwellers-20170228-gun689

9.4 What if the transition is halted?

It's possible that investment in wind and solar generation could dry up, if government policy works against it.

If this occurs, new fossil fuel generators would have to be built to replace the ageing coal-fired power stations. This would be a poor outcome for consumers, locking Australia into purchasing coal and gas for many decades to come.

This would also be an uncertain course. It takes many years to approve, plan and build a new coal-fired power station. During this time political opposition to fossil fuels may harden, especially as the impact of climate change becomes obvious and harder to deny. Construction would likely attract vigorous local protests.

Potentially we could be left with abandoned fossil fuel projects and no backup plan, leading to power shortages.

Figure 19: Anglesea coal mine and power station in Vic. Closed August 2015.
Photo: Flickr user Takver, licensed under CC BY-SA 2.0

[91] http://sustainablemelbournefund.com.au/services/environmental-upgrade-finance/

10. Conclusion

Australia should transition quickly to a 100% renewable electricity grid, as it is cheaper and less risky than the alternative of building new coal-fired power stations. This can be achieved by 2030 by accelerating the installation of wind and solar generation by 80% (compared to 2017 rates), backed up by pumped hydro energy storage facilities and extra transmission lines.

Electricity from new-build coal-fired power stations would likely cost between $81 and $182 per MWh. This becomes a range of $102 to $103 once we allow for hidden health impacts ($13/MWh) and climate impacts ($8/MWh). In a fully-renewable electricity grid, electricity would cost about $93 per MWh.[92] This includes the cost of building energy storage and extra transmission to manage intermittency.

The cost of renewable electricity is already in the lower range of the cost estimates for new-build coal-fired generation, even if coal's hidden costs are ignored. And renewable costs will fall further in the future.

Retail electricity prices from the 1990s are unlikely to return, regardless of the option chosen. Consumers are advised to shop around for a good deal, work on reducing their energy consumption and install rooftop solar if possible. Energy efficiency must not be neglected. Although this paper's focus is on electricity generation, Australia has massive opportunities to save money and help the environment by getting smarter about how we use energy.

Australia should prepare a proper plan for 100% renewable energy, and implement it. Decisions should not be left to separate companies driven by short-term profits, as this may lead to a poor overall system. Until Snowy Hydro 2.0 is built, wind and solar should focus on NSW and QLD as their level of renewables is low. This will avoid the operational problems that see the market operator ordering South Australian wind farms to reduce their output, burning expensive gas instead of using free wind. Authorities should also address how to manage a high-renewable grid – the energy market must ensure that energy stores can be conserved for use at the end of a cloudy, calm week.

Figure 20: Amazon CEO Jeff Bezos opening a new 253 MW wind farm in Texas, October 2017 [93].

[92] Ibid

[93] https://www.cnbc.com/2017/10/19/amazons-jeff-bezos-has-just-opened-a-massive-wind-farm-in-texas.html

11. Glossary

AEMO	Australian Energy Market Operator https://www.aemo.com.au/About-AEMO
Alternating Current (AC)	An electric current in which the flow of electric charge periodically reverses direction, e.g. 50 cycles per second.
ATA	Alternative Technology Association www.ata.org.au
Bagasse	Residue left over from processing sugar cane.
Base Load	(1) Demand for electricity that's always present – minimum demand. (2) A power station that can operate when desired, not dependent on weather etc.
Biofuel	Liquid fuel made from biological sources, e.g. ethanol from sugarcane or biodiesel from canola.
Biogas	Methane gas created from biological sources such as landfill sites.
Biomass	Woody waste such as sawdust and crop stubble.
BZE	Beyond Zero Emissions, http://bze.org.au
Carbon Capture & Storage (CCS)	A way to lock up carbon dioxide emitted by power plants.
Concentrated Solar Thermal (CST)	A power station using mirrors to concentrate sunlight creating heat.
CSIRO	Commonwealth Scientific And Industrial Research Organisation, www.csiro.au
Curtail	Instruct a generator to reduce its output.
Current	The flow of electricity. Similar to the flow rate in a water pipe.
Demand Response Mode (DRM)	A method of remotely controlling appliances, to assist the grid.
Dispatch	An instruction from the grid operator to a power station.
Grid fault	A disruption in the grid with abnormal electric current, e.g. due to a short-circuit or lightning strike.
Inertia	A useful property of resisting change in speed. Big, heavy things naturally have this property.
Interconnector	An electricity transmission line connecting two states.
Intermittent generation	Generation that varies depending on weather conditions etc.
Megawatt (MW)	A unit of power (1 million watts). More than 1,000 horsepower.
Megawatt-hour (MWh)	A unit of energy (1 million watt-hours). Equal to 1 MW for 1 hour.
Levelised Cost of Energy (LCOE)	The cost of energy from a power station, averaged over its lifespan.
National Electricity Market (NEM)	The electricity grid covering most of Australia, and its associated market for companies to buy and sell electricity. Excludes WA & NT.
Pumped Hydro	Pumping water uphill, to store energy.
Voltage (Volts, V)	A kind of force that drives electric current. Similar to pressure in a water pipe.