SOUTH AUSTRALIAN RENEWABLE ENERGY REPORT

SOUTH AUSTRALIAN ADVISORY FUNCTIONS

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AUSTRALIAN ENERGY MARKET OPERATOR

IMPORTANT NOTICE

Purpose

The purpose of this publication is to provide information to the South Australian Minister for Mineral Resources and Energy about renewable generation in South Australia. This publication is based on information available to AEMO as at 30 June 2017, although AEMO has endeavoured to incorporate more recent information where practical.

AEMO publishes this report in accordance with its additional advisory functions under section 50B of the National Electricity Law.

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Acknowledgement

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Version control

Version	Release date	Changes
1	23/11/2017	

EXECUTIVE SUMMARY

The 2017 *South Australian Renewable Energy Report* (SARER) focuses on the performance of wind and rooftop photovoltaic (PV) generation in South Australia over the last five financial years (2012–13 to 2016–17).

- **South Australia had the highest penetration of renewable generation of all NEM regions in the last five years.**
- **Total renewable generation in South Australia (including wind and rooftop PV) for 2016–17 was 5,359 gigawatt hours (GWh), the highest production in the last five years.**
- **Both wind generation capacity and rooftop PV capacity have increased in the five years to 2016–17:**
  - Rooftop PV installed capacity rapidly increased from 402 megawatts (MW) in 2012–13 to 781 MW in 2016–17. More than 30% of dwellings in South Australia now have rooftop PV systems installed.[1]
  - Registered wind capacity increased about 41%, from 1,203 MW in 2012–13 to 1,698 MW in 2016–17.
- **Instantaneous wind penetration (the ratio of wind generation to operational demand[2] at any point in time) continues to increase.**
  - In 2016–17, wind generation exceeded demand from the grid for around 139 hours in total spread across 30 separate days, with surplus wind generation available for export to Victoria.
- **In 2016–17, maximum instantaneous rooftop PV penetration (ratio of rooftop PV generation to underlying demand[3]) reached 41% during the middle of the day, the highest ratio in the past five years.**

Renewable generation and its contribution to peak demand

Total installed wind generation capacity increased from 1,576 MW in 2015–16 to 1,698 MW in 2016–17, with Waterloo Wind Farm's expansion (19.8 MW) and Hornsdale Stage 2 Wind Farm (102.4 MW) being registered in October 2016 and February 2017 respectively.

Total generation from both semi-scheduled and significant non-scheduled wind farms in South Australia for the year was 4,343 GWh.

Total installed rooftop PV generation capacity is estimated[4] to have increased 95 MW in 2016–17, to 781 MW. Total rooftop PV generation[5] in South Australia for the year was 1,016 GWh, 12% higher than in 2015–16.

[1] Analysis taken from the Australian PV Institute (APVI) Solar Map, funded by the Australian Renewable Energy Agency, accessed from pv-map.apvi.org.au. Viewed 31 July 2017.

[2] Operational reporting includes the electrical energy supplied by scheduled, semi-scheduled, and significant non-scheduled generating units.

[3] Underlying electricity demand refers to 30-minute as-generated operational demand plus estimated 30-minute rooftop PV output, so it is an estimation of that region's total electricity requirement, excluding small non-scheduled generation.

[4] Historical installed capacity for rooftop PV was extracted from a data set provided by the Clean Energy Regulator (CER). CER publishes an update on the capacity of rooftop PV systems every month. For each system, there can be a delay of up to 12 months between the installation of the system and its appearance in the CER data. This is due to the fact that participants in the scheme are permitted up to 12 months to register the system and claim the Small-scale Technology Certificate subsidy.

[5] The energy generated by a rooftop PV system was estimated using a model developed by the University of Melbourne. For each half-hour, the generation model takes into account solar radiation and cloud coverage. It models inefficiencies related to shading effects and takes into account the geographic distribution of the rooftop PV installations at that time.

Both wind and rooftop PV generation technologies are intermittent, with output dependent on weather conditions:

- The wind contribution to peak demand analysis[6] shows that on average, for 85% of summer peak demand periods, wind generation contributed at least 9.4% of South Australia's registered wind capacity (and for winter, 6.7%).
- Similar analysis of expected rooftop PV generation over the past five years indicates that on average, for 85% of summer underlying peak demand periods, rooftop PV generation contributed at least 1.6% of its estimated capacity.

Instantaneous penetration

'Instantaneous penetration' is a measure of the maximum observed ratio of generation output to operational demand at any instant in time during the year.

Wind penetration was over 100% for 139 hours across the 2016–17 year, on 30 separate days across the year. On these occasions, South Australia could have supplied its local demand entirely from wind generation, with surplus wind generation available to export to Victoria.

Table 1 summarises the change from 2015–16 to 2016–17 in maximum instantaneous wind and rooftop PV penetration and a number of other internationally-recognised generation indices.[7] Because minimum demand decreased in 2016–17 relative to 2015–16 and installed capacity increased, the maximum possible instantaneous penetration of wind increased in 2016–17.

Table 1 South Australian penetration indices

Description	Wind value for South Australia		Rooftop PV value for South Australia	
	2015–16	2016–17	2015–16	2016–17
Capacity penetration: installed capacity as a percentage of total installed generation[A]	31%	36%	13%	14%
Energy penetration: ratio of annual energy to annual total energy consumption[B]	32%	34%	6%	7%
Maximum instantaneous penetration (excluding exports): maximum observed ratio of energy to demand at any instant in time during the year [B]	119%	143%	37%	41%
Maximum possible instantaneous penetration: the ratio of installed capacity to minimum demand [C]	170%	213%	NA	NA
Periods of 100% (or greater) instantaneous penetration	24 hours	139 hours	0 hours	0 hours

A. Wind calculations are based on AEMO registered capacity for all South Australian generating systems at the end of the financial year. However, excluded are generating units that are effectively mothballed for more than six months of the financial year, and wind farms whose output did not yet reach 90% of registered capacity by end of the financial year. Rooftop PV capacity penetration is calculated by adding estimated rooftop PV capacity at end of the financial year to registered capacity.
B. Wind generation analysis is based on operational demand as generated, while rooftop PV is based on underlying demand.
C. Maximum possible instantaneous penetration for rooftop PV is not a valid metric, given minimum underlying demand can occur at periods when rooftop PV could never generate at its maximum capacity.

The maximum instantaneous wind penetration in 2016–17 reached 143% on 30 October 2016 in the five-minute period ending 1:55 pm. At the same time, there were only three thermal generating units online in South Australia, producing a combined total of approximately 87 MW, and a total of approximately 410 MW was being exported to Victoria across the two interconnectors (Heywood and Murraylink).

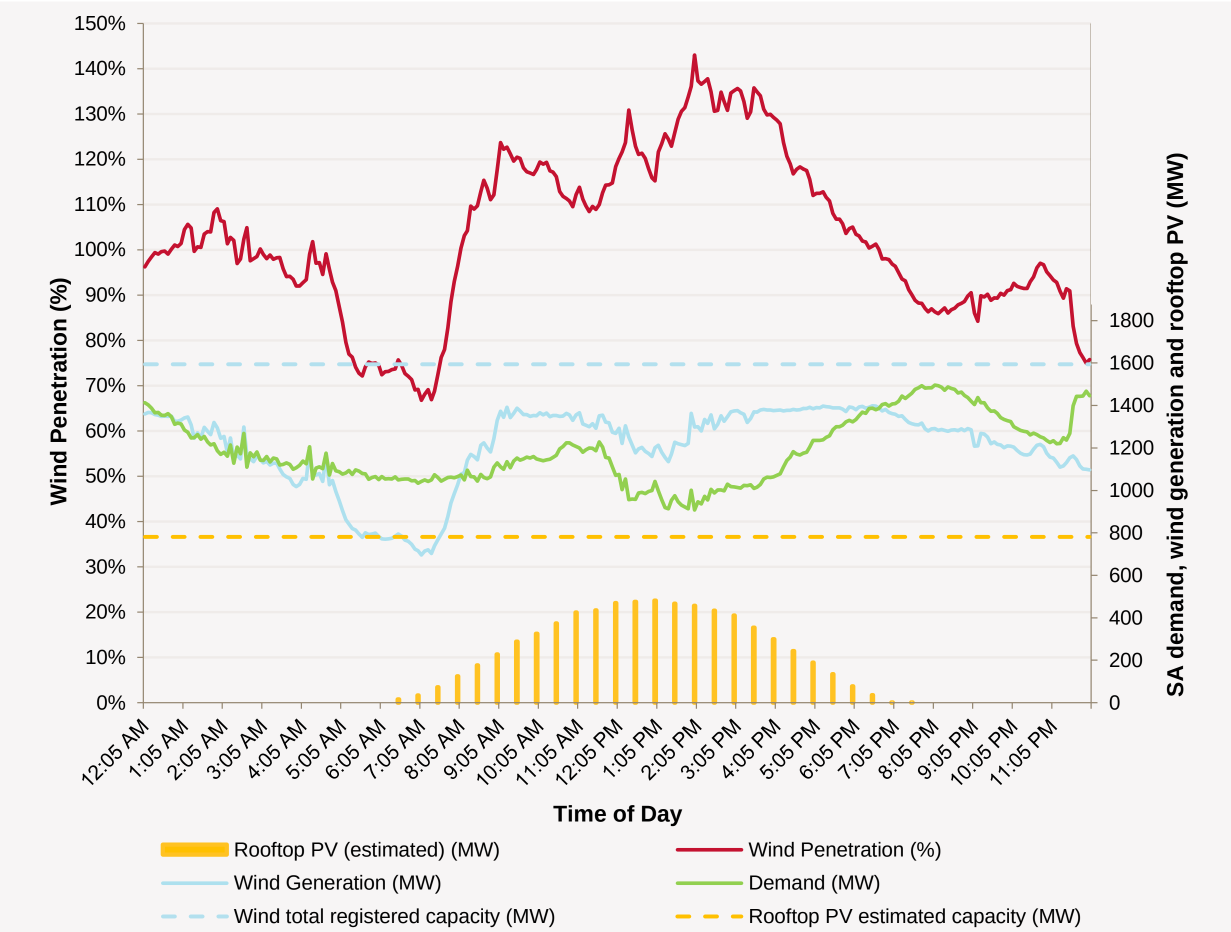
[6] AEMO computes the wind contribution to peak demand to be the 85th percentile level of expected wind generation across summer or winter peak periods (that is, the top 10% of five-minute demand dispatch intervals) over the past five years.
[7] The period of the South Australian black system event has been excluded for all instantaneous penetration analysis.

Wind generation is generally slightly higher overnight than during the day. Because of this, average wind penetration levels are greatest between 2:00 am and 5:00 am, when average operational demand is normally lowest. In contrast, the impact of rooftop PV generation only occurs during daylight hours.

Figure 1 shows wind generation, estimated rooftop PV generation[8], demand from the grid, and instantaneous wind penetration, for 30 October 2016, the day maximum wind penetration occurred.

The figure illustrates the interaction between wind generation and operational demand. Depending on the time of day, rooftop PV will affect operational demand and wind output will dictate the instantaneous penetration. In 2016–17, maximum wind instantaneous penetration occurred in the middle of the day when both wind and rooftop PV generation were very high and demand was low. By contrast, in 2015–16, maximum wind instantaneous penetration occurred in the early hours of the morning when wind output was very high and demand was low.

Figure 1 South Australian wind generation, demand, rooftop PV, and wind penetration on 30 October 2016



[8] Rooftop PV generation is seen as a reduction in demand, as it is not metered by AEMO.

Renewable generation variation

Due to the intermittent nature of wind and rooftop PV, there is potential for sudden variations in generation.

Analysis of output in 2016–17 shows that:

- The maximum variation of all South Australian wind generation was 763 MW (44.9% of registered capacity) across five-minute periods, and 963 MW (56.7% of registered capacity) across 30-minute periods.
- Wind farms located in the mid-north of South Australia showed lower wind variation than those installed in the south-east and coastal peninsula areas.
- The aggregated South Australian wind variation is lower than any single area, reflecting the smoothing effect of geographic diversity across the region.

In 2016–17, South Australian estimated rooftop PV generation varied by up to 190 MW (24.3% of estimated capacity) across 30-minute periods. The analysis of summer and winter daily generation profiles shows the rate of change in generation, particularly during mornings and evenings, increasing year on year, concurrent with growth in installed capacity.

This high variability in wind and rooftop PV generation means there is a greater variability of the residual demand[9], which must be met by more responsive dispatchable capacity in South Australia, or by changes in power flow from Victoria on the Heywood and Murraylink interconnectors.

[9] Residual demand refers to demand that is met by generation other than wind generators and rooftop PV.

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1. INTRODUCTION

The *South Australian Renewable Energy Report* (SARER) analyses the region's historical wind farm and rooftop photovoltaic (PV) performance, including electricity market pricing insights, over the five years 2012–13 to 2016–17, and winter 2017 where applicable.

1.1 Information sources and assumptions

The SARER reports on electricity generated by South Australian renewable generating systems that operate in the National Electricity Market (NEM):

- Wind farms are typically greater than or equal to 30 megawatts (MW) registered capacity, and are described in Appendix A.1.
- Historical estimates of rooftop PV installed capacity and generation output are taken from the 2017 *Electricity Statement of Opportunities* (ESOO)[10] for the NEM, to illustrate its impact on operational consumption and pricing.[11]

Table 2 summarises the data sources used in the reporting presented in the 2017 SARER.

Table 2 SARER data sources summary

Data reported	Data source(s) in 2017 reports
Reporting on: • **Generation output (including for capacity factor and volume-weighting of average prices)** • **Interconnector flows** • **Demand**	Five-minute averages of as-generated Supervisory Control and Data Acquisition (SCADA) metering. When not available, five-minute SCADA snapshots or the last known good SCADA value were used instead.
Rooftop PV capacity and generation estimates – annual totals	As forecast in 2017 NEM ESOO.
Rooftop PV capacity and generation estimates – 30-minute analysis	Based on 30-minute generation estimates calculated using a model developed with the University of Melbourne.
Pricing	Average of six five-minute dispatch prices over a 30-minute trading interval from AEMO's Wholesale Energy Market Management System (EMMS).

Key definitions throughout the report

- **Rooftop PV** refers to installations up to 100 kilowatts (kW) capacity.
  - Small-scale solar PV with estimated installed capacity greater than 100 kW and smaller than 30 MW are included in small non-scheduled generation (SNSG). SNSG generators typically do not have the same NEM registration and metering requirements as scheduled, semi-scheduled, and significant non-scheduled generators, so it is not practical for AEMO to report on SNSG capacity or output to the same granularity as it does for larger generators. The PV component of SNSG is considered to be the main growth area in SNSG. AEMO has now begun tracking the PV component of SNSG separately (as PVNSG) for future analysis.
- **Operational demand** refers to electricity used at a specific point in time (typically at a five-minute or 30-minute interval, measured in MW), while operational consumption is the electricity used over a period of time (typically over one year, measured in gigawatt hours (GWh)).

[10] AEMO. *Electricity Statement of Opportunities for the National Electricity Market*, September 2017. Available at http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/NEM-Electricity-Statement-of-Opportunities.
[11] Annual operational consumption is the electrical energy supplied by scheduled, semi-scheduled, and significant non-scheduled generating units. Annual operational consumption does not include the electrical energy supplied by small non-scheduled generating units.

- **Underlying demand** refers to electricity consumed by customers at their premises, supplied from both the grid and rooftop PV combined. In this report, it is estimated to be the sum of operational demand plus rooftop PV generation.
- **South Australian demand** refers to the as-generated operational demand met by local scheduled, semi-scheduled, and significant non-scheduled generating systems[12] plus interconnector imports from Victoria, and excludes demand supplied by rooftop PV generation.
- **Time** has been expressed in Australian Eastern Standard Time (AEST) with no daylight savings applied. This is referred to as NEM time (or market time).
- **Summer** has been defined as the period from 1 November to 31 March, and **winter** from 1 June to 31 August.

Due to changes in scheduling type in 2015–16, Angaston, Lonsdale, and Port Stanvac power stations are included in operational demand and generation analysis from 12 January 2016. Angaston power station is included in reporting on individual generator outputs and capacity factors before this date.

The South Australian black system event period over September and October 2016 has been excluded for all instantaneous penetration analysis.

1.2 Treatment of wind farms during commissioning period

Wind farms typically take several months to ramp up their generation from very small amounts to their full capacity during commissioning. AEMO attempts to minimise the impact of this commissioning period on analysis that involves generator capacity, as wind farm output during this period is non-typical.[13]

The following methodology applies throughout this report, except where specifically noted:

- Wind farms are considered to be in their commissioning period from the time they are registered with AEMO until their five-minute generation value first reaches 90% of their registered capacity.
- Wind farms in their commissioning period are included in calculations of:
  - Operational demand, as supplied by scheduled, semi-scheduled and significant non-scheduled generating units.
  - Individual and total wind generation (except for wind contribution during peak demand, as stated below).
- Wind farms in their commissioning period are excluded from:
  - Calculations of capacity factor.
  - Calculations of capacity penetration and maximum possible instantaneous penetration.
  - Any capacity calculations of wind variation analysis (but are included in the generation calculations, as stated above).
  - The capacity and generation calculations of wind contribution during peak demand analysis (but included in the demand calculations, as stated above).

For the 2017 SARER, four wind farms in South Australia are affected by the above methodology, and are described in various analyses throughout the report. These are the Hallett 5 (the Bluff), Snowtown Stage 2, Hornsdale Stage 1, and Hornsdale Stage 2 wind farms.

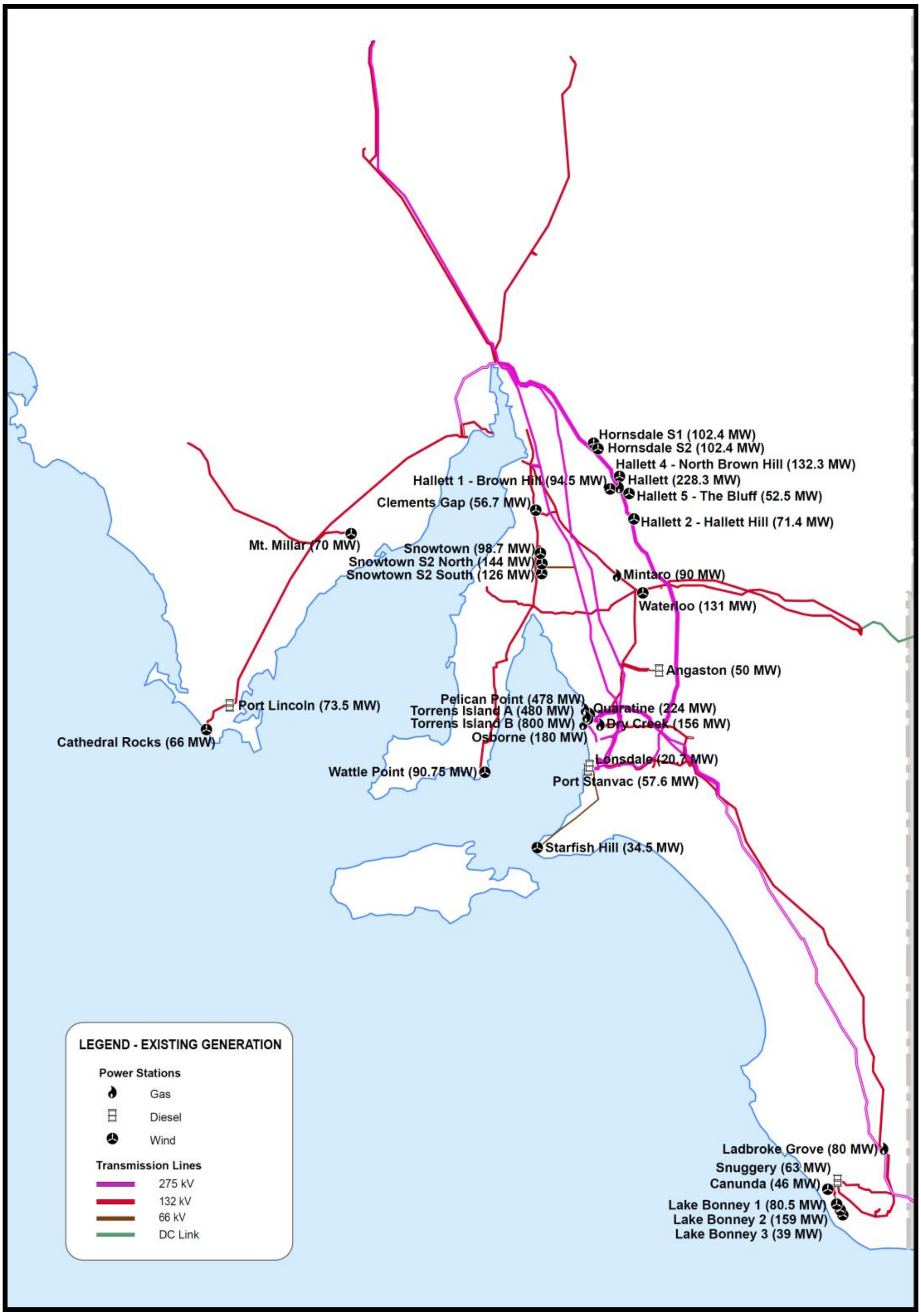
1.3 Generating systems maps

Figure 2 shows the location, nameplate capacity, and energy source of registered operational generators in South Australia (all scheduled, semi-scheduled, and significant non-scheduled generators

[12] Significant non-scheduled generating units in South Australia are all non-scheduled wind farms, as their capacity exceeds 30 MW.
[13] Capacity factor calculations would be especially distorted if no consideration was made for the commissioning period.

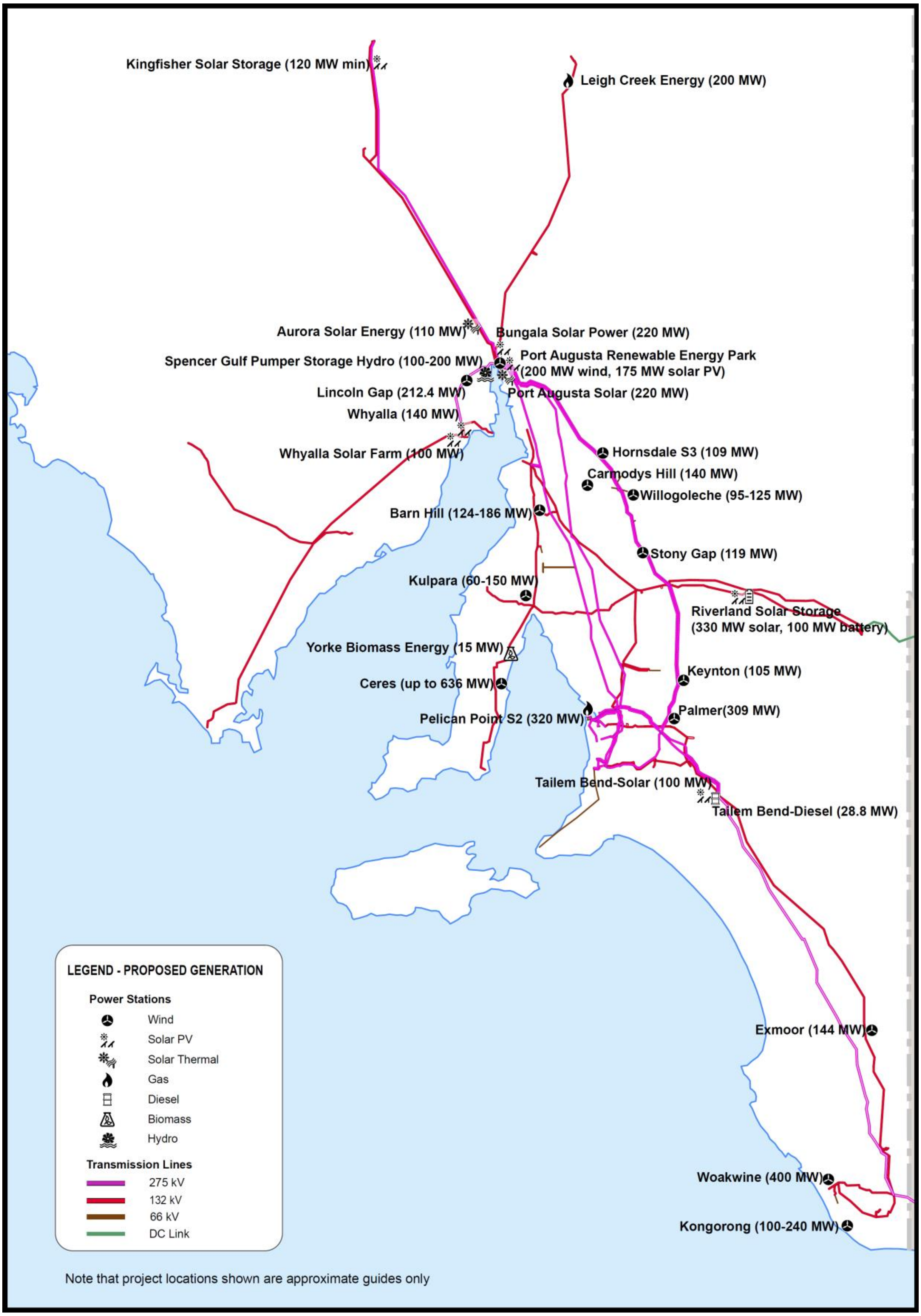
used in operational reporting). Figure 3 shows the location and capacity of publicly announced generation projects as at 5 June 2017.[14]

Figure 2 Location and capacity of South Australian generating systems as at 5 June 2017



[14] AEMO Generation Information for South Australia, 5 June 2017. Available at: http://www.aemo.com.au/Electricity/Planning/Related-Information/Generation-Information.

Figure 3 Location and capacity of proposed South Australian generation projects as 5 June 2017



Local generation capacity

Table 3 summarises the capacity mix of fuel types for all registered generation in South Australia, as at 30 June 2017.

In South Australia, in 2016–17, local wind generation was the second largest proportion of registered capacity, at approximately 31.2% of total registered capacity.

Table 3 South Australian registered capacity by fuel type as at 30 June 2017

Fuel Type	Registered capacity (MW)	% of total capacity
Gas	2,668	49.1%
Wind	1,698	31.2%
Rooftop PV[A]	781	14.4%
Diesel + SNSG[B]	289	5.3%
Total	5,436	100%

A. Rooftop PV installations are not registered with AEMO, but are included here given their material contribution to generation in 2016–17. Rooftop PV capacity and generation estimates as listed build on those presented in the 2017 NEM ESOO forecasts.
B. Diesel + SNSG includes small and large diesel, small landfill methane, hydro generating systems and the PV systems larger than 100 kW and smaller than 30 MW.

1.4 Recent renewable generation and network developments

Generation investment interest in South Australia continues to be focused largely on renewable energy proposals. As at 5 June 2017, AEMO's generation information page listed 25 publicly announced renewable electricity generation developments in South Australia, totalling 4,708 MW.

Table 4 aggregates the new renewable developments by energy source.[15]

Table 4 Publicly announced and committed renewable generation projects by energy source as at 5 June 2017

Energy source	Number of projects	Capacity (MW)	Capacity (%)
Solar	9[A]	1,515[B]	32.2%
Biomass	1	15	0.3%
Wind	15[A]	3,178	67.5%
Total	**25**	**4,708**	**100.0%**

A. Port Augusta Renewable Energy Park (combined wind and solar PV project) capacity is split between both the solar and wind categories, but is counted once in the total number of projects.
B. This does not include the newly announced 150 MW solar thermal power plant for Port Augusta.

There are four new publicly announced solar generation developments since the 2016 SARER:

- Riverland Solar (330 MW).
- Tailem Bend Solar (100 MW).
- Whyalla Solar – Adani (140 MW).
- Whyalla Solar Farm – Energy Pacific (100 MW).

AEMO is not aware of any NEM-connected geothermal power plant proposals currently being pursued in South Australia. For further information about generating systems and withdrawals, please refer to the latest AEMO Generation Information page.[16]

[15] AEMO. Generation Information for South Australia, 18 November 2016. Available at: http://www.aemo.com.au/Electricity/Planning/Related-Information/Generation-Information. Viewed: 18 November 2016.
[16] AEMO. Generation Information page: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Generation-information.

2. WIND FARMS

2.1 Summary

This chapter presents a historical analysis of South Australian wind generation performance, including information highlighting the relationship between wind generation and consumption (aggregated across a financial year), and wind generation and maximum demand (measured at five-minute intervals).

Table 5 below summarises annual wind generation and its annual change from 2012–13 to 2016–17. For further information on wind farm generation and capacity factors, please refer to the 2017 *South Australian Historical Markets Information Report* (SAHMIR).[17]

Table 5 Total South Australian wind generation

Financial year	Annual South Australian wind generation (GWh)	Annual change in wind generation (%)	Annual capacity factor [A] (%)
2012–13	3,475		33
2013–14	4,088	+18	32
2014–15	4,223	+3	33
2015–16	4,322	+2	31
2016–17	4,343	+0	29

A. Capacity factor means the annual wind generation compared to the theoretical maximum possible, assuming the annual capacity reported.

Key observations include:

- Annual wind generation in South Australia increased in line with installed capacity increases from 2012–13 to 2016–17.
- The total wind generation only increased 21 GWh from 4,322 GWh to 4,343 GWh in 2016–17 due to lower wind quality for sustained periods.

2.2 Wind contribution during peak demand

Wind generation during peak demand depends on both wind speed and the operational limitations of wind turbines across the region. Wind is intermittent by nature, with periods of low wind (and in some cases very high wind[18]) resulting in low generation output.

When these situations arise in South Australia, residual demand must be met by other types of generation within the region, or by imports from Victoria.

A review of wind generation performance for the top 10% of five-minute demand dispatch intervals, over a five-year period, highlights that the output from wind generation is variable between seasons and across years.

Table 6 provides the 85th percentile level of expected wind generation across summer and winter peak periods over the past five years.[19] On average, for 85% of summer peak demand periods, wind generation contributed at least 9.4% of its registered capacity (and for winter, 6.7%). The wind contribution factor is generally higher in summer than in winter.

[17] AEMO. *2016 South Australian Historical Market Information Report*. Available at: http://aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/South-Australian-Advisory-Functions.

[18] The occurrence of high winds, potentially in combination with high temperatures, can often result in mechanical and thermal design limitations being reached. In extreme cases this may result in individual units shutting down to prevent physical damage.

[19] Analysis for wind contribution factors excludes wind generation from the period before a new wind farm first reached 90% of registered capacity.

Table 6 85th percentile wind contribution factor (wind generation as a % of registered wind capacity) during top 10% seasonal peak demand

Summer peak period	% of registered capacity	Winter peak period	% of registered capacity
2012–13	8.1%	2012	8.9%
2013–14	9.3%	2013	6.0%
2014–15	11.5%	2014	6.1%
2015–16	8.9%	2015	4.9%
2016–17	9.1%	2016	7.7%
Five-year summer average	9.4%	Five-year winter average	6.7%

Table 7 compares the minimum expected contribution of wind generation during peak demand periods across different NEM regions.[20]

Table 7 Expected wind contribution during peak demand (wind generation as a % of registered wind capacity)

Minimum expected wind contribution during peak demand [A]	South Australia	Victoria	Tasmania	New South Wales
Five-year summer average	9.4%	8.1%	10.5%	6.7%
Five-year winter average	6.7%	7.3%	7.3%	3.7%

A. Expressed as a percentage of registered capacity, with peak demand defined as the top 10% of demand periods.

Figures 4 and 5 show wind generation duration curves over the top 10% summer and winter demand periods for South Australia, with the 85th percentile point indicated. The duration curves provide additional insight into wind generation during peak demand periods. These figures illustrate that:

- For 10% of summer peak demand periods, wind generation contributes about 49.3–54.5% of its registered capacity, and for 50% of summer peak demand periods, it contributes about 21.8–27.1% of its registered capacity.
- For 10% of winter peak demand periods, wind generation contributes about 76.7–83.6% of its registered capacity, and for 50% of winter peak demand periods, it contributes about 30.7–40.9% of its registered capacity.

[20] Victorian analysis excludes the smaller non-scheduled wind farms in that region, which are registered with AEMO, but not reportable. Queensland is not included in the analysis at all, as there are no reportable wind farms for that region.

Figure 4 Summer peak demand wind generation duration curve (% of registered wind capacity)

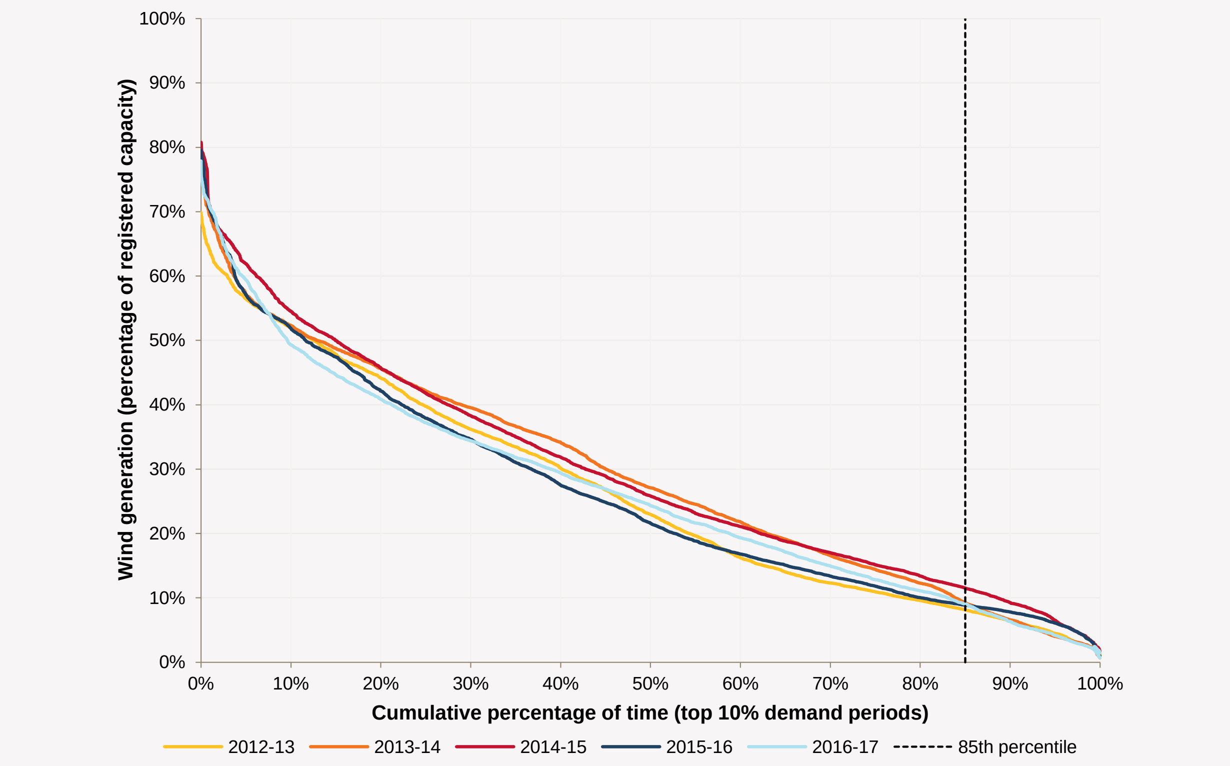
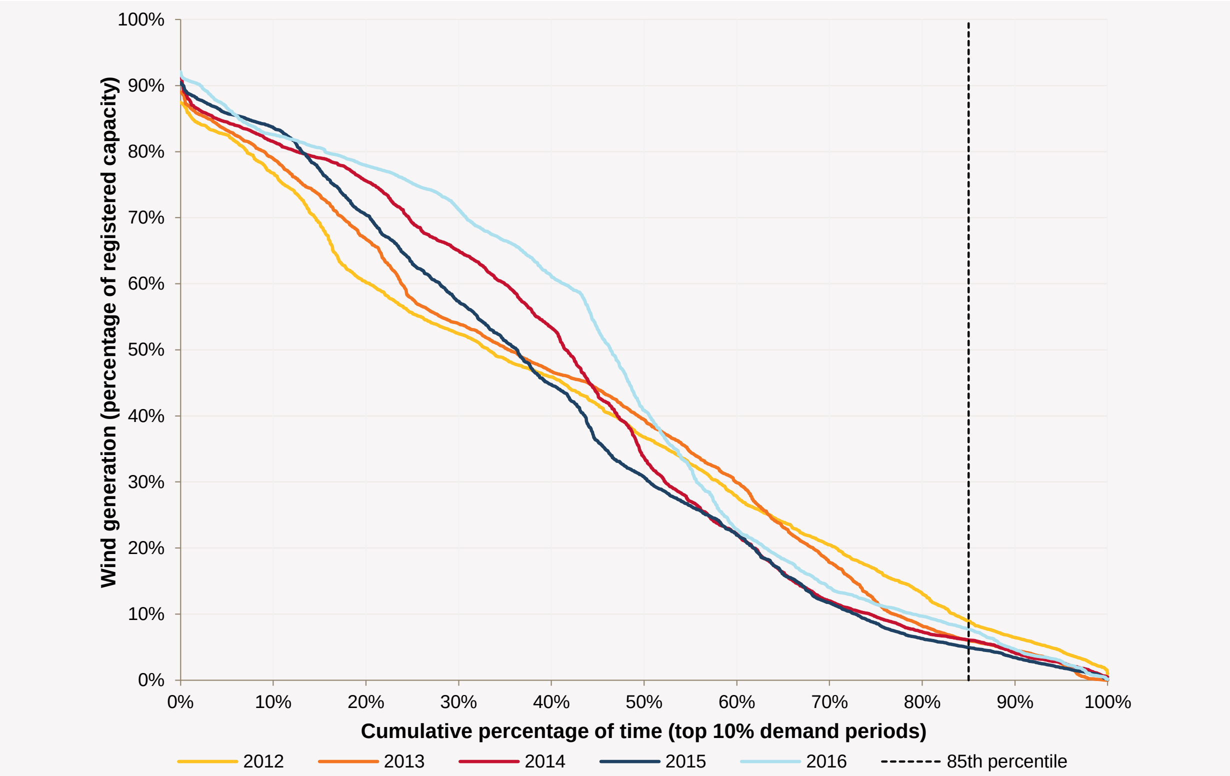


Figure 5 Winter peak demand wind generation duration curve (% of registered wind capacity)



2.3 Wind penetration

2.3.1 Wind penetration indices

Internationally, a number of indices are used to measure wind penetration. Table 8 sets out the calculations for South Australian wind penetration using four common indices. Corresponding with increases in installed wind generation capacity, all other indices have tended to increase over time. The increasing trends in energy and instantaneous penetration are also partly attributable to:

- The region's decreasing operational consumption and increasing rooftop PV generation.
- Withdrawal of gas- and coal-fired generation.
- Changes in minimum demand from year to year.

Table 8 South Australian wind penetration indices (%)

	2012–13	2013–14	2014–15	2015–16	2016–17
Capacity penetration: installed capacity as a percentage of total installed generation [A]	26	30	30	31	36
Energy penetration: ratio of annual wind energy to annual total energy consumption	25	31	32	32	34
Maximum instantaneous penetration (excluding exports): maximum observed ratio of wind energy to demand at any instant in time during the year	87	99	109	119	143
Maximum possible instantaneous penetration: the ratio of installed capacity to minimum demand [B]	116	126	189	170	213

A. Calculations are based on AEMO registered capacity for all South Australian generating systems at the end of the financial year. However, excluded are generating units that are effectively mothballed for more than six months of the financial year, and wind farms whose output did not yet reach 90% of registered capacity by the end of the financial year.
B. Minimum demand outside the black system event in South Australia.

With reduced consumption and higher wind installed capacity, 2016–17 saw the highest wind penetration indices compared to the previous four years. Maximum instantaneous penetration reached 143% in 2016–17, and wind supplied 34% of the region's consumption from the grid.

In 2016–17, the maximum instantaneous wind penetration reached 143% on 30 October 2016 at around 1:55 pm. At the same time, there were only three thermal generating units online in South Australia, producing a combined total of approximately 87 MW, and a total of approximately 410 MW was being exported to Victoria across the two interconnectors (Heywood and Murraylink). Wind penetration was over 100% on 30 separate days across the year. On these occasions, South Australia could have supplied its local demand entirely from wind generation, with surplus wind generation available to export to Victoria.

Periods of 100% (or greater) instantaneous wind penetration occurred for around 139 hours in 2016–17, compared to 24 hours in 2015–16, coinciding with decreased operational consumption and increased wind generation.

2.3.2 Daily demand, wind generation, and penetration profile

Wind generation and demand vary both seasonally and throughout the day. When high wind generation coincides with low operational demand, instantaneous wind penetration tends to be maximised.

Figure 6 illustrates the average South Australian demand, wind generation, and wind penetration values throughout the day for 2015–16 and 2016–17. It indicates that:

- The average daily demand profile decreased in 2016–17 relative to 2015–16, especially between 8.00 am and 6.00 pm (coinciding with periods of increasing rooftop PV generation, which reduces demand during the middle of the day).

- Wind generation maintained a similar daily profile, peaking overnight from around 10.00 pm through to 6.00 am the next day.
- Average wind penetration was highest around 2.00 am to 5.00 am, when average demand was lowest.

Figure 6 Daily demand, wind generation, and penetration profile

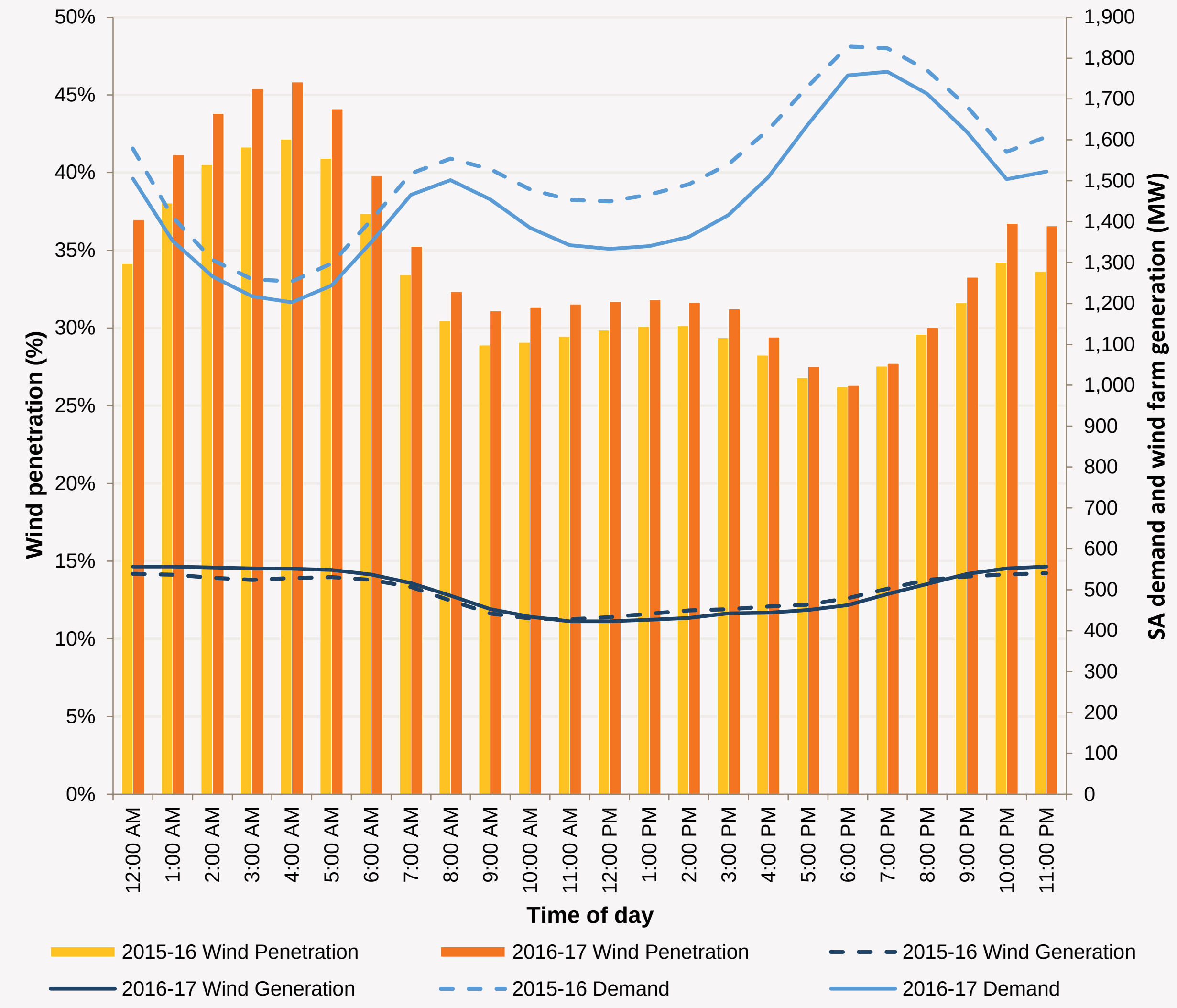


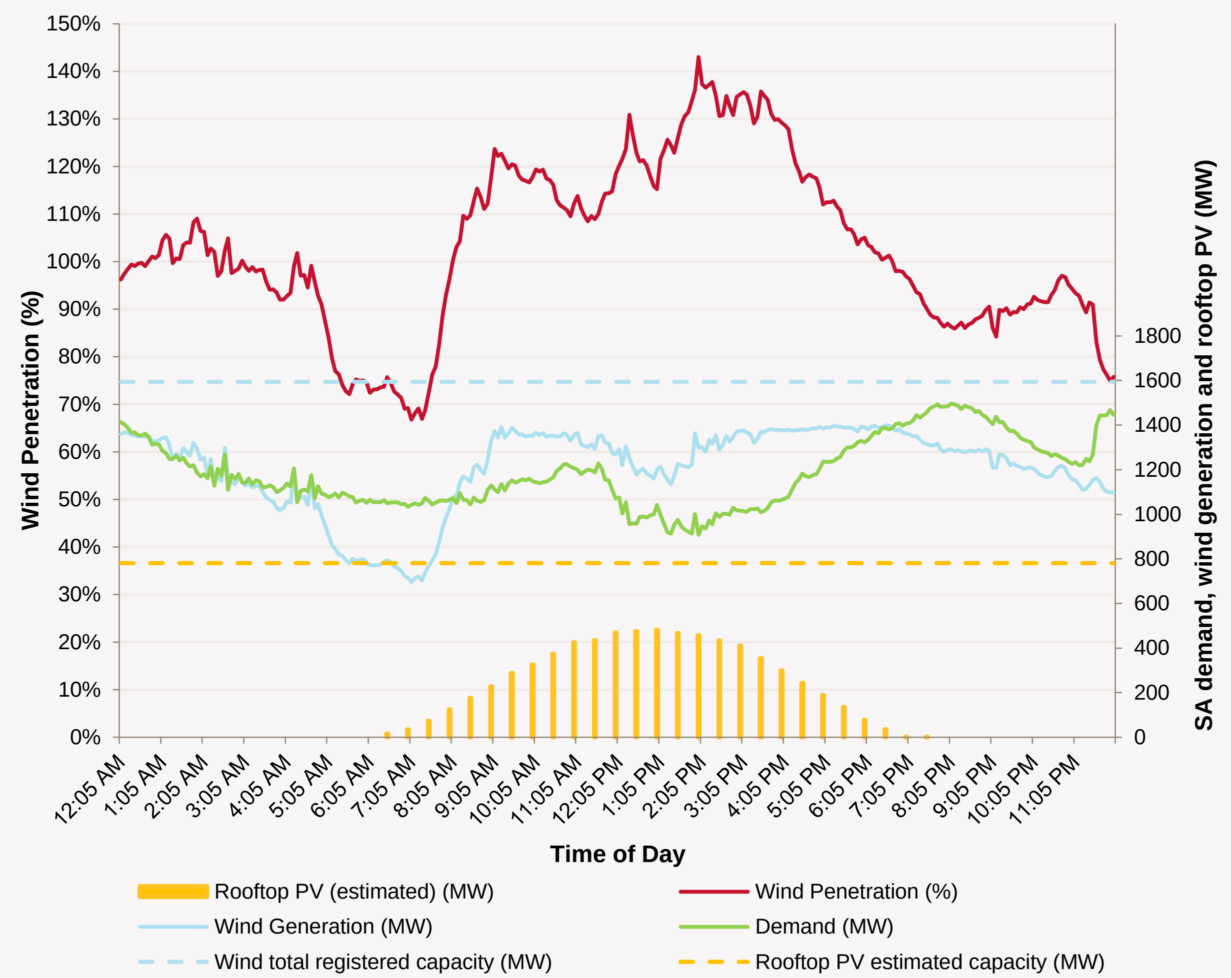
Figure 7 shows the South Australian estimated rooftop PV, wind generation, wind penetration, and demand from the grid, for 30 October 2016 (the day when maximum instantaneous wind penetration occurred). This figure also shows an estimation of South Australian rooftop PV generation output at half-hourly intervals.[21]

This figure illustrates the interaction between the wind and operational demand. Depending on the time of day, rooftop PV will affect the demand and the given wind output will dictate the instantaneous

[21] Rooftop PV generation is seen as a reduction in demand, as it is not metered by AEMO. Rooftop PV calculations are based on 30-minute generation estimates calculated using a model developed with the University of Melbourne, which takes into account data on rooftop PV installed capacity from the Clean Energy Regulator (CER). This is sourced from V. Depoorter Ruelle, M. Jeppeson, M, Brear, *Rooftop PV Model Technical Report*, July 2016, University of Melbourne. Available at: http://aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/National-Electricity-Forecasting-Report.

penetration. In 2016–17, maximum wind instantaneous penetration occurred in the middle of the day, when both wind and rooftop PV generation were very high and demand was low.

Figure 7 South Australian wind generation, demand, rooftop PV, and wind penetration on 30 October 2016



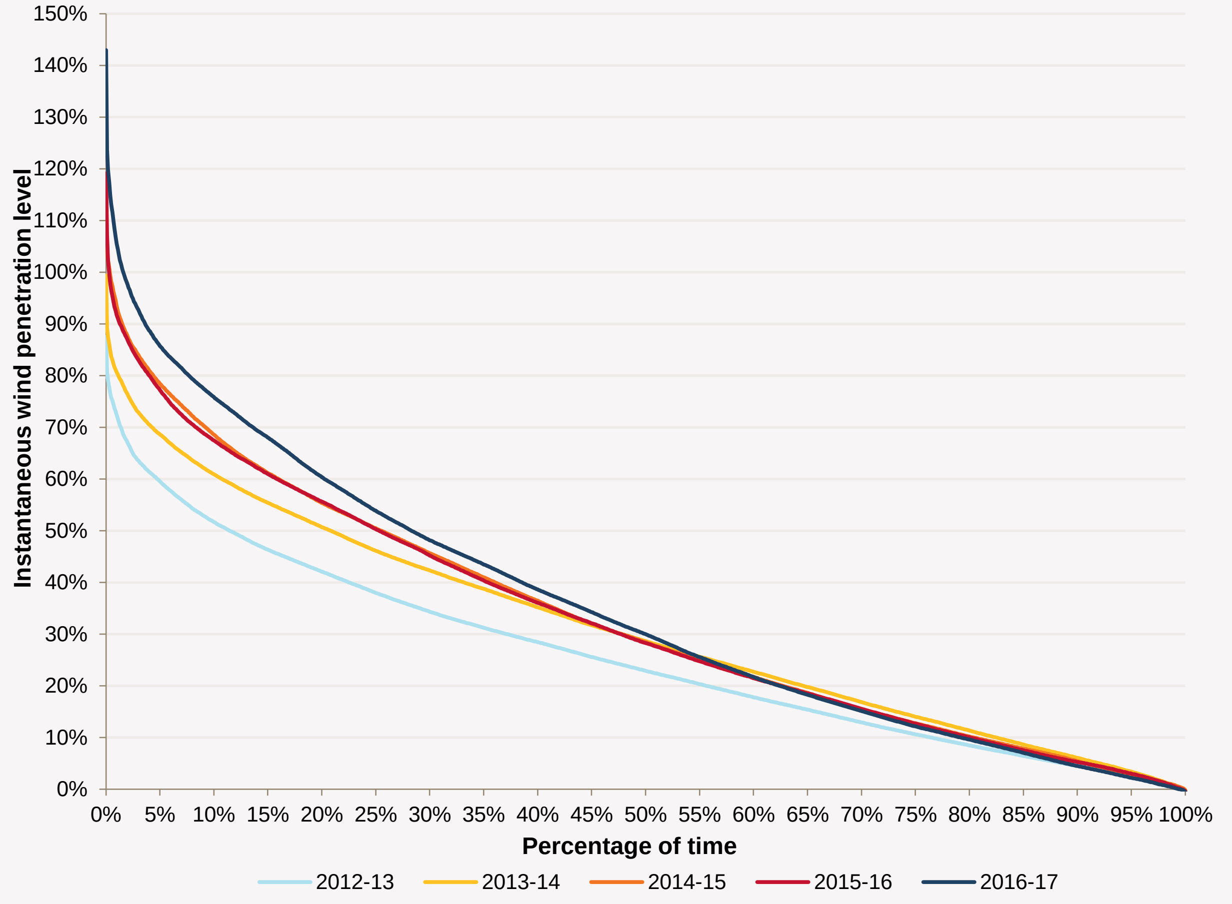
2.3.3 Wind penetration duration curves

Figure 8 shows wind penetration duration curves for the past five financial years, indicating that penetration levels have increased over time. This is due to a combination of increasing wind generation and declining operational consumption and minimum demand.[22]

Overall, extremely high penetration levels occur for a small percentage of time, as indicated by the steep gradient at the left-hand side of the curves.

[22] Details of operational consumption and minimum demand trends can be found in the 2017 *South Australian Electricity Report* (SAER). Available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/South-Australian-Advisory-Functions.

Figure 8 Instantaneous wind penetration duration curves



3. ROOFTOP PV

3.1 Rooftop PV capacity

Since 2009, South Australian total installed rooftop PV capacity has grown strongly. This is primarily due to government incentives in the form of rebates and feed-in tariffs, the Small-scale Technology Certificate (STC) multiplier, falling system costs, and increasing electricity prices. These factors helped reduce payback periods for consumers, making rooftop PV generation an attractive option for households, particularly from 2010 to 2012. South Australia's installed rooftop PV penetration per household is higher than in any other NEM region.[23] More than 30% of South Australian dwellings now have rooftop PV systems installed.[24]

In South Australia, the rate of growth of residential rooftop PV systems is forecast[25] to decline because saturation has been reached in some areas, however the business sector is forecast to have steady growth.

Different drivers between residential and business installations are now becoming important, particularly:

- Residential rooftop PV system uptake continues to be driven by the Federal Small-scale Renewable Energy Scheme (SRES) and the increasing retail cost of electricity.
- Additionally, declining installation costs has improved economic viability for residential rooftop PV and Integrated PV and Storage Systems (IPSS). For rooftop PV systems, short term cost reductions are expected to come mainly in non-hardware related "soft costs", including marketing and customer acquisition, system design, installation labour, permit and inspection costs, and installer margins. In the longer term, cost reductions are expected to come from better system efficiencies and improvements from research and development.[26]
- Uptake in the business sector has been more recent, driven by a combination of programs such as the Clean Technology Investment Fund and SRES, as well as the continued decrease in PV costs making the business case more attractive, a continuing focus by businesses on sustainability initiatives, and an increased marketing push by installers into this sector.

In the 2017 NEM ESOO and 2017 *South Australian Electricity Report* (SAER)[27], AEMO illustrated a detailed impact of rooftop PV. The breakdown of rooftop PV installed generation capacity by sector with estimated actuals and forecasts for South Australia from the 2017 NEM ESOO forecast are shown in Figure 9 and broken down by sector in Table 9.

[23] This refers to the proportion of dwellings with a PV system. Source: Australian PV Institute (APVI) Solar Map, funded by the Australian Renewable Energy Agency, accessed from pv-map.apvi.org.au on 24 August 2015.

[24] Analysis taken from: Australian PV Institute (APVI) Solar Map, funded by the Australian Renewable Energy Agency, accessed from pv-map.apvi.org.au on 11 Aug 2017.

[25] AEMO's forecast of capacity for rooftop PV is based on advice from external consultancy Jacobs. Jacob's consultancy report "Projections of uptake of small-scale systems" is available on AEMO's website: https://www.aemo.com.au/-/media/Files/Electricity/WEM/Planning_and_Forecasting/ESOO/2017/2017-WEM-ESOO-Methodology-Report---Projections-of-Uptake-of-Small-scale-Systems.pdf.

[26] Refer to footnote 25.

[27] AEMO. 2017 *South Australian Electricity Report*, October 2017. Available at http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/South-Australian-Advisory-Functions.

Figure 9 South Australian rooftop PV installed capacity forecasts at the end of each financial year

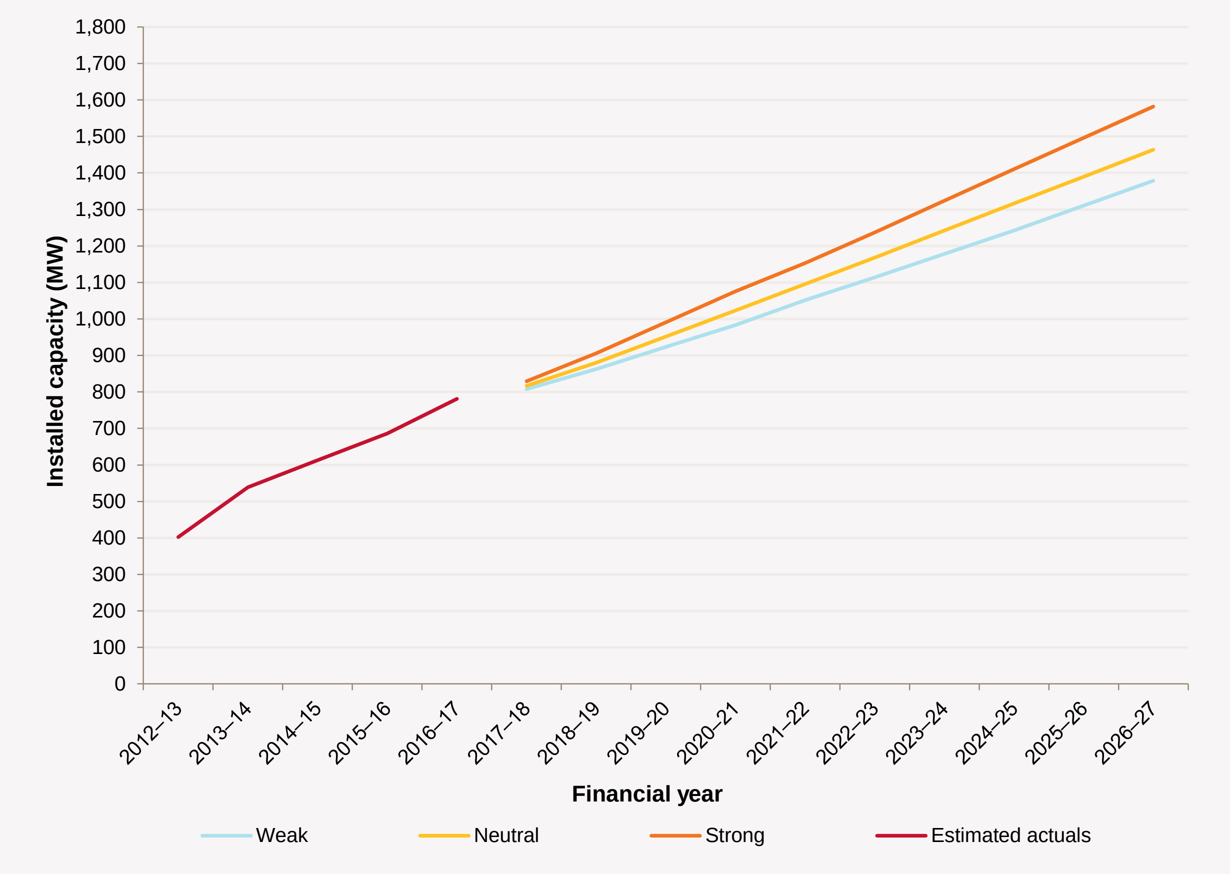


Table 9 South Australian rooftop PV installed capacity forecasts

Year	Installed capacity (MW)					
	Residential		Business		Total	
	Estimated Actual	Neutral sensitivity	Estimated Actual	Neutral sensitivity	Estimated Actual	Neutral sensitivity
2012–13	389		14		402	
2013–14	504		35		539	
2014–15	560		53		613	
2015–16	613		73		686	
2016–17	682		100		781	
2017–18		705		112		817
2018–19		751		129		880
2019–20		804		148		952
2020–21		857		166		1,023
2021–22		909		186		1,096
2022–23		962		206		1,168
2023–24		1,016		226		1,242
2024–25		1,071		246		1,316
2025–26		1,125		265		1,390
2026–27		1,179		285		1,464

3.2 Generation

In the NEM, South Australia has the highest ratio of rooftop PV generation to operational consumption. This is attributed to the region's high penetration of rooftop PV installations, good solar resources, and the second lowest operational consumption of all NEM regions.

Table 10 shows the breakdown of estimated rooftop PV generation by sector for the last five years.

Table 10 South Australian rooftop PV generation estimates

Year	Estimated generation (GWh)		
	Business	Residential	Total
2012–13	12	470	482
2013–14	34	638	672
2014–15	62	758	820
2015–16	87	821	908
2016–17	121	896	1,016

3.3 Rooftop PV contribution during maximum underlying demand

As rooftop PV capacity has increased its penetration into the South Australian market, so too has its generation contribution to underlying peak demand, increasing at an average of 1.37% a year for the past five years.

Table 11 shows the percentage of estimated rooftop PV contribution during periods of maximum underlying demand in South Australia. Rooftop PV calculations are based on 30-minute generation estimates calculated using a model developed with the University of Melbourne, which takes into account data on rooftop PV installed capacity from the Clean Energy Regulator (CER).[28]

Table 11 Rooftop PV contribution during periods of maximum underlying peak demand

Year	Contribution of rooftop PV (%) [A]	Date of underlying peak demand	Total installed rooftop PV capacity as at 30 June (MW)	Total estimated rooftop PV output at time of underlying peak demand (MW)
2012–13	4.05	18/02/2013 16:30	402	130
2013–14	6.13	16/01/2014 16:30	539	211
2014–15	10.06	07/01/2015 13:30	613	304
2015–16	9.91	17/12/2015 16:00	686	315
2016–17	9.52	08/02/2017 16:30	781	313

A. The amount rooftop PV is contributing to the maximum underlying demand per financial year. I.e. rooftop PV generation estimate / (rooftop PV generation estimate plus operational demand), at the time of maximum (rooftop PV generation estimate plus operational demand). Rooftop PV values differ from 2016 SAHMIR due to an improvement in the process to estimate actual generation was performed in AEMO's 2017 demand forecasts

Figure 10 provides a review of rooftop PV generation performance for the top 10% of 30-minute trading intervals, over a five-year period. It highlights that the output from rooftop PV generation is variable between seasons and across years.

[28] Rooftop PV methodology paper: : http://aemo.com.au/Electricity/National-Electricity-Market-NEM/~/-/media/CEDBBF70073149ABAD19F3021A17E733.ashx

Table 12 provides the 85th percentile level of expected rooftop PV generation across summer peak periods over the past five years. On average, for 85% of summer underlying peak demand periods, rooftop PV generation contributed at least 1.6% of its estimated capacity[29].

As expected, the contribution in winter was much lower compared to summer due to fewer daylight hours. Figure 11 illustrates that at the 85th percentile level of underlying winter peak demand periods, there was no contribution from rooftop PV.

Figure 10 Summer peak demand rooftop PV generation duration curve (% of estimated rooftop PV capacity)

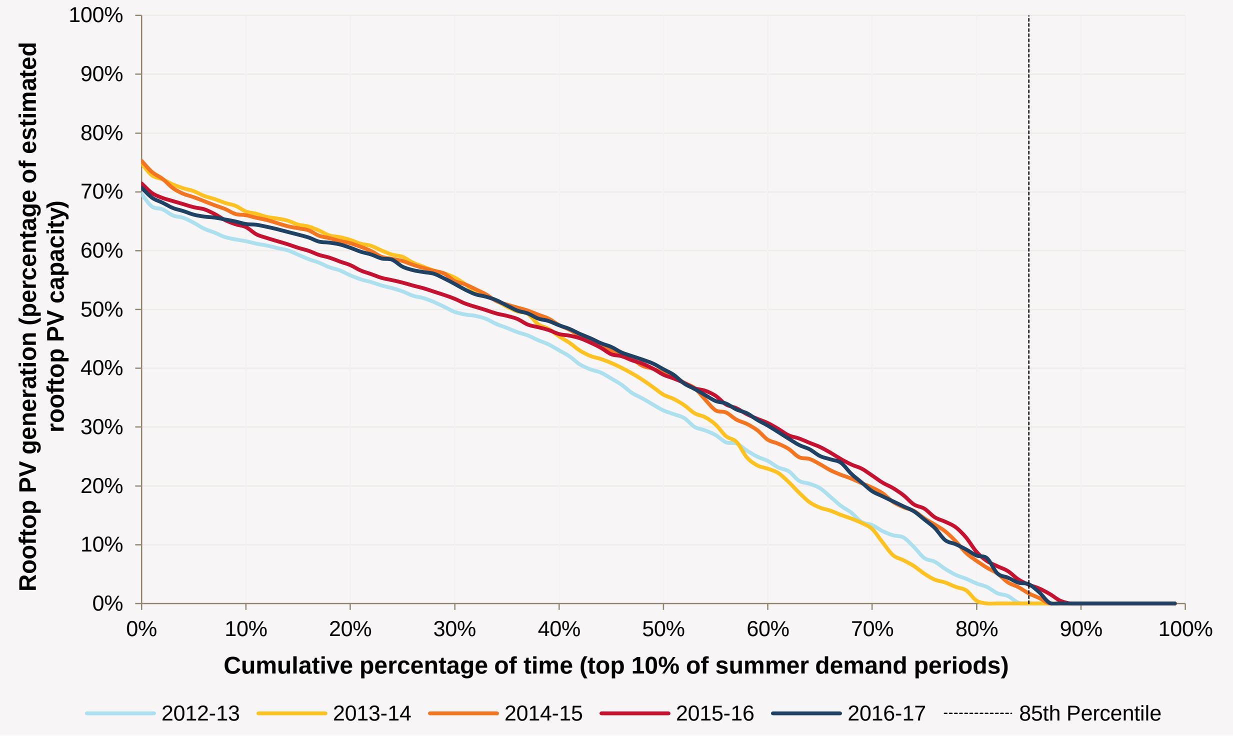
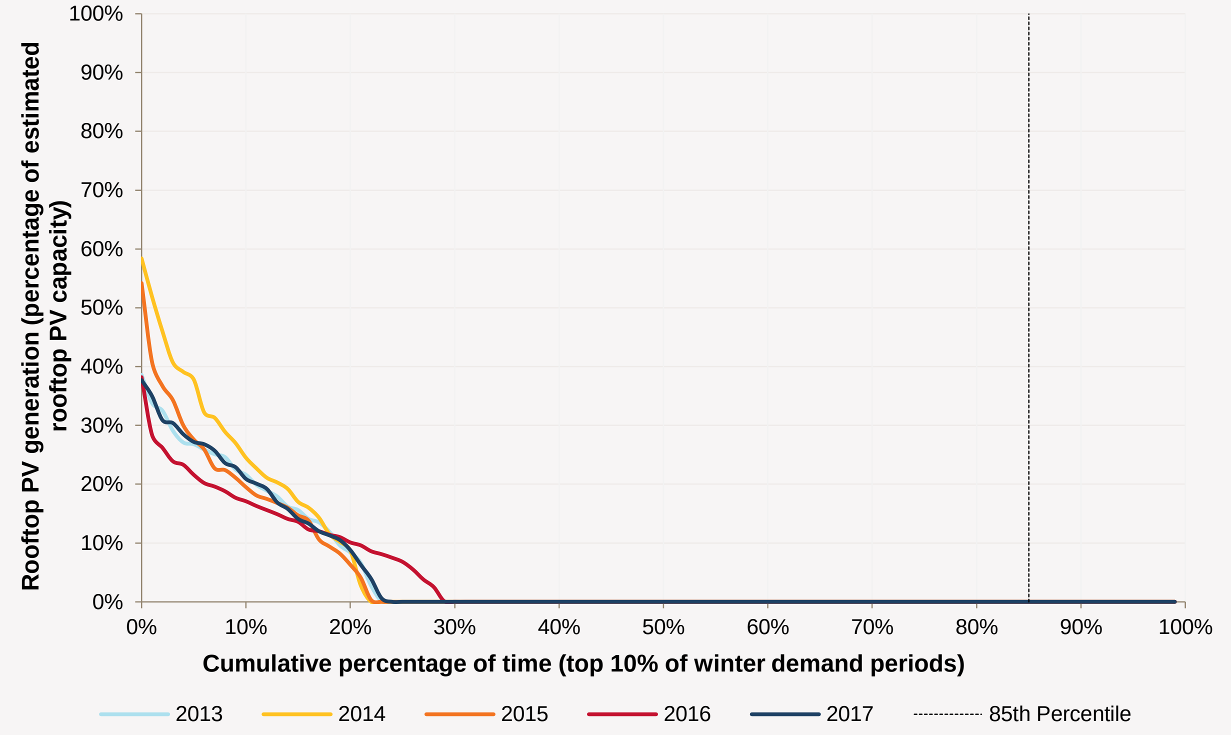


Table 12 Rooftop PV generation (% of estimated capacity) during top 10% of summer peak demand periods

Summer peak period	% of estimated capacity at the 85th percentile for summer
2012–13	0.0
2013–14	0.0
2014–15	1.7
2015–16	3.2
2016–17	3.3
Five-year summer average	1.6

[29] The contribution factor is a capacity metric, not to be confused with contribution to reducing the peak electricity demand. It presents how much of rooftop PV was contributing, as a percentage of its estimated installed capacity, during the top 10% of the peak periods of *total electricity requirement*, over each summer.

Figure 11 Winter peak demand rooftop PV generation duration curve (% of estimated rooftop PV capacity)



3.4 Rooftop PV penetration

Figure 12 shows the rooftop PV contribution to total generation in South Australia over the last five financial years. It highlights that rooftop PV is contributing more each year. Since rooftop PV can only operate during daylight hours, about 50% of the time there is no generation output.

Figure 12 Rooftop PV generation compared to total South Australian generation

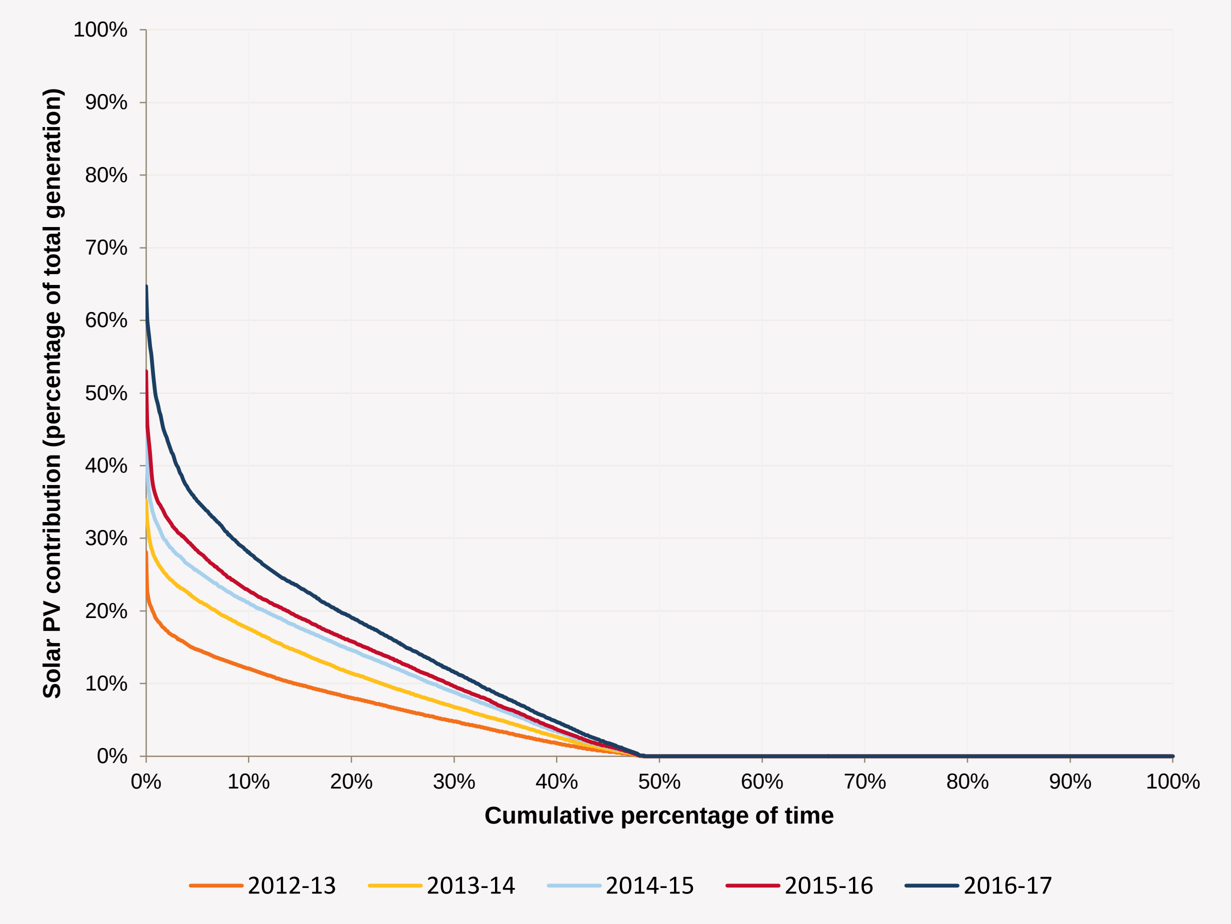


Table 13 sets out the calculations for South Australian estimated rooftop PV penetration using three indices. Corresponding with increases in installed rooftop PV generation capacity, all indices have tended to increase over time.

Table 13 South Australian rooftop PV penetration indices

Description	South Australian value				
	2012–13	2013–14	2014–15	2015–16	2016–17
Capacity penetration: installed capacity as a percentage of total installed generation [A]	8%	10%	11%	13%	14%
Energy penetration: ratio of annual rooftop PV energy to annual total energy consumption	3%	5%	6%	6%	7%
Maximum instantaneous penetration (excluding exports): maximum observed ratio of rooftop PV energy to demand at any instant in time during the year	21%	29%	37%	37%	41%

A. Calculations are based on AEMO registered capacity for all South Australian generating systems at the end of the financial year, with rooftop PV capacity based on estimates as reported in the 2017 SAER. However, excluded are generating units that are effectively mothballed for more than six months of the financial year, and wind farms whose output did not yet reach 90% of registered capacity by end of the financial year.

In 2016–17, maximum instantaneous rooftop PV penetration (ratio of rooftop PV generation to underlying demand[30]) reached 41% during the middle of the day, the highest ratio in the past five years.

[30] In this report, it is estimated to be the sum of operational demand plus rooftop PV generation

4. INTERMITTENCY AND DEMAND VARIATIONS

This section provides statistical information on aggregate wind and rooftop PV generation output variations occurring in response to changing weather conditions. Variation is calculated as the difference in generation between each five-minute dispatch interval (for wind) and each 30-minute dispatch interval (for rooftop PV).

The intermittency of wind and rooftop PV generation, leading to sudden changes in the supply and demand balance, makes managing the power system more challenging.

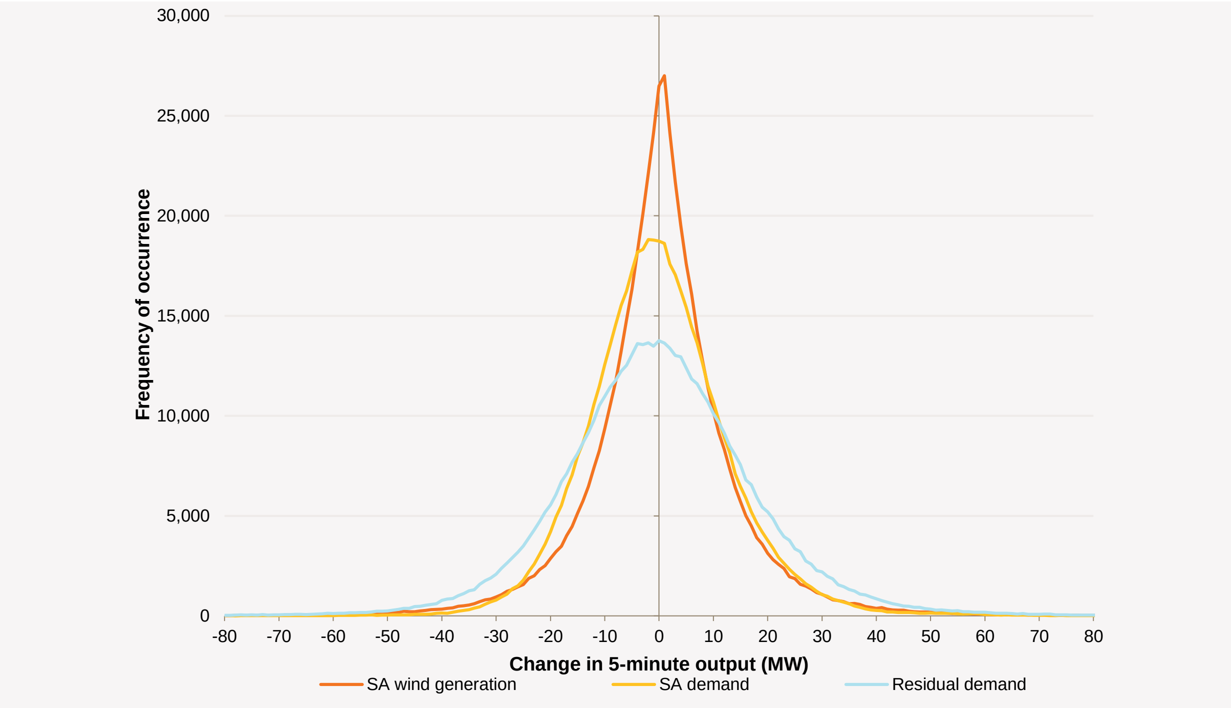
In terms of power system operation, AEMO considers aggregate wind farm generation variation, rather than individual wind farm variation. Geographic diversity across a number of wind farms allows for smoothing, where variation in individual wind farms is partially offset by other nearby wind farms.

Three geographical areas are used across South Australia to facilitate analysis of the impact of geographical diversity: mid-north[31], south-east, and coastal peninsula. The areas are described in Appendix Section A.1, noting that the term “all South Australian wind farms” in this report refers to all semi-scheduled and non-scheduled wind farms in the region.

4.1 Wind, rooftop PV, and demand variation

Figure 13 shows the frequency-of-occurrence distributions for five-minute variations in South Australian wind generation, demand, and their combined effect (residual demand) from 2012–13 to 2016–17. Operationally, this combined variation must be managed by AEMO and network service providers to maintain power system standards.

Figure 13 South Australian wind generation, operational demand, and residual demand from 2012–13 to 2016–17 (variation distribution)



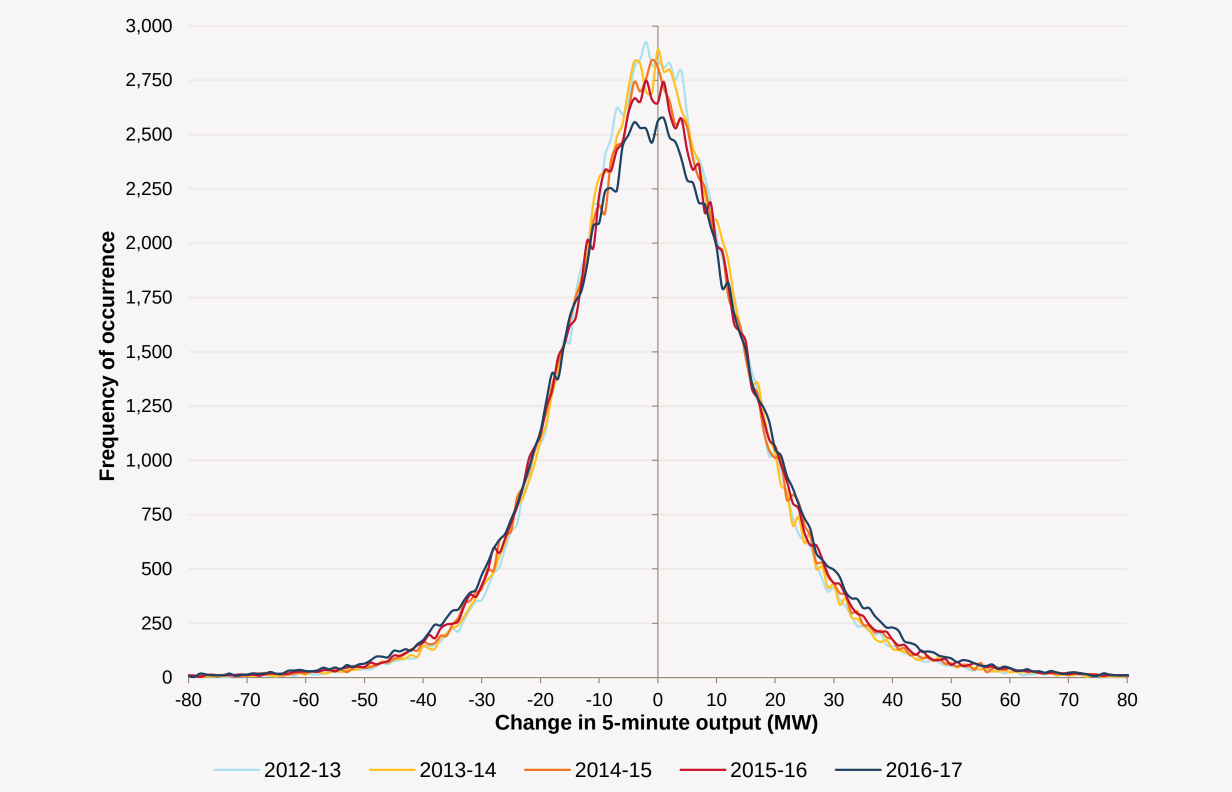
[31] Analysis for the Mid-north area now includes Mount Millar Wind Farm. This is due to a re-assessment of wind farm generation over the last five financial years, which considered correlation between wind farm five-minute generation outputs amongst the areas. In earlier (*South Australian Wind Study*) reports, Mount Millar Wind Farm was not included in areas analysed.

Wider and flatter distributions indicate a higher frequency of larger changes in output between five-minute intervals, while steeper and taller distributions indicate a higher frequency of smaller changes in output. While the wind generation is slightly less variable than South Australian demand (which has rooftop PV variability included), its combined effect on the residual demand is more noteworthy.

This residual demand is met by generation other than wind and rooftop PV, with wider distributions requiring more responsive generating units, which are able to manage large demand variations. Residual demand change can also be met by changes in power flow on the Heywood or Murraylink interconnectors.

Analysis of the residual demand each year from 2012–13 to 2016–17, shown in Figure 14 below, indicates that the distribution has flattened over this period, with fewer changes in the plus or minus 10 MW range, and more changes occurring across larger ranges. This means that, as more wind farms come online, and rooftop PV installations increase, the residual demand changes in South Australia are becoming more variable.

Figure 14 South Australian residual demand (variation distribution)



4.1.1 Wind variation across geographical areas

Figure 15 presents key statistical information about five-minute and 10-minute wind generation variation for the mid-north[32], south-east, and coastal peninsula areas in South Australia, and all South Australian wind farms in aggregate, for 2016–17. Appendix Section A.3 shows tables of the statistics for 2015–16 and 2016–17.

[32] Analysis for the mid-north area now includes Mount Millar Wind Farm; in earlier (South Australian Wind Study) reports, Mount Millar Wind Farm was not included in areas analysed. This is due to a re-assessment of wind farm generation over the last five financial years, which considered correlation between wind farm five-minute generation outputs among the areas.

In 2016–17, the mean five-minute variation for all South Australian wind farms in aggregate was 11 MW, and the maximum variation was 763 MW.

Key observations from Figure 15 are:

- Wind generation variation differed by area. For 90% of the time, the variation across a 10-minute period for south-east area was no more than 6% of registered capacity, whereas total South Australian absolute wind generation variation was no more than 2.6%.
- The mean was higher than the median for all areas and all South Australian wind farms, indicating that while occurrences were skewed toward the lower values, larger fluctuations (though less frequent) did exist.

Figure 15 Five-minute and 10-minute absolute wind generation variation for 2016–17

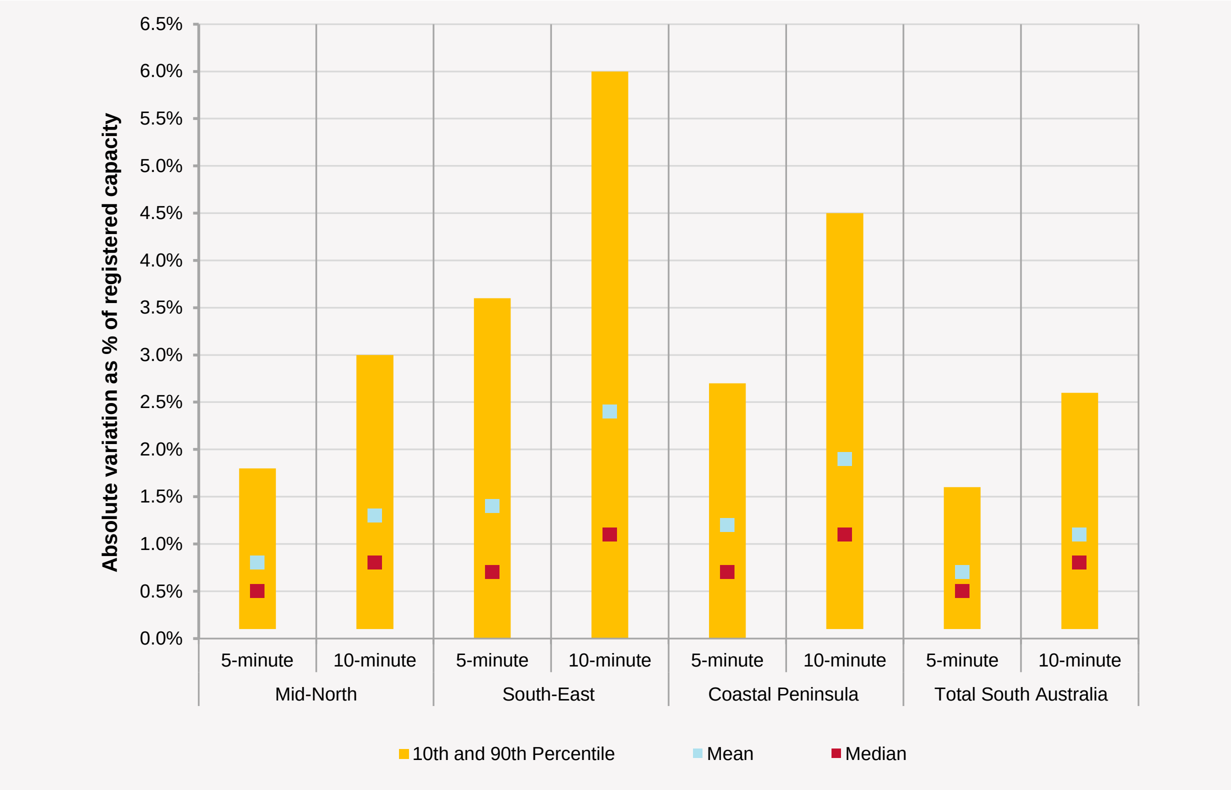
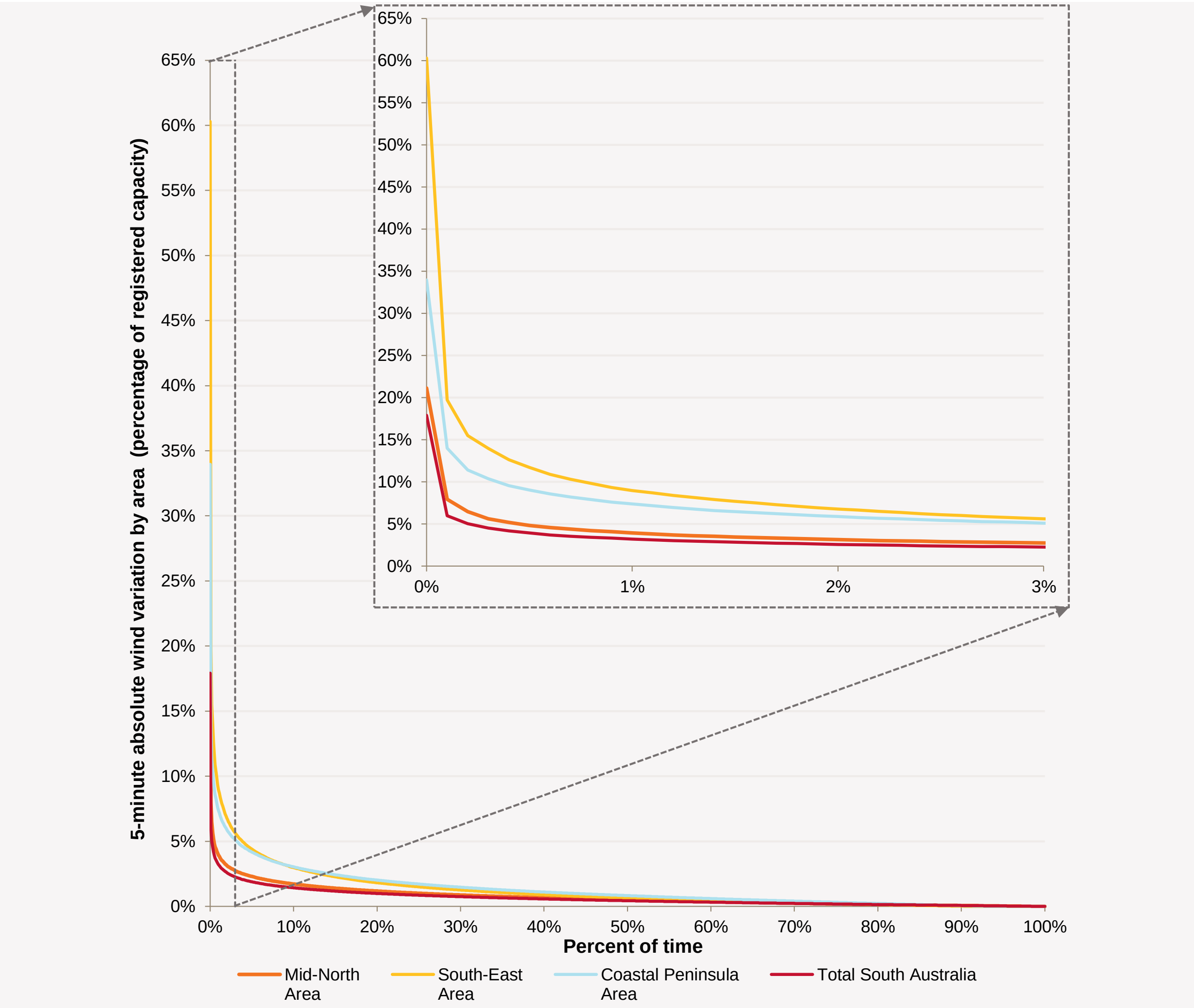


Figure 16 shows the full distribution of the five-minute absolute wind generation variation for the mid-north, south-east, and coastal peninsula areas, and all South Australian wind farms, for 2016–17.

Key observations are:

- South Australian wind farms in aggregate had lower absolute wind variation than the individual areas, indicating that greater wind generation geographical diversity led to lower absolute wind variation.
- The coastal peninsula had the highest absolute wind variation of the three areas for around 80% of the time. The south-east had the highest absolute wind variation around 8.7% of the time.
- In the south-east area, a maximum wind farm variation of 60.3% was observed from one five-minute period to another.

Figure 16 Absolute wind variation as percentage of registered capacity



4.1.2 Maximum wind generation increase and decrease

Table 14 below shows variations in wind generation for three operational timeframes (five-minute, 30-minute, and 60-minute) for the three geographical areas and all South Australian wind farms in aggregate, from 2012–13 to 2016–17.

Variations at the 30-minute and 60-minute timeframe are larger than within the five-minute timeframe.

South Australian wind farm variations from 2012–13 to 2016–17 show differences year on year, which can be attributed to seasonal variations in wind speeds, as well as increases in capacity.

Table 14 Total registered capacity and historical maximum variation outputs (MW) by area

Area		2012–13	2013–14	2014–15	2015–16	2016–17
Mid-north	Registered capacity	688	958	958	958	1,182
	Max. 5-minute increase	117	140	170	202	195
	Max. 5-minute decrease	122	129	248	200	546
	Max. 30-minute increase	275	367	410	366	502
	Max. 30-minute decrease	223	381	381	373	656
	Max. 60-minute increase	404	434	539	483	540
	Max. 60-minute decrease	279	449	416	466	853
South-east	Registered capacity	325	325	325	325	325
	Max. 5-minute increase	142	166	169	196	188
	Max. 5-minute decrease	158	149	148	174	213
	Max. 30-minute increase	275	273	291	294	296
	Max. 30-minute decrease	264	268	266	253	314
	Max. 60-minute increase	278	268	297	294	316
	Max. 60-minute decrease	286	277	287	302	314
Coastal peninsula	Registered capacity	191	191	191	191	191
	Max. 5-minute increase	47	65	57	51	58
	Max. 5-minute decrease	74	70	61	65	71
	Max. 30-minute increase	94	119	93	89	91
	Max. 30-minute decrease	136	103	89	104	104
	Max. 60-minute increase	104	126	113	110	127
	Max. 60-minute decrease	136	132	91	117	103
All South Australia	Registered capacity	1,203	1,473	1,473	1,473	1,698
	Max. 5-minute increase	152	162	177	236	248
	Max. 5-minute decrease	193	166	215	264	763
	Max. 30-minute increase	369	406	408	461	502
	Max. 30-minute decrease	325	442	400	534	963
	Max. 60-minute increase	489	566	548	571	607
	Max. 60-minute decrease	414	490	456	506	1,168

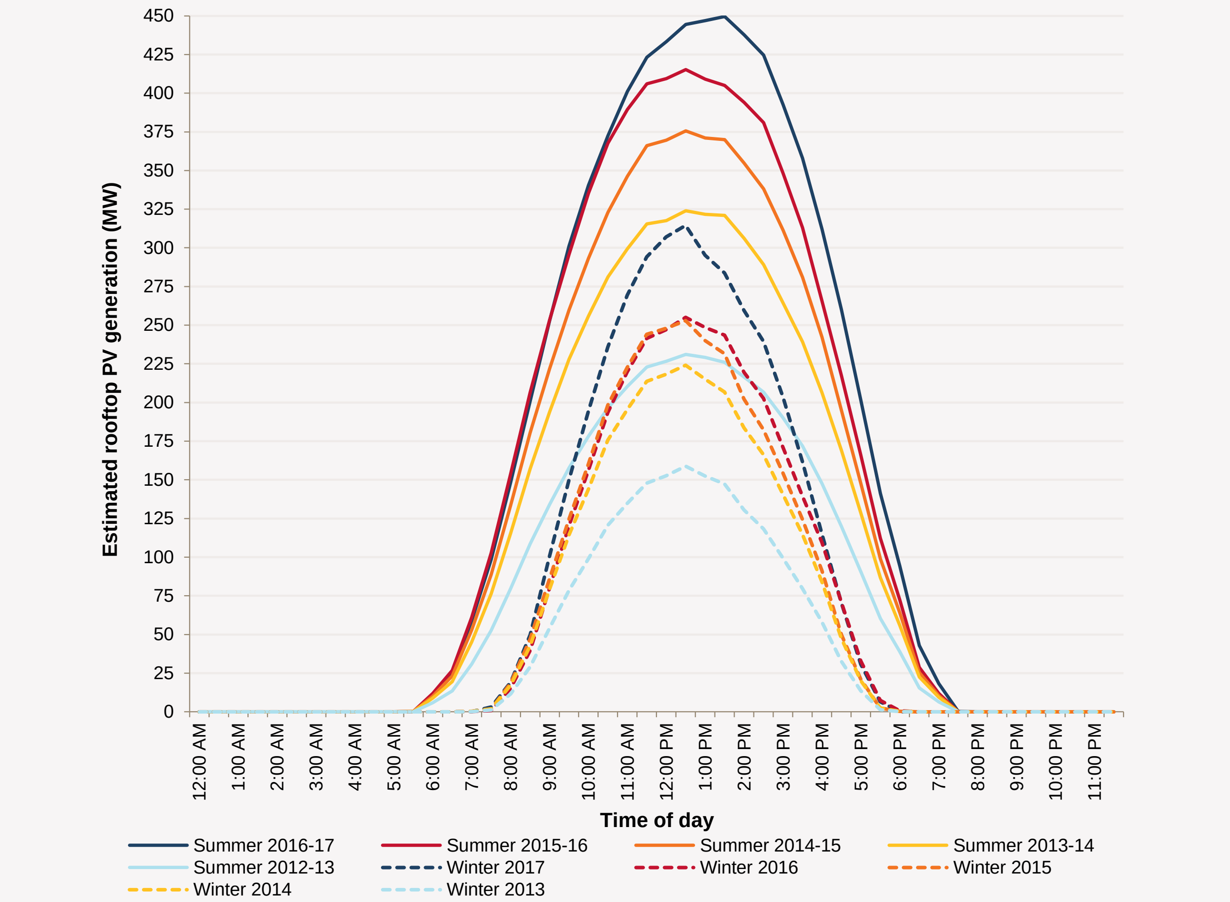
4.2 Rooftop PV variation

Figure 17 shows the average daily profile for estimated South Australian rooftop PV generation for the last five summers and winters. Wider and flatter distributions indicate a higher frequency of larger changes in output between 30-minute intervals, while steeper and taller distributions indicate a higher frequency of smaller changes in output.

The figure shows there has been greater generation in the summer months, due to longer daylight hours and greater solar irradiance. The maximum average rooftop PV output in summer is 450 MW, which is 135 MW higher than winter.

The increase across financial years is a function of growth in rooftop PV installed capacity. This growth is shifting the timing of maximum operational peak demand to later in the day.

Figure 17 Daily estimated rooftop PV generation profile



4.2.1 Maximum rooftop PV generation increase and decrease

Analysis of summer and winter daily generation profiles shows the rate of change in generation, particularly during mornings and evenings, increasing year on year, concurrent with growth in installed capacity.

Table 15 shows the estimated historical maximum variation in outputs in the last five years. In 2016–17, South Australian estimated rooftop PV generation varied by up to 190 MW (24.3% of estimated capacity) across 30-minute periods.

Table 15 Total installed capacity and estimated historical maximum variation outputs (MW)

	2012–13	2013–14	2014–15	2015–16	2016–17
Installed capacity	402	539	613	686	781
Max. 30-minute increase	64	236	109	244	190
Max. 30-minute decrease	80	251	118	192	188

4.3 Wind forecast performance

This section presents information on the forecast accuracy of the Australian Wind Energy Forecasting System (AWEFS) for South Australian wind farms.

Under National Electricity Rules clause 3.7B(a), AEMO is required to prepare forecasts of the available capacity of semi-scheduled generation for the purposes of projected assessment of system adequacy, dispatch and pre-dispatch (see explanations of these terms below).

This system aims to improve the efficiency of overall NEM dispatch. Greater AWEFS accuracy results in more accurate and efficient scheduling of other forms of generation.

South Australia has the highest wind penetration in the NEM, so AWEFS accuracy in forecasting South Australian wind generation may affect the market by contributing to determination of pre-dispatch levels at different forecast time horizons.

AWEFS produces wind generation forecasts for all NEM semi-scheduled and significant non-scheduled wind farms, for all NEM forecasting timeframes:

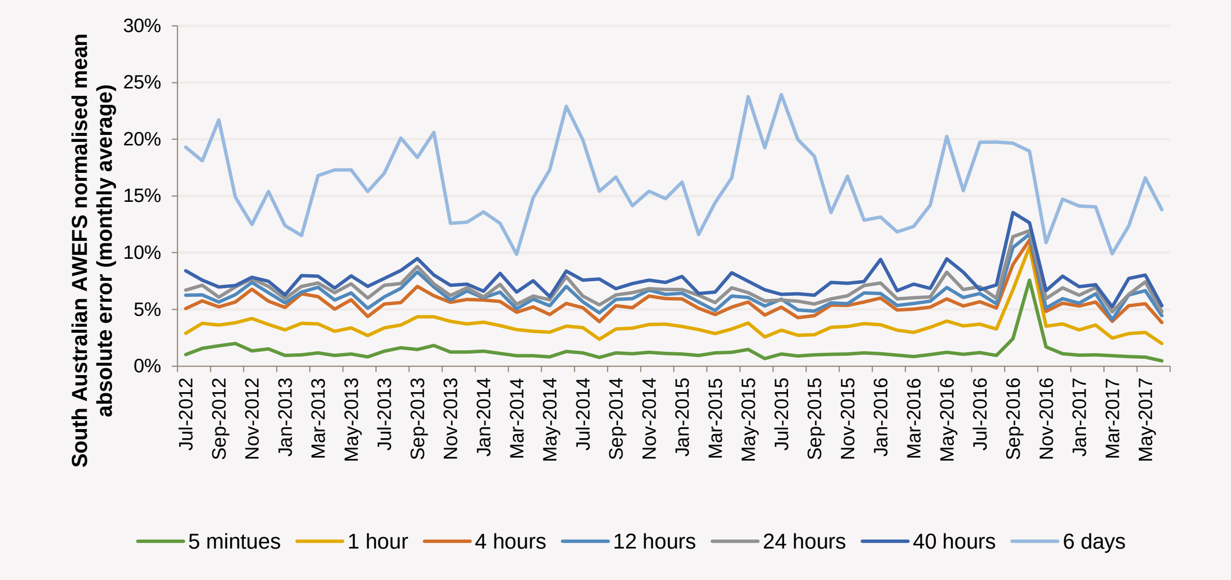
- Dispatch (five minutes ahead).
- Five-minute pre-dispatch (five-minute resolution, one hour ahead).
- Pre-dispatch (30-minute resolution, up to 40 hours ahead).
- Short-term Projected Assessment of System Adequacy (ST PASA) (30-minute resolution, seven days ahead).
- Medium-term Projected Assessment of System Adequacy (MT PASA) (daily resolution, two years ahead).[33]

AWEFS accuracy is most commonly measured as the normalised mean absolute error (NMAE) of the forecast. The NMAE is calculated as the absolute difference between forecast and actual output, divided by the nominal capacity.

AEMO monitors AWEFS accuracy for compliance with performance standards on a NEM aggregate level. Performance standards are also monitored at regional level, although this is not mandated.

Figure 18 shows monthly average NMAE figures of the AWEFS forecasts for South Australian wind farms over a five-year period.

Figure 18 Normalised mean absolute error of AWEFS forecasts for South Australia from 2012–13 to 2016–17



[33] Further information available at: https://aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Solar-and-wind-energy-forecasting.

Forecast accuracy decreases as the forecast horizon extends, corresponding with the decreasing accuracy of the input weather models. Uncharacteristic NMAE values occurred around September 2016, due to the South Australian black system event.

The Energy Conversion Model (ECM) Guidelines define the static and dynamic information that semi-scheduled generators provide to AEMO for use in AWEFS and ASEFS. Formal consultation[34] on amendments to the ECM Guidelines for wind and solar farms was completed in late 2016, after which the ECM Guidelines were updated. AEMO held a stakeholder meeting in early 2017 to progress implementation of the changes to the ECM.

These amendments were designed to increase accuracy of the AWEFS dispatch forecast by:

- Adding a new Supervisory Control and Data Acquisition (SCADA) signal for generators to communicate any local limitations to their capacity.
- Adding a new SCADA signal for generators to communicate any wind turbines being in high wind speed cut-out.
- Refining the definition of the Wind Speed SCADA signal, to recommend the use of a reading that is an average of all turbine wind speeds.

AEMO continues to work with stakeholders to improve AWEFS dispatch forecasts by improving or implementing new SCADA signals.

[34] Further information available at: http://aemo.com.au/Stakeholder-Consultation/Consultations/Energy-Conversion-Model-Guidelines-Consultation---Wind-and-Solar-Farms

5. RENEWABLE GENERATION AND MARKET PRICES

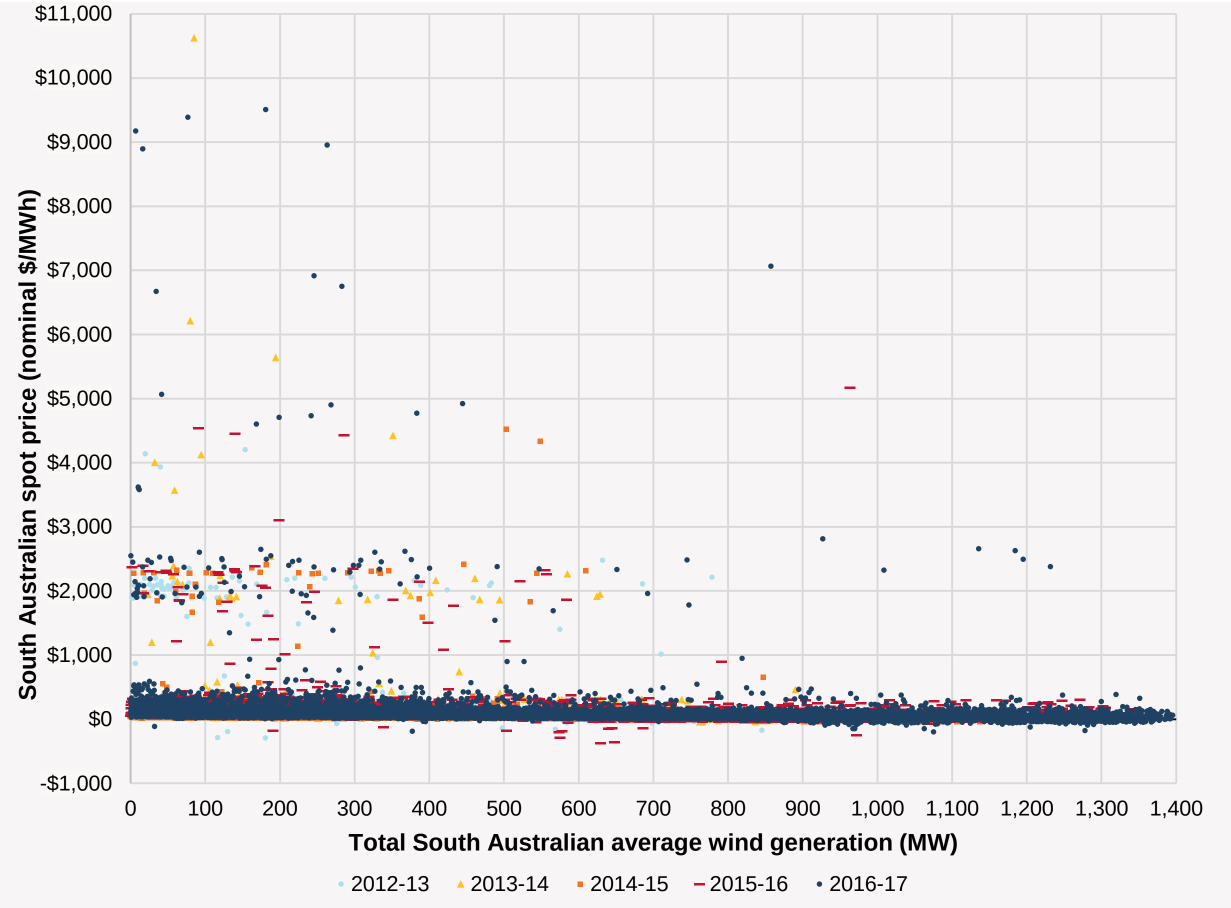
This section provides information on wind and rooftop PV generation and market prices in South Australia. More general market pricing information is available in the 2017 SAHMIR[35].

Figure 19 and Figure 20 plot South Australian average wind generation and estimated rooftop PV against spot prices for all periods over the past five financial years. All prices are in nominal dollars unless otherwise indicated.

Market prices are not typically set by renewable generators, however, the volume of wind and rooftop PV generation does have some influence on spot prices. High spot prices are generally happening at times with low wind output. Negative prices were most likely to occur when wind generation was high.

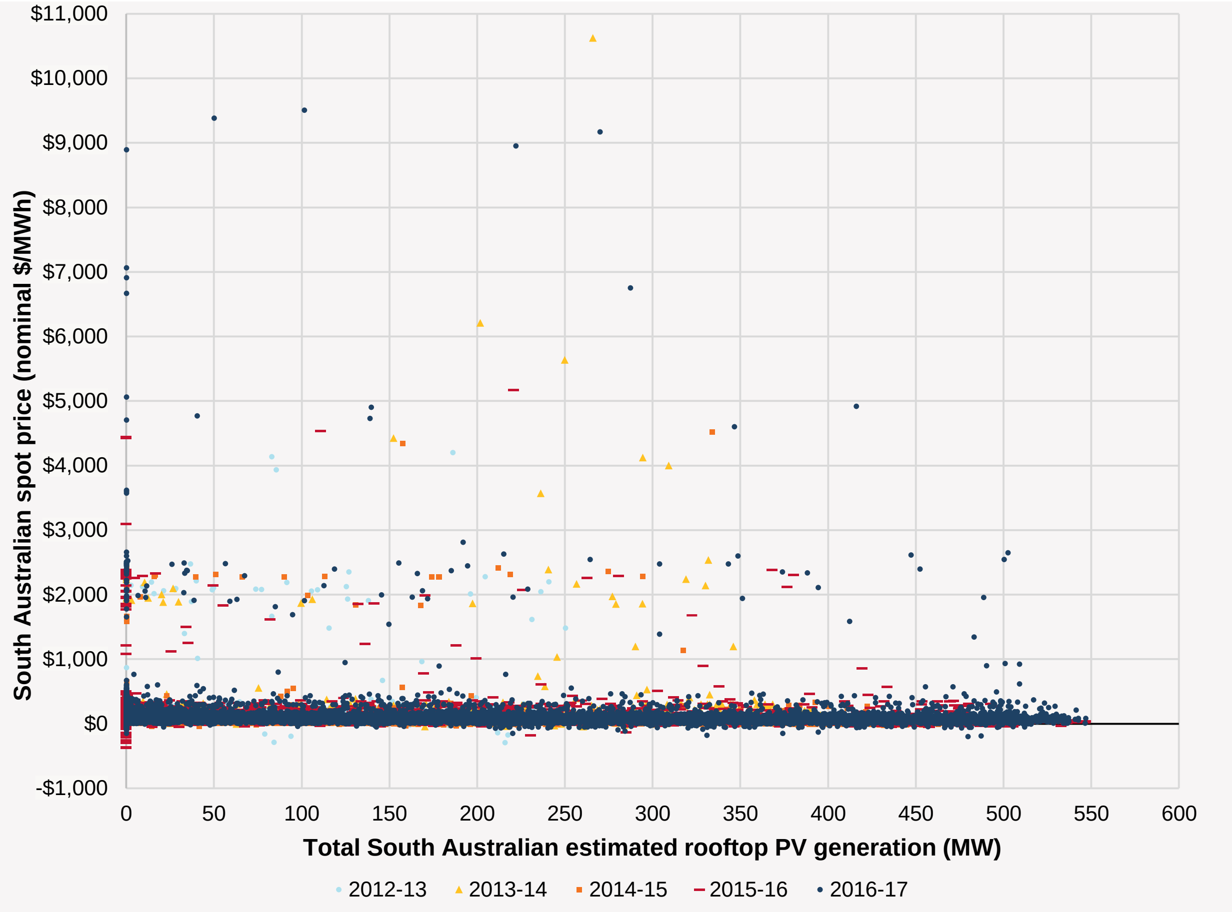
Separate analysis on positive and negative prices is provided in sections 5.1.1 and 5.1.2 respectively.

Figure 19 South Australian average wind generation and spot prices (30-minute data for 2012–13 to 2016–17)



[35] AEMO. 2016 South Australian Historical Market Information Report. Available at: http://aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/South-Australian-Advisory-Functions.

Figure 20 South Australian estimated rooftop PV generation and spot prices (30-minute data for 2012–13 to 2016–17)



5.1.1 Positive spot price trading intervals

Figures 21 and 22 show spot prices for the South Australian region, and the corresponding average wind and estimated rooftop PV generation levels, for each 30-minute dispatch interval from 2012–13 to 2016–17. Spot prices are plotted on a logarithmic axis to better represent the variance.

The volume-weighted average spot price (in nominal dollars) for South Australia wind generation over each 12-month period is also displayed (as a horizontal line) on each graph for reference.

Excluding very high and very low prices, Figure 21 illustrates that:

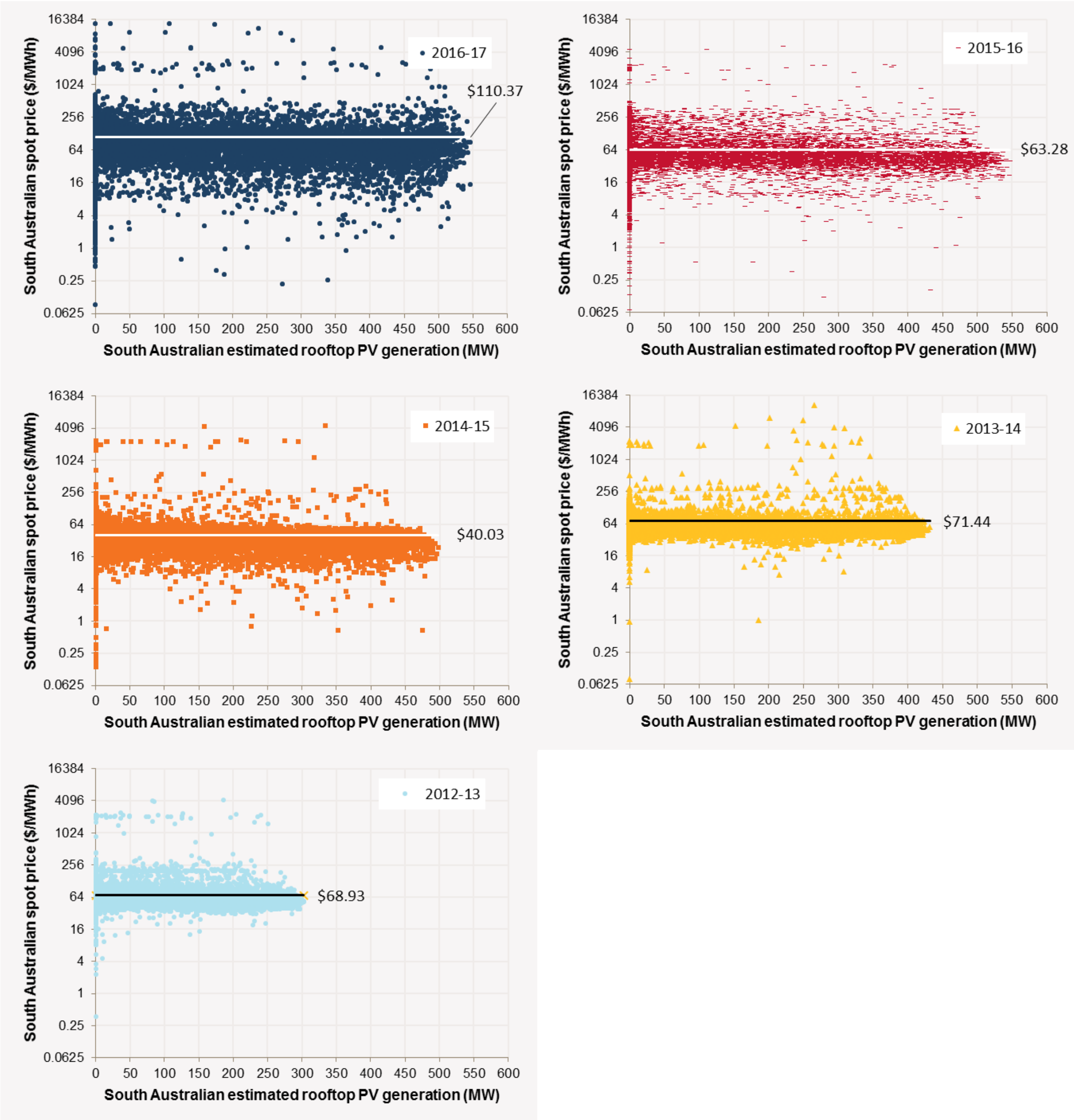
- Most prices cluster around the mean, and decrease as wind generation output increases.
- Very high prices tend to occur when wind generation is low, while low prices tend to occur when wind generation is high.

In contrast, Figure 22 does not show any correlation between price and the generation level of rooftop PV.

Figure 21 South Australian 30-minute spot prices and average wind generation (positive market prices)

Note: Logarithmic axis

Figure 22 South Australian 30-minute spot prices and estimated rooftop PV generation (positive market prices)



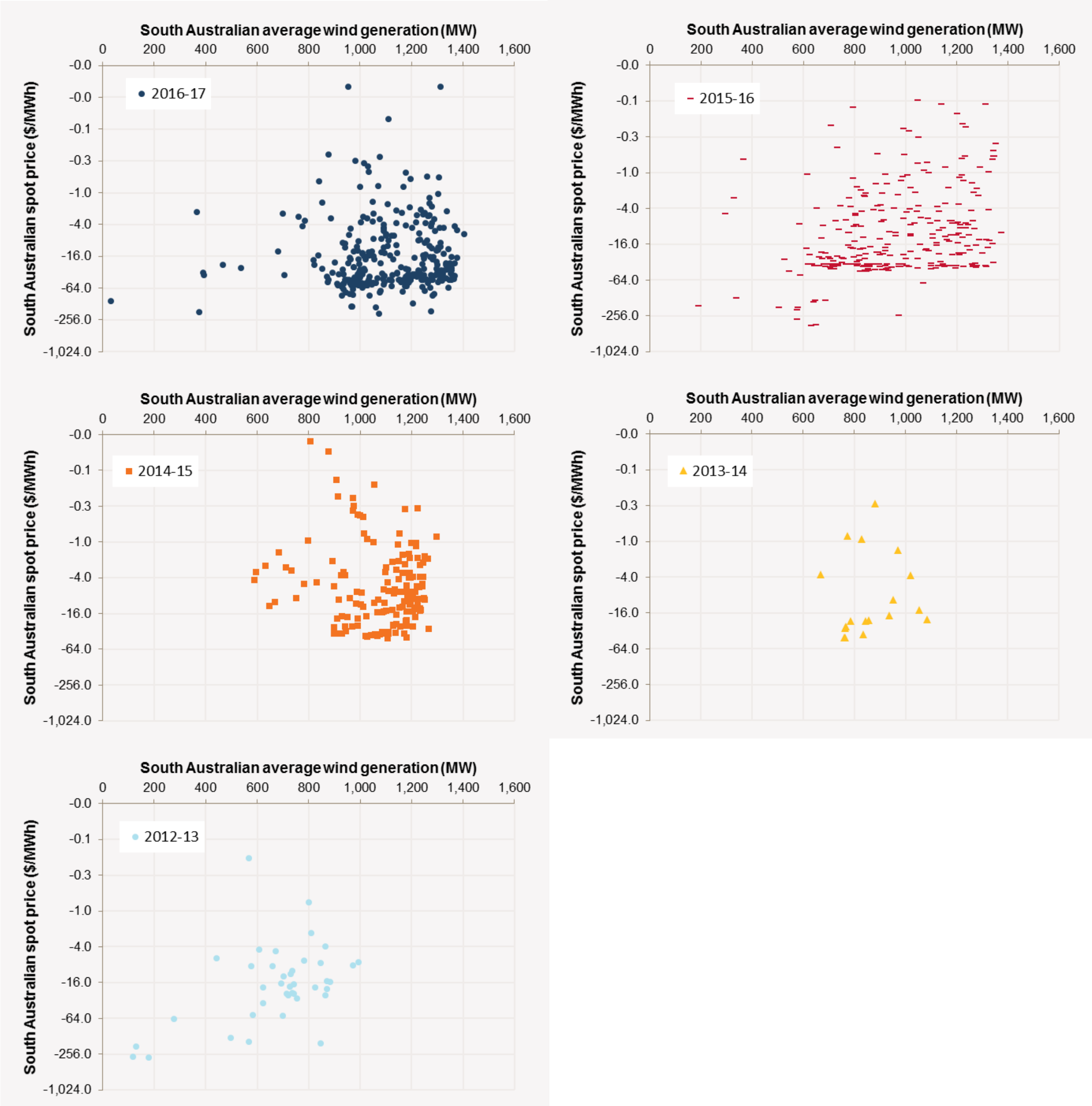
Note: Logarithmic axis

5.1.2 Negative spot price trading intervals

Figure 23 and Figure 24 show only the negative spot prices for the South Australian region, and the corresponding average wind and estimated rooftop PV generation levels, for each 30-minute dispatch interval from 2012–13 to 2016–17. Spot prices are again plotted on a logarithmic axis to better represent the variance.

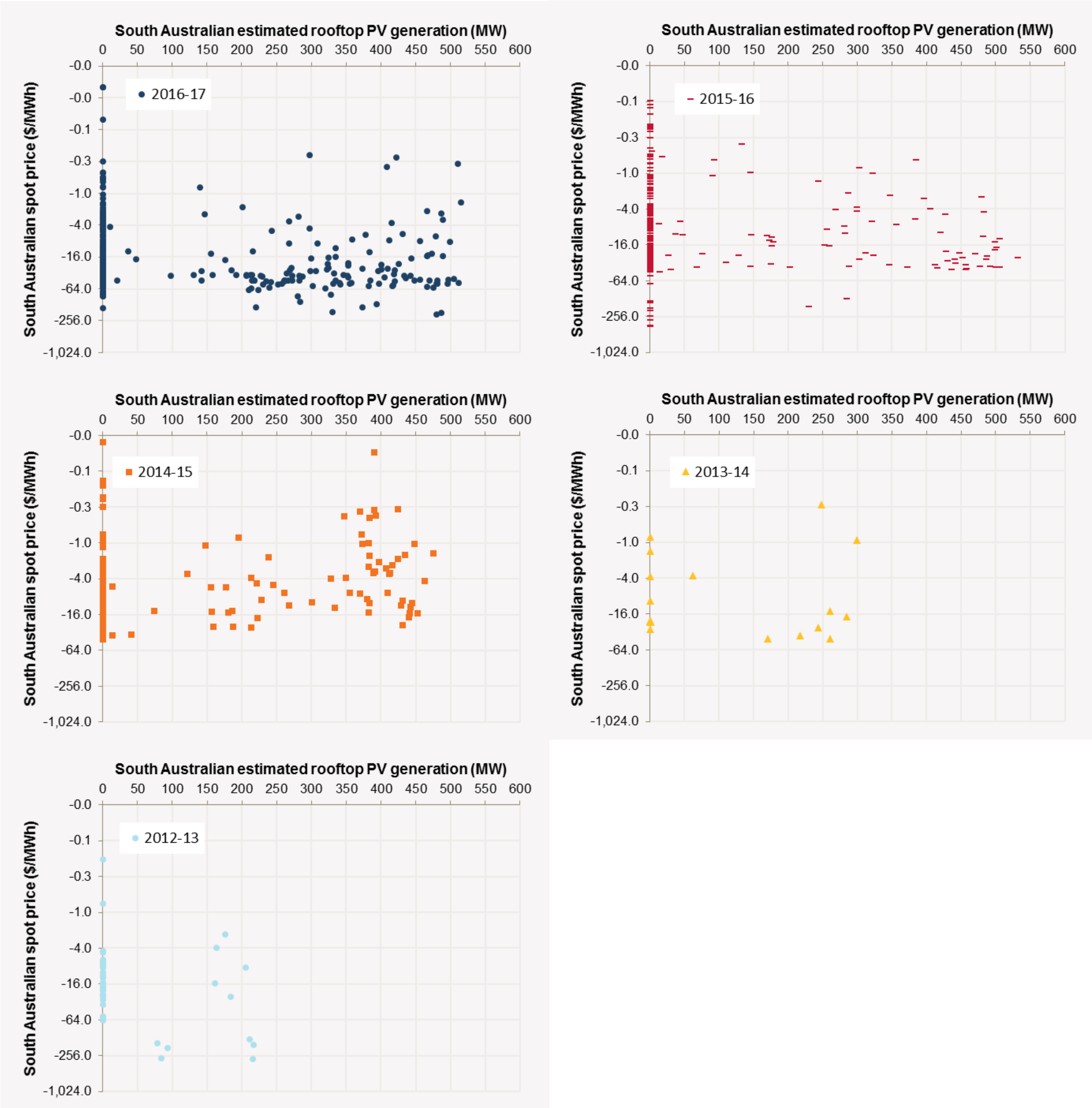
The number of negative spot prices has increased since 2014–15. A correlation is observed between the occurrences of negative prices at times of higher levels of wind generation. Negative prices also often occurred overnight when there was no rooftop PV generation, as discussed after the figures.

Figure 23 South Australian 30-minute spot prices and average wind generation (negative market prices)



Note: Logarithmic axis

Figure 24 South Australian 30-minute spot prices and estimated rooftop PV generation (negative market prices)



Note: Logarithmic axis

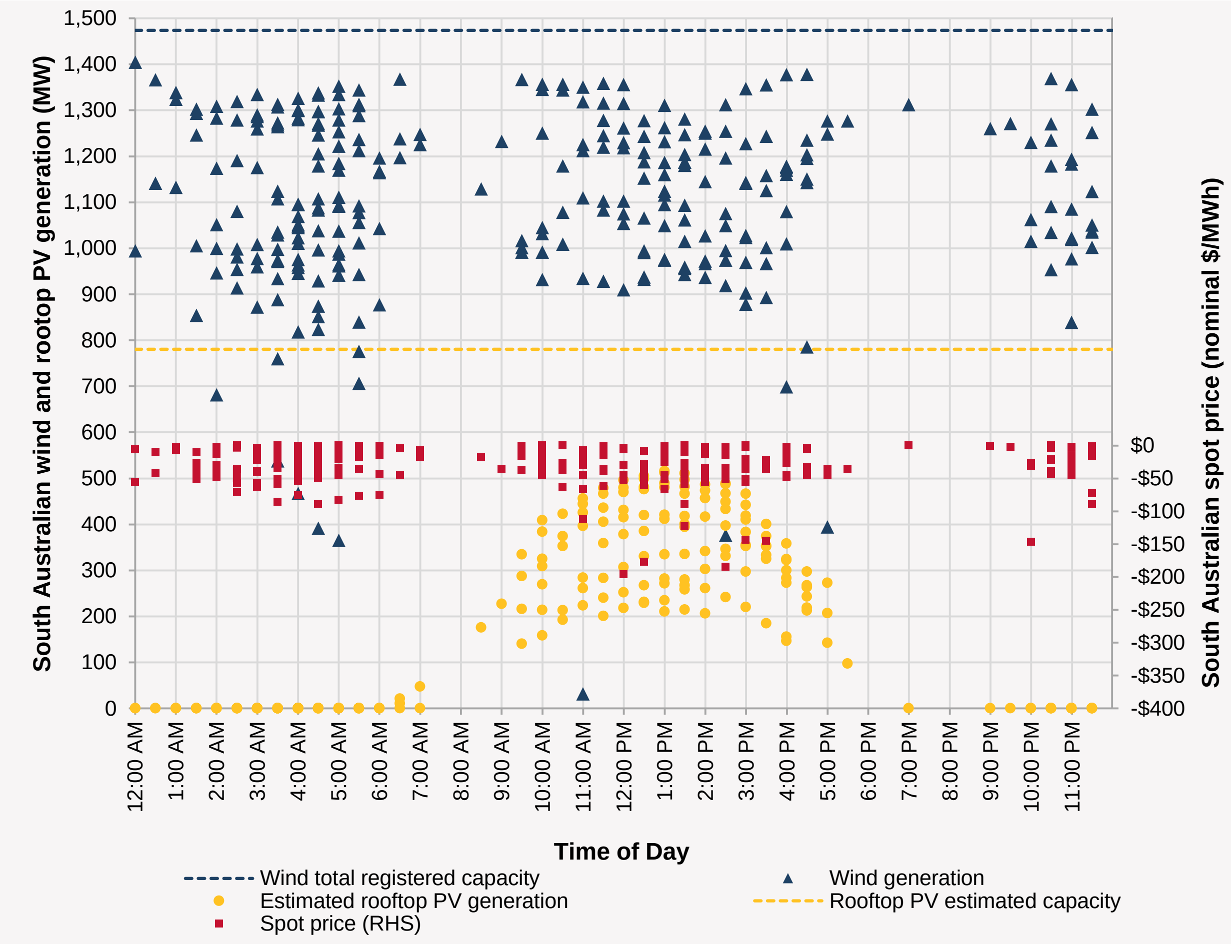
Negative spot prices by time of day

Figure 25 shows the time of day and wind generation level[36] for negative spot prices in 2016–17.

Most negative spot prices occurred either early in the morning, when wind generation was relatively high, or during the middle of the day when high wind generation coincides with rooftop PV generation at the peak of daylight hours.

[36] Five-minute wind generation data, averaged across the 30-minute interval.

Figure 25 Negative South Australian spot price, average wind and rooftop PV generation by time of day (2016–17)



Note: Wind total registered capacity excludes Hornsdale stage 1 (102.4 MW) as it was registered late in the financial year and had no material contribution to the analysis.

APPENDIX A. WIND FARM STATISTICS

A.1 Wind farm capacities

Table 16 Registered capacities of South Australian wind farms

Wind farm	Dispatchable unit identifier (DUID)	Registered capacity (MW)[A]	Classification	Area for SARER analysis
Canunda Wind Farm	CNUNDAWF	46	Non-scheduled	South-east
Cathedral Rocks Wind Farm	CATHROCK	66	Non-scheduled	Coastal peninsula
Clements Gap Wind Farm	CLEMGPWF	57	Semi-scheduled	Mid-north
Hallett 1 (Brown Hill)	HALLWF1	94.5	Semi-scheduled	Mid-north
Hallett 2 (Hallett Hill)	HALLWF2	71.4	Semi-scheduled	Mid-north
Hallett 4 (North Brown Hill Wind Farm)	NBHWF1	132.3	Semi-scheduled	Mid-north
Hallett 5 (The Bluff) Wind Farm	BLUFF1	52.5	Semi-scheduled	Mid-north
Hornsdale Stage 1 Wind Farm	HDWF1	102.4	Semi-scheduled	Mid-north
Hornsdale Stage 2 Wind Farm	HDWF2	102.4	Semi-scheduled	Mid-north
Lake Bonney 2	LKBONNY2	159	Semi-scheduled	South-east
Lake Bonney 3	LKBONNY3	39	Semi-scheduled	South-east
Lake Bonney Wind Farm	LKBONNY1	80.5	Non-scheduled	South-east
Mount Millar Wind Farm	MTMILLAR	70	Non-scheduled	Mid-north[B]
Snowtown Stage 2 Wind Farm North	SNOWNTH1	144	Semi-scheduled	Mid-north
Snowtown Stage 2 Wind Farm South	SNOWSTH1	126	Semi-scheduled	Mid-north
Snowtown Wind Farm	SNOWTWN1	99	Semi-scheduled	Mid-north
Starfish Hill Wind Farm	STARHLWF	34.5	Non-scheduled	Coastal peninsula
Waterloo Wind Farm	WATERLWF	131	Semi-scheduled	Mid-north
Wattle Point Wind Farm	WPWF	90.75	Non-scheduled	Coastal peninsula

A. Registered capacity sourced from AEMO's NEM Registration and Exemption List, 28 September 2017. Available: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Participant-information/Current-participants/Current-registration-and-exemption-lists.

B. Mount Millar Wind Farm has been reclassified to the mid-north analysis area – it was not included in area analysis in the 2015 *South Australian Wind Study Report*.

A.2 Wind farm capacity factors

Table 17 Financial year capacity factors of South Australian wind farms

Wind farm	Schedule type	DUID	2012–13	2013–14	2014–15	2015–16	2016–17
			Capacity factor (%)	Capacity factor (%)	Capacity factor (%)	Capacity factor (%)	Capacity factor (%)
Canunda	Non-scheduled	CNUNDAWF	28.2	31.0	29.3	27.9	27.9
Cathedral Rocks	Non-scheduled	CATHROCK	30.3	34.0	29.4	29.1	26.1
Clements Gap	Semi-scheduled	CLEMGPWF	33.4	36.0	33.8	34.6	31.7
Hallett 1 (Brown Hill)	Semi-scheduled	HALLWF1	40.1	42.2	37.2	37.8	33.6
Hallett 2 (Hallett Hill)	Semi-scheduled	HALLWF2	41.0	40.9	37.3	38.7	34.9
Hallett 4 (North Brown Hill)	Semi-scheduled	NBHWF1	36.7	40.8	36.2	38.3	33.1
Hallett 5 (The Bluff)	Semi-scheduled	BLUFF1	33.8	36.4	29.6	32.6	26.6
Hornsdale Stage 1	Semi-scheduled	HDWF1					38.2
Hornsdale Stage 2	Semi-scheduled	HDWF2					25.8
Lake Bonney	Non-scheduled	LKBONNY1	27.0	29.2	27.2	25.8	25.7
Lake Bonney Stage 2	Semi-scheduled	LKBONNY2	27.2	29.7	28.4	27.4	27.5
Lake Bonney Stage 3	Semi-scheduled	LKBONNY3	27.8	29.0	27.4	27.1	27.9
Mount Millar	Non-scheduled	MTMILLAR	30.2	33.3	30.5	29.8	26.2
Snowtown	Semi-scheduled	SNOWTWN1	43.1	44.7	38.4	39.2	34.9
Snowtown Stage 2[A]	Semi-scheduled	SNOWNTH1 and SNOWSTH1	0.0	52.5	34.9	37.0	34.2
Starfish Hill	Non-scheduled	STARHLWF	22.6	31.3	28.4	28.5	19.8
Waterloo	Semi-scheduled	WATERLWF	32.0	34.8	30.1	30.7	28.2
Wattle Point	Non-scheduled	WPWF	31.2	37.0	33.3	33.8	29.3

Data taken from the 2017 SAHMIR. Available at: http://aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/South-Australian-Advisory-Functions.
A. Snowtown Stage 2 capacity factor is calculated for Snowtown Stage 2 North and Snowtown Stage 2 South wind farms combined.

A.3 Wind generation variation

Table 18 Key statistical characteristics of wind generation variation for 2016–17

	South Australian wind farm area								
	Mid-north		South-east		Coastal peninsula		Total South Australia		
	5-minute	10-minute	5-minute	10-minute	5-minute	10-minute	5-minute	10-minute	30-minute
Key statistical characteristics of absolute variation (% of registered capacity)									
Mean	0.8	1.3	1.4	2.4	1.2	1.9	0.7	1.1	2.4
Median	0.5	0.8	0.7	1.1	0.7	1.1	0.5	0.8	1.7
Standard deviation	1.0	1.5	2.4	3.9	1.5	2.5	0.8	1.3	2.5
Key statistical characteristics of absolute variation (megawatt equivalent)									
Mean	8.5	13.7	4.7	7.8	2.2	3.6	11	18.1	38.6
Median	5.3	8.8	2.1	3.5	1.3	2.1	7.1	11.9	26.8
Standard deviation	10.6	16.3	7.8	12.8	2.9	4.7	13.1	20.5	39.9
Absolute variation (%)									
90th percentile	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.2
10th percentile	1.8	3.0	3.6	6.0	2.7	4.5	1.6	2.6	5.6
5th percentile	2.5	4.0	5.5	9.2	3.8	6.3	2.2	3.5	7.3
1st percentile	4.5	7.1	11.6	19.3	7.0	11.6	3.9	6.1	11.6
Maximum	51.5	61.9	65.7	92.9	37.3	51.3	48.4	61.1	61.1

Table 19 Key statistical characteristics of wind generation variation for 2015–16

	South Australian wind farm area								
	Mid-north		South-east		Coastal peninsula		Total South Australia		
	5-minute	10-minute	5-minute	10-minute	5-minute	10-minute	5-minute	10-minute	30-minute
Key statistical characteristics of absolute variation (% of registered capacity)									
Mean	0.7	1.3	1.2	2.2	1.3	2.1	0.6	1.1	2.5
Median	0.5	0.9	0.6	1.1	0.8	1.3	0.4	0.8	1.8
Standard deviation	0.9	1.5	1.9	3.3	1.6	2.5	0.7	1.2	2.4
Key statistical characteristics of absolute variation (megawatt equivalent)									
Mean	7.2	12.6	4.0	7.0	2.5	4.1	9.4	16.4	36.5
Median	4.8	8.4	2.1	3.6	1.6	2.6	6.4	11.3	25.9
Standard deviation	8.3	14.2	6.2	10.6	3.0	4.9	10.2	17.4	36.1
Absolute variation									
90th percentile	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.3
10th percentile	1.7	3.0	3.0	5.2	3.0	5.0	1.4	2.5	5.6
5th percentile	2.3	4.0	4.4	7.8	4.2	6.9	1.9	3.3	7.3
1st percentile	3.9	6.8	9.0	15.7	7.4	12.0	3.2	5.4	11.1
Maximum	21.1	31.3	60.3	74.7	34.0	46.6	17.9	30.7	36.2

MEASURES AND ABBREVIATIONS

Units of measure

Abbreviation	Unit of measure
$	Australian dollar
GWh	gigawatt hour
hr	hour
kW	kilowatt
MW	megawatt
MWh	megawatt hour

Abbreviations

Abbreviation	Expanded name
AEMO	Australian Energy Market Operator
ASEFS	Australian Solar Energy Forecasting System
AWEFS	Australian Wind Energy Forecasting System
DUID	Dispatchable unit identifier
ECM	Energy Conversion Model
ESOO	Electricity Statement of Opportunities
MT PASA	Medium-term Projected Assessment of System Adequacy
NEM	National Electricity Market
NER	National Electricity Rules
NMAE	Normalised Mean Absolute Error
PV	Photovoltaic
RRP	Regional Reference Price
SAER	South Australian Electricity Report
SAHMIR	South Australian Historical Market Information Report
SAWSR	South Australian Wind Study Report
SCADA	Supervisory Control and Data Acquisition
ST PASA	Short-term Projected Assessment of System Adequacy

GLOSSARY

The 2017 SARER uses many terms that have meanings defined in the National Electricity Rules (NER). The NER meanings are adopted unless otherwise specified. Other key terms used in the 2017 SARER are listed below.

Term	Definition
Absolute variation	The total variation, regardless of whether it is positive (an increase) or negative (a decrease).
ASEFS	Australian Solar Energy Forecasting System. An AEMO system that produces solar generation forecasts for large solar power stations.
AWEFS	Australian Wind Energy Forecasting System. A system used by AEMO to produce wind generation forecasts ranging from five minutes ahead to two years ahead.
Capacity penetration	The ratio of registered wind capacity to registered total generation capacity, excluding generating units that were effectively mothballed for at least the last six months of the financial year in consideration. This gives a relative measure of wind generation potential compared to the rest of the generating systems.
Cleared supply	The National Electricity Market Dispatch Engine (NEMDE) dispatches generation at five-minute intervals. Cleared Supply represents the dispatched supply values.
Energy penetration	The ratio of annual wind generation to annual total consumption from the grid (excludes any net interconnector exports).
Maximum demand	An absolute value (MW) of demand, observed to be the maximum during a specified time period. Generally the maximum demand is the maximum over an annual or summer period, though any period (e.g. daily) can be defined.
Maximum instantaneous penetration	The maximum observed ratio of wind generation output to demand during the year. This captures the extreme of wind generation relative to other generation, including interconnector exports.
Maximum possible instantaneous penetration	The ratio of maximum possible wind generation output (registered capacity) to minimum demand, assuming zero interconnector exports. Wind capacity is the total registered at the time of minimum demand during the year.
Minimum demand	An absolute value (MW) of demand, the lowest amount of electrical power delivered, or forecast to be delivered, over a defined period (day, week, month, season, or year).
MT PASA	Medium-term Projected Assessment of System Adequacy. The projected assessment of system adequacy covering two years and in a daily resolution.
Mothballed	A generation unit that has been withdrawn from operation but may return to service at some point in the future.
Nameplate capacity	The maximum continuous output or consumption in MW of an item of equipment as specified by the manufacturer, or as subsequently modified.
Operational	Operational reporting includes the electrical energy used by all residential, commercial, and large industrial consumption, and transmission losses (as supplied by scheduled, semi-scheduled and significant non-scheduled generating units). Significant non-scheduled generating units in South Australia are Angaston, Port Stanvac 1, Port Stanvac 2 and all non-scheduled wind farms. It does not include the output of small non-scheduled generating systems, typically less than 30 MW capacity.
Peak demand	The time period over which demand is observed to peak above a nominal value, during the total time period specified.
SCADA	Supervisory Control and Data Acquisition. A system that gathers real-time data from remote terminal units and other communication sources in the field and enables operators to control field devices from their consoles.
ST PASA	Short-term Projected Assessment of System Adequacy. The projected assessment of system adequacy covering seven days ahead and in a 30-minute resolution.
Spot price	The price in a trading interval for one megawatt hour (MWh) of electricity at a regional reference node. Prices are calculated for each dispatch interval (five minutes) over the length of a trading interval (a 30-minute period). The six dispatch prices are averaged each half hour to determine the price for the trading interval.
Summer	For the purposes of the analysis in this report, 1 November to 31 March.
Summer peak	The top 10% of demand over the summer period on a five-minute basis.

Term	Definition
Wind penetration	The relative amount of wind energy or capacity compared to total energy or capacity. This can be measured in a number of different ways (see Section 2.6). Also see glossary entries for Capacity penetration, Energy penetration, Maximum instantaneous penetration, and Maximum possible instantaneous penetration.
Winter	For the purposes of the analysis in this report, 1 June to 31 August.
Winter peak	The top 10% of demand over the winter period on a five-minute basis.