UTS: INSTITUTE FOR SUSTAINABLE FUTURES

Wind Power in Australia

Quick Facts

2017

ABOUT THE AUTHORS

The Institute for Sustainable Futures (ISF) was established by the University of Technology, Sydney in 1996 to work with industry, government and the community to develop sustainable futures through research and consultancy. Our mission is to create change toward sustainable futures that protect and enhance the environment, human wellbeing and social equity. For further information visit: **www.isf.uts.edu.au**

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TABLE OF CONTENTS

Australia has amazing wind resources....1
How does Australia compare with the rest of the world?....1
Wind power is reliable and predictable....2
Wind power in Australia is growing rapidly and getting cheaper all the time....3
Wind power is great for the environment and our health....4

Table 1 Average capacity factor for operational wind farms....1
Table 2 Wind energy in Australia – costs over time....4
Figure 1 Cumulative capacity and average turbine size, Australian wind farms....4

AUSTRALIA HAS AMAZING WIND RESOURCES

There are enough onshore wind power resources in Australia to provide all our electricity more than 12 times over[1], and potentially the same again offshore[2].

How much electricity does Australia currently use?
212 TWh [3]

How much of this is produced from wind?
Australia generates just 6% of the electricity we use in Australia from wind power.[4]

How much electricity could Australia produce from wind?
Australia currently uses less than half a percent of this potentially abundant energy source[5].

Australia could install up to 879 GW of onshore wind power just in the eastern states[6]. This would generate 2,532 TWh, twelve times more than all the electricity that we use[7]. Australia could also generate 2,081 TWh electricity from offshore wind farms[8]. Australia's full wind power potential could provide enough power to meet all the electricity needs of Australia, USA, and the UK combined[9].

As wind is the cheapest form of new generation[10], Australia could be getting a great deal more of our electricity needs met by wind power.

HOW DOES AUSTRALIA COMPARE WITH THE REST OF THE WORLD?

Australia has amazingly good wind resources compared to the rest of the world.

Capacity factor

Table 1 Average capacity factor for operational wind farms[a]

Country	Capacity factor
Australia	33%
USA	31%
Global average	23%
Germany	18%
China	17%

The actual energy generated over a year divided by the amount that would have been generated if the generator had operated at full power the entire time is called its "capacity factor" [b]; the higher the capacity factor, the higher the annual electricity output. The

[a] International capacity factors derived from BP (2017) Statistical Review of World Energy and GWEC (2017) Global Wind Report 2016; see endnotes 11 and 12 for details.
[b] If a hypothetical generator was on 24/7 at full power, all year, without a break, the capacity factor would be 100% (no generator would operate 100% of the time).

average capacity factor of wind farms around the globe was 23% between 2007 and 2016[11]. In this same period Australia had an average capacity factor for its wind farms of 33%[12]. This reflects the extremely high quality wind resource in Australia. This means a wind turbine in Australia, on average, will generates 142 MWh for every 100 MWh generated by an average wind turbine worldwide.

Newer Australian wind farms are expected to have even higher capacity factors. Three wind farms, Ararat, Coonooer Bridge, and Hornsdale, are expected to have capacity factors of 38%, 48% and 49% respectively[13].

Wind farms with a higher capacity factor bring quicker returns on investment and generate more renewable electricity per wind farm – which means cheaper electricity. A higher capacity factor primarily reflects the quality of the wind resource, although improved turbine design is increasing capacity factors around the world.

If you look at the countries that are leading the globe on wind power installations (China, USA, Germany, and India), only the USA has an average capacity factor which comes close to Australia, at 31%. China, with the most wind power installed anywhere in the world, has an average capacity factor of only 17%, and Germany (third in the world) is similar at 18%. The average capacity factor of the four leading countries taken together is just 22%.

Installed capacity
Actual installations lag behind other countries, with Australia 17th in installed capacity in the world[14].

Australia's capacity is equivalent to one 2 MW turbine for every 11,000 people, compared to one per 7,800 in the USA, one per 3,000 people in Germany or Sweden, and one for every 2,000 people in Denmark[15].

WIND POWER IS RELIABLE AND PREDICTABLE

Advances in modern forecasting technologies ensure that wind power is a predictable source of power. Our Australian Energy Market Operator (AEMO) uses comprehensive wind forecasting tools, and can predict with over 97% accuracy wind generation one hour ahead of time[16]. Wind farm operators and AEMO can say with over 90% accuracy how much power they can produce for the next hour 24 hours[17].

This information provides grid operators with important information to balance demand and supply of electricity on the grid, remembering of course that demand from households, businesses and industry is highly variable and our dynamic grid system is designed to respond to these changes.

It's important that wind turbines are reliably ready to produce power when the wind blows. This is known as the "equivalent availability factor". In 2016, AGL's wind farms were available over 95% of the time, in contrast to AGL's coal-fired power station fleet which, on average, was available 75% of the time[18].

Sudden changes, such as when a large generator or a power line suddenly and unexpectedly goes offline, can trigger blackouts, so the predictability and availability of wind power is enormously important.

Diversity in our grid – both in terms of putting generators in lots of locations (geographic diversity) and using a range of different technologies (generation diversity) – is key to ensuring there's enough electricity available to meet demand. When the wind is not blowing in one region or part of the grid, it is likely to be blowing somewhere else. Other power sources complement generation from wind, for example solar PV, solar thermal, biomass hydro, fossil fuel power plants; we also have energy storage technologies and the option to manage demand to even out supply fluctuations. This is why our grid is integrated and connected across South Australia, Tasmania, NSW, Victoria and Queensland[19].

WIND POWER IN AUSTRALIA IS GROWING RAPIDLY AND GETTING CHEAPER ALL THE TIME

Wind energy has been used in Australian agriculture since the 1800s. The old-fashioned wind pump is an iconic feature of outback landscapes.

Through the 1980s and 1990s, small wind turbines of about 1/100th of a MW (10kW) were installed, and total capacity in Australia was less than 0.5 MW.

Changing size and power

The first modern wind farm was installed in 1987 at Salmon Beach, near Esperance in WA, and had 6 turbines of 60 kW each. This was followed by Ten Mile Lagoon in 1992, also near Esperance, with 9 turbines of 225 kW and a total capacity of 2 MW. Crookwell and Blayney in NSW followed in 1998 and 1999, with turbine sizes approaching 700 kW, and by 1999 there was about 20 MW installed in Australia. Wind power started increasing steeply in 2001, and today there is more than 4,000 MW installed.

Turbine sizes have followed a similar trajectory. The early wind farms used turbines of around 250 kW (1/4 of a MW), which has increased 12 fold, so that today's onshore turbines in Australia average 2.8 MW[20]. Internationally, off shore wind turbines are even larger. The largest installed turbine is 8 MW standing 105 m tall at hub height (185m tall at the tip of the blade)[21]. All of this means that fewer turbines are needed to provide the same amount of electricity.

Costs

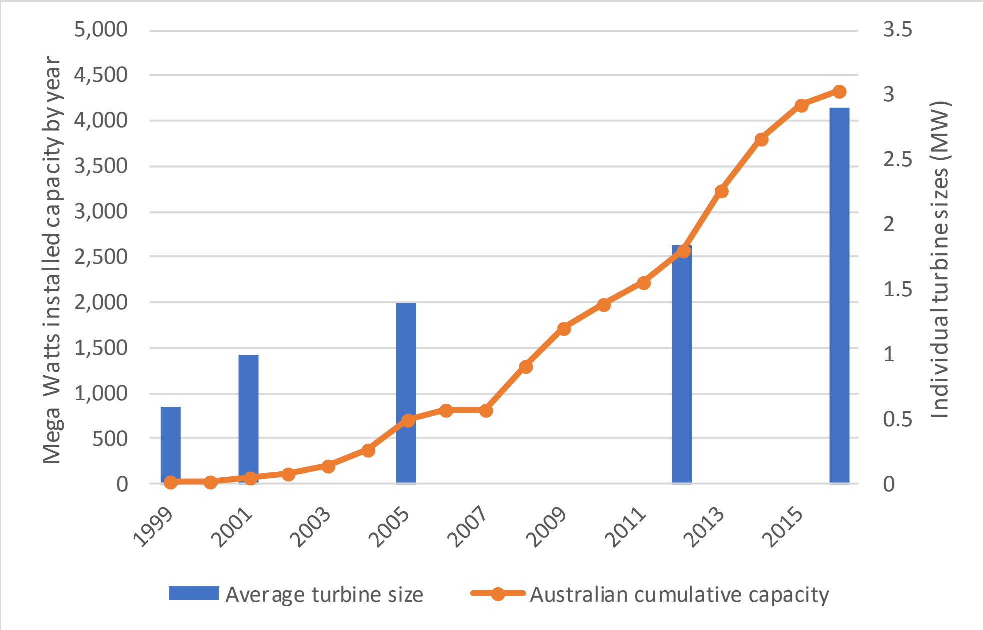
As the size of wind turbines has gone up, costs have come down, so that wind power today has the lowest electricity cost for any newly installed power plant[22]. In 2000, the average cost of electricity from a wind farm in Australia was estimated as $150 per MWh[23], in 2012 as $125/MWh, and in 2017 the cost of electricity from new Australian wind farms is estimated as having a price of $61-$118/MWh[24].

In fact, some projects are even lower. Bids in the second ACT auction in came in at $77 – $89/MWh[25], and prices of $65/MWh for the Silverton wind farm[26] and below $60 for the Stockyard Hill wind farm[27] have been reported this year.

Table 2 Wind energy in Australia – costs over time

Project/ source of estimate	Cost per MWh	Year
Australian Wind Energy Association estimate	$150	2000
Australian Energy Technology Assessment	$125	2012
Hornsdale Wind Farm	$77	2016
Sapphire Wind Farm	$89.10	2016
Silverton Wind Farm	$65	2017
Stockyard Hill Wind Farm	< $60	2017

Figure 1 Cumulative capacity and average turbine size, Australian wind farms



WIND POWER IS GREAT FOR THE ENVIRONMENT AND OUR HEALTH

Wind power is a clean, zero pollution source of electricity, and the output of an average wind farm is enough to power 97,000 households[28].

21 wind farms the size of Ararat Wind Farm would produce the equivalent output of Loy Yang coal fired power station in Victoria and there are 23 windfarms under construction, approved or in the approval pipeline in Victoria[29]. This would cut Victorian carbon emissions by a full 15% and significantly reduce the health impacts of the pollution released. Loy Yang released 426.5kg of mercury into the atmosphere and 2.49 million tonnes of particulate air pollutants PM2.5 and PM10, known to cause death and disease, including lung and heart disease, exacerbation of asthma and adverse birth outcomes[30]

29 wind farms the size of Silverton wind Farm in Broken Hill would produce the equivalent output of Bayswater coal fired power station in NSW[31], and there are 29 windfarms approved or in the approval pipeline in NSW[32]. This would cut NSW carbon emissions by a full 12%[33] and significantly reduce the health impacts of the pollution released.

The Australian Academy of Technological Sciences and Engineering estimated health damage costs of pollution from coal fired power stations in Australia as $2.6 billion per annum and $13/MWh[34]. Closing down Loy Yang coal and Bayswater power stations could reduce health costs by $400 m/year[35].

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[1] Capacity calculated from the publicly available data set from Australian Energy Market Operator (AEMO), 2013, *100 Per Cent Renewables Study - Modelling Outcomes.* Total potential capacity is derived by addition of the moderate build limits in each of the 52 polygons in the data set which make up the National Electricity Market (NEM) (two scenarios were modelled by ROAM – one with moderate transformation and one with high). We have taken a conservative approach by using the average Australian capacity factor for the years 2010-2016 (see Footnote 122) to calculate potential generation, rather than the ROAM data, which gives an average capacity factor of 39%. Australia used a total of 212 TWh in the NEM and the SWIS. NEM consumption was 193 TWh, including generation from non-scheduled generation and from rooftop PV (AEMO 2017 Electricity Forecasting Insights (replaces National Electricity Forecasting Report).

[2] Calculated from the same dataset and by the same method as reference 1, however owing to the lack of current offshore wind installations in Australia, we have calculated the ratio for onshore only.

[3] Australia used a total of 212 TWh in the NEM and the SWIS. NEM consumption was 193 TWh, including generation from non-scheduled generation and from rooftop PV (AEMO 2017 Electricity Forecasting Insights (replaces National Electricity Forecasting Report).

[4] 2016 wind generation and capacity for Australia from Clean Energy Council (2016) 'Clean Energy Australia'. Pages 8 & 54. Available at: http://www.cleanenergycouncil.org.au/policy-advocacy/reports.html

[5] Generation from wind power in Australia in 2016 was 12,903 GWh, from 4237 MW of wind power in 2106 turbines (Clean Energy Council (2016) 'Clean Energy Australia'. Available at: http://www.cleanenergycouncil.org.au/policy-advocacy/reports.html)

[6] Calculated by the addition of NEM polygon build limits from AEMO (2013) *100 Per Cent Renewables Study - Modelling Outcomes*

[7] Australia used a total of 212 TWh in the NEM and the SWIS. NEM consumption was 193 TWh, including generation from non-scheduled generation and from rooftop PV (AEMO 2017 Electricity Forecasting Insights (replaces National Electricity Forecasting Report) http://forecasting.aemo.com.au/Electricity/AnnualConsumption/Operational Downloaded 7-8-2917 and 19 TWh in the SWIS (Australian Energy Market Operator (2017) '2017 Electricity Statement of Opportunities for the Wholesale Electricity Market', (June). Available at: http://www.imowa.com.au/home/electricity/electricity-statement-of-opportunities.)

[8] Offshore estimate of 660 MW is for the NEM states only, and is from the data set and method outlined in footnote 1. Calculations for output using capacity factor of 33% for onshore and 36% for offshore are compared with country from Statistics, I.E.A. "Key world energy statistics." *Paris. International Energy Agency* (2016). Offshore capacity factor uses the USA offshore CF from REN21. 2017, Renewables 2017 Global Status Report, (Paris: REN21 Secretariat).

[9] Global Energy Statistical Yearbook 2017, Available at: https://yearbook.enerdata.net/electricity/electricity-domestic-consumption-data.html

[10] Bloomberg New Energy Finance data, reported in Clean Energy Council (2016) '*Clean Energy Australia'*. Pages 19.

[11] Average international capacity factors are calculated using the time series of wind generation from BP. 2017. *BP Statistical Review of World Energy June 2017*. http://www.bp.com/statisticalreview, and the cumulative installed capacities by region and country from GWEC (2017) *'Global Wind Report 2016*', page 15. Available at: http://files.gwec.net/files/GWR2016.pdf.

[12] The average capacity factor for Australia is calculated from the time series of wind generation downloaded from Office of the Chief Economist. *Australian Energy Update 2016*. Published Australian Government Department of Industry, Innovation and Science, http://www.environment.gov.au/energy/publications/australian-energy-update-2016, figure 4.5 up to 2014/15, with 2016 data from Clean Energy Council (2016) '*Clean Energy Australia*', page 8. Available at: http://www.cleanenergycouncil.org.au/policy-advocacy/reports.html. Capacity data from GWEC (2017) 'Global Wind Report 2016', page 15. Available at: http://files.gwec.net/files/GWR2016.pdf

[13] ACT Government. 2017. How wind will power Canberra homes. Available at http://www.environment.act.gov.au/__data/assets/pdf_file/0009/688275/150048-Renewable-energy-brochure-ACC.pdf

[14] GWEC (2017) '*Global Wind Report 2016'*. Available at: http://files.gwec.net/files/GWR2016.pdf

[15] Per capita installations are calculated using installation data from population data for 2015 from the World Bank World Development Indicators http://data.worldbank.org/indicator/SP.POP.TOTL

[16] AEMO Normalised mean absolute error of AWEFS (Australian Wind Energy Forecast System) forecasts for the National Electricity Market 2012-2013 page 103 and South Australia from 2012-2016 page 37.

[17] Ibid.

[18] AGL Equivalent availability factor – which measures the percentage of rated energy available when required. AGL wind farms in 2016 includes Wattle Point, Hallett 1,2,3,4&5 Oaklands Hill and Macarthur Wind farms. AGL coal fired powerstations include Loy Yang, Bayswater and Liddell. The equivalent availability factor at Liddell in 2016 was reduced due to unexpected forced outages. At the height of the NSW electricity shortage in February 2017, 2 out of 4 units at Liddell was also unavailable taking out 1,000MW of registered capacity from the system. (AEMO System Event Report NSW 10 February 2017)

[19] https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM. AEMO's 100 per cent Renewables Study – Modelling Outcomes Report 2013 states "AEMO's available data indicates that this [variability and ramping issue] is unlikely to be a fundamental constraint as the anticipated geographic distribution of renewable generation plant should help smooth out any fluctuations in very short timeframes (seconds or minutes).

[20] Based on the average turbine size of wind projects completed or under construction by 31st December 2016, 201MW (Clean Energy Australia Report 2016 page 11&13)

[21] Vestas have launched a 9.5 MW version of the V164 turbine http://www.windpowermonthly.com/10-biggest-turbines. There are 32 of the slightly smaller 8MW models of the turbine operational at Burbo Bank near Liverpool in the UK http://www.4coffshore.com/windfarms/burbo-bank-extension-united-kingdom-uk59.html

[22] Lazard (2016) 'Lazard's Levelised Cost of Energy Analysis (version 10.0)', page 2. Available at: https://www.lazard.com/media/438038/levelized-cost-of-energy-v100.pdf., Bloomberg New Energy Finance data, reported in Clean Energy Council (2016) 'Clean Energy Australia'. Available at: http://www.cleanenergycouncil.org.au/policy-advocacy/reports.html. Page 19

[23] 2000 price International Energy Agency (2005) *IEA Wind Energy Annual Report 2004.* Page 76. Available at: http://www.dpi.vic.gov.au/energy/sustainable-energy/wind-energy, adjusted to 2016 dollars using average inflation of 2.7% per year. 2012 price from Bureau of Resources and Energy Economics (2012) *Australian Energy Technology Assessment*.(page 73), adjusted using average inflation of 1.9%. Adjustments to 2016 $ were made using the calculator at http://www.rba.gov.au/calculator/annualDecimal.html

[24] Clean Energy Council (2016) 'Clean Energy Australia'. Available at: http://www.cleanenergycouncil.org.au/policy-advocacy/reports.html. Page 19.

[25] AECOM (2017) *ACT Wind Auction II Review Summary Report*.

[26] http://reneweconomy.com.au/agls-new-200mw-silverton-wind-farm-to-cost-just-65mwh-94146/

[27] Calabria, F. and Tremaine, L. (2017) *Origin Energy. 2017 Full Year Results Announcement.*

[28] Calculation based on average household electricity consumption of 6MWh/h (Derived from Australian Energy Market Operator (2017) 2017 Electricity Statement of Opportunities for the Wholesale Electricity Market, Australian Energy Market Operator (AEMO) (2016) National Electricity Forecasting Report, and ABS 2016 QuickStats) and estimated wind farm output based on windfarm size of 201MW, the average of large wind farms completed or under construction during 2016 (Clean Energy Australia Report 2016 page 11&13) and the average capacity factor of Australian windfarms from 2010 – 2016, 33% (see footnote 12).

[29] https://www.energy.vic.gov.au/renewable-energy/wind-energy/wind-projects

[30] A 2013 review of evidence on health aspects of air pollution summarised the known health effects of PM10 and PM2.5 including upper respiratory tract irritation and infection; exacerbation of asthma; decreased lung function; exacerbation of, and increased mortality from, cardiorespiratory diseases; myocardial infarction; premature mortality; atherosclerosis; adverse birth and neurodevelopment outcomes. World Health Organization (WHO), (2013). Review of evidence on health aspects of air pollution – REVIHAAP. WHO Regional Office for Europe: Copenhagen.

[31] Calculation based on the generation sent out of Bayswater Power station in FY2016 of 16,849GWh and estimated wind farm output (based on the average size wind farm installed capacity (111MW) built or under construction in 2016 and the average capacity factor of windfarms of 33% Clean Energy Australia Report 2016 page 11&13 and (AGL Investor Day 14/11/2016 Supplementary Information Generation Portfolio Page 44) accessed 15/08/2017.

[32] http://www.planning.nsw.gov.au/Policy-and-Legislation/~/media/80AC5889AD294B6F90B600B46FF169FC.ashx

33 Calculation based on the generation sent out of Bayswater Power station in FY2016 of 16,849GWh and Bayswater carbon intensity (0.95tCO2e/MWh)and NSW total emissions 2015 tCO2e Figure 1: State and

Territory total emissions (including those from Land Use, Land Use Change and Forestry) Australia's National Greenhouse Accounts May 2017.

[34] Australian Academy of Technological Sciences and Engineering adapted the health damage costs of powerstations from air pollutants SO2, NOx and PM10 from European research via the European Union's (EU) ExternE Project, which draws on a significant body of research and analysis to produce estimates of monetary costs of greenhouse, health and other environmental impacts of power station emissions, based on full life-cycle assessments. AATSE adapted the European research to Australia by scaling for population density, and Australian power station generation pollution data from the NPI National Pollutant Inventory. The Hidden Costs of Electricity: Externalities of Power Generation in Australia, The Australian Academy of Technological Sciences and Engineering (ATSE) 2009.

[35]The total health damage costs of pollution from coal fired power stations in Australia was estimated as $2.6 billion per annum and $13/MWh. The Australian Academy of Technological Sciences and Engineering adapted the health damage costs of power stations from air pollutants SO2, NOx and PM10 from European research conducted by Extern E; by scaling for population density, power station generation pollution from the national pollutant inventory.