SOUTH AUSTRALIAN RENEWABLE ENERGY REPORT

SOUTH AUSTRALIAN ADVISORY FUNCTIONS

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IMPORTANT NOTICE

Purpose

The purpose of this publication is to provide information about renewable generation in South Australia. This publication is based on information available to AEMO as at 30 June 2016, although AEMO has endeavoured to incorporate more recent information where practical.

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EXECUTIVE SUMMARY

South Australia has the highest wind and solar generation capacity of any National Electricity Market (NEM) region in Australia. Since the withdrawal of Northern and Playford coal fired power stations in May 2016, over 43% of installed generation capacity in South Australia utilises renewable fuel sources such as wind and solar (rooftop photovoltaic (PV)).

When levels of wind and/or solar generation relative to demand are high, frequency control and network support services need to be sourced from Victoria to maintain power system security. Also, at times of high operational demand in South Australia, reliable supply depends on the contribution from wind generation and imports. Therefore, understanding the performance of wind and solar generation in South Australia is key to managing operational risks in maintaining system security and reliability.

This report supersedes the annual *South Australian Wind Study Report*, produced by AEMO since 2013, and broadens the focus to other renewable sources. It focuses on the performance of wind and rooftop PV generation in South Australia over the last five financial years (2011–12 to 2015–16).

- South Australia had the highest penetration of renewables of all NEM regions in the last five years. Total renewable generation including wind and rooftop PV for 2015–16 was 5,260 gigawatt hours (GWh), 3% higher than in 2014–15. This was about 42% of the region's total local generation supply in 2015–16.
- Both wind and rooftop PV capacity have increased in the five years to 2015–16:
  - Rooftop PV rapidly increased, more than doubling, from 294 megawatts (MW) in 2011–12 to 679 MW in 2015–16. More than 29% of dwellings in South Australia now have rooftop PV systems installed.
  - Registered wind capacity increased about 30%, from 1,203 MW in 2011–12 to 1,576 MW in 2015–16.
    - In 2015–16, one wind farm, Hornsdale Stage 1 Wind Farm (102.4 MW), was registered (June 2016) and is presently undergoing commissioning.
- Instantaneous wind penetration (ratio of wind generation to operational demand[1] at any point in time), continues to increase. In 2015–16, wind generation exceeded demand from the grid for around 24 hours across 10 separate days, with surplus wind generation available for export to Victoria.
- In 2015–16, maximum instantaneous wind penetration (119%) occurred at the five-minute period ending 4:45 am, when there was no contribution from rooftop PV generation and operational demand was low. By contrast, in 2014–15 maximum instantaneous wind penetration occurred in the middle of the day, when rooftop PV generation was relatively high.
- Maximum instantaneous rooftop PV penetration (ratio of rooftop PV generation to underlying demand[2]) reached 38% in 2015–16, the equal highest ratio in the past five years.
- In 2015–16, rooftop PV contribution at the time of South Australia's peak underlying electricity demand reached 9.93% (322 MW), the highest contribution in the past five years.

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

Renewable generation and contribution to peak demand

Total installed wind generation capacity increased from 1,473 MW in 2014–15 to 1,576 MW in 2015–16, with one new wind farm – Hornsdale Stage 1 Wind Farm (102.4 MW) – being registered in South Australia in June 2016 (presently undergoing commissioning).[3] Total wind farm generation in South Australia for the year was 4,322 GWh. This was 2.3% higher than in 2014–15, largely driven by increased wind speeds.

Total installed rooftop PV generation capacity is estimated to have increased from 610 MW in 2014–15 to 679 MW in 2015–16. Total rooftop PV generation in South Australia for the year was 938 GWh. This was 7.6% higher than in 2014–15.

- Both wind and rooftop PV generation technologies are intermittent, with output dependent on weather conditions. Analysis of the contribution of wind generation to the top 10% of summer operational peak demand periods in the past five years shows that more than 9.4% of South Australia's registered wind capacity was generating 85% of the time. In winter, the 85th percentile wind contribution was 7.0%. These contribution factors are the highest in the NEM.
- Similar analysis of expected rooftop PV generation across summer underlying peak periods over the past five years indicates that more than 4.9% of South Australia's estimated rooftop PV capacity was generating 85% of the time.

Instantaneous penetration

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

Wind penetration was over 100% on 10 separate days (about 24 hours) 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 2014–15 to 2015–16 in maximum instantaneous wind and rooftop PV penetration and a number of other internationally-recognised generation indices. As minimum demand increased in 2015–16 relative to 2014–15 and installed capacity remained constant, the maximum possible instantaneous penetration of wind decreased in 2015–16.

Table 1 South Australian penetration indices

Description	Wind value for South Australia		Rooftop PV value for South Australia	
	2014–15	2015–16	2014–15	2015–16
Capacity penetration: installed capacity as a percentage of total installed generation*	30%	31%	11%	13%
Energy penetration: ratio of annual energy to annual total energy consumption**	32%	32%	6%	7%
Maximum instantaneous penetration (excluding exports): maximum observed ratio of energy to demand at any instant in time during the year**	109%	119%	38%	38%
Maximum possible instantaneous penetration: the ratio of installed capacity to minimum demand***	189%	170%	NA	NA
Periods of 100% (or greater) instantaneous penetration	32 hours	24 hours	0 hours	0 hours

* 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.
** Wind generation analysis is based on operational demand as generated, while rooftop PV is based on underlying demand.
*** 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.

[3] Waterloo Stage 2 (completed, undergoing commissioning) and Hornsdale Stage 2 (committed) wind farms were not registered in the 2015–16 financial year.

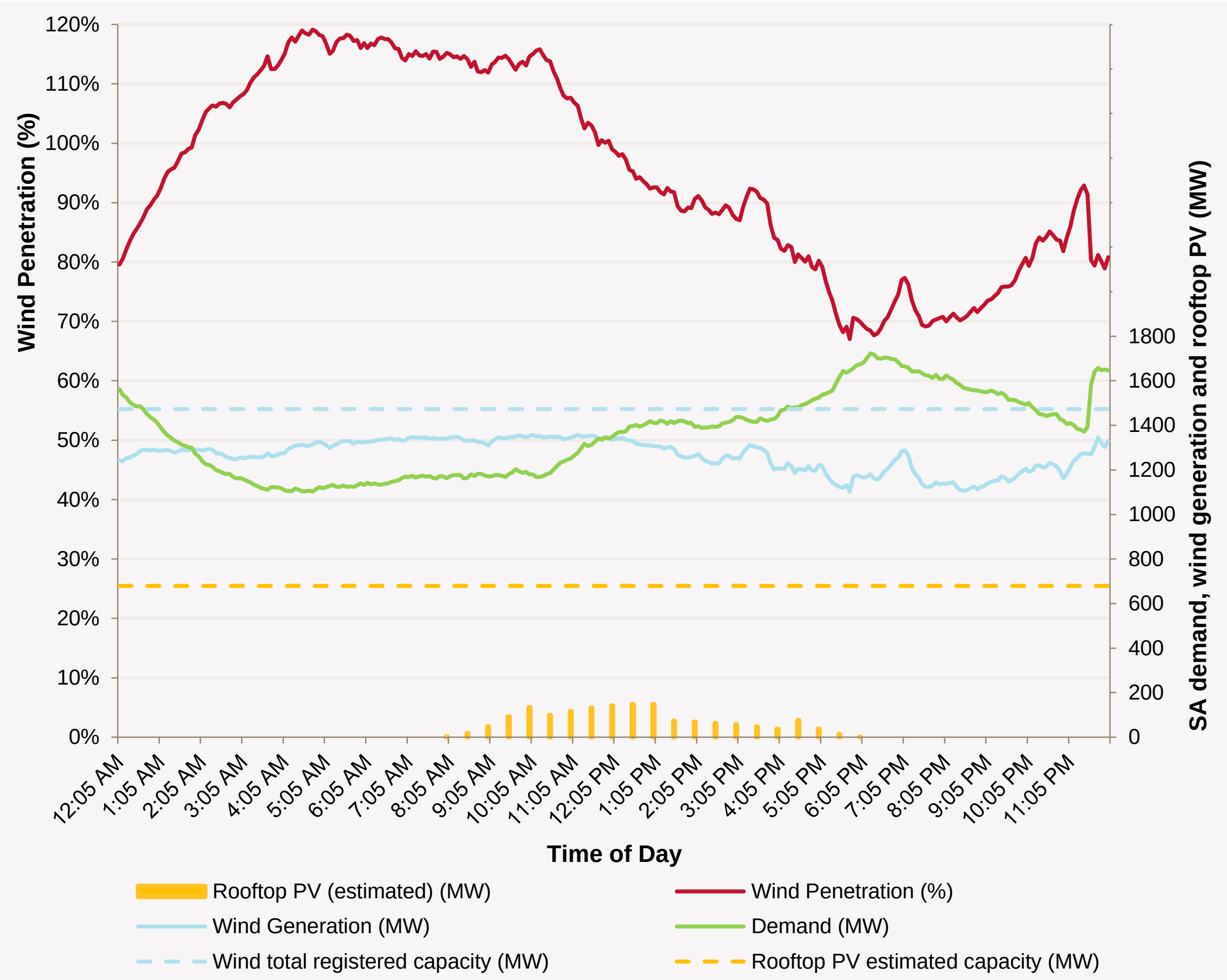
The maximum instantaneous wind penetration in 2015–16 reached 119% on 22 May 2016 in the five-minute period ending 4:45 am. At the same time, there were only two thermal generating units online in South Australia, producing a combined total of approximately 81 MW, and a total of approximately 292 MW was being exported to Victoria across the two interconnectors (Heywood and Murraylink).

Wind generation is generally slightly higher overnight than during the day. Because of this, average wind penetration levels are greatest between 3:00 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[4], demand from the grid, and instantaneous wind penetration, for 22 May 2016, when maximum wind penetration occurred.

The 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 penetration. In 2015–16, maximum wind instantaneous penetration occurred in the early hours of the morning when wind was very high and demand low. By contrast, in 2014–15, it occurred in the middle of the day during low demand and corresponding high generation of both rooftop PV and wind.

Figure 1 South Australian wind generation, demand, rooftop PV, and wind penetration for 22 May 2016



4 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 2015–16 shows that for 90% of the time, South Australian total wind generation varied by no more than 21 MW (1.4% of registered capacity) across five-minute periods, and by no more than 83 MW (5.6% of registered capacity) across 30-minute periods. Of the three South Australian geographical areas, the mid-north shows lower wind variation than the south-east and coastal peninsula areas. The aggregated South Australian wind variation is lower than any single area, reflecting the smoothing effect of multiple generating units in different areas across the region.

In 2015–16, South Australian estimated rooftop PV generation varied by up to 176 MW (25.9% 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 variability in wind and rooftop PV generation means there is a resultant residual demand, which must be met by more responsive non-wind generators, or by changes in power flow on the Heywood Interconnector. As more wind farms come online and rooftop PV installations increase, larger residual demand changes in South Australia are observed more often.

CONTENTS

EXECUTIVE SUMMARY **3**

1. INTRODUCTION **10**
1.1 Information sources and assumptions 10
1.2 Treatment of wind farms during commissioning period 12
1.3 Generating systems maps 12
1.4 Recent generation and network developments 15

2. WIND FARMS **16**
2.1 Summary 16
2.2 Wind contribution during peak demand 16
2.3 Wind penetration 19

3. ROOFTOP PV **23**
3.1 Rooftop PV capacity 23
3.2 Generation 25
3.3 Rooftop PV contribution during maximum underlying demand 25
3.4 Rooftop PV penetration 28

4. INTERMITTENCY AND DEMAND VARIATIONS **30**
4.1 Wind, rooftop PV and demand variation 30
4.2 Rooftop PV variation 34
4.3 Wind forecast performance 35

5. RENEWABLE GENERATION AND MARKET PRICES **38**

APPENDIX A. WIND FARM AND ROOFTOP PV STATISTICS **45**
A.1 Wind farm capacities 45
A.2 Wind farm capacity factors 46
A.3 Wind generation variation 47

MEASURES AND ABBREVIATIONS **48**
Units of measure 48
Abbreviations 48

GLOSSARY **49**

TABLES

Table 1 South Australian penetration indices 4
Table 2 SARER data sources summary and comparison to previous reports 11
Table 3 South Australian registered capacity by fuel type as at 30 June 2016 12
Table 4 Publicly announced and committed renewable generation projects by energy source as at 18 November 2016 15
Table 5 Total South Australian wind generation 16
Table 6 85th percentile wind contribution factor (% of registered capacity) during top 10% seasonal peak demand 17
Table 7 Expected wind contribution during peak demand (% of registered wind capacity) 17
Table 8 South Australian wind penetration indices 19
Table 9 South Australian rooftop PV installed capacity forecasts 24
Table 10 South Australian rooftop PV generation estimates 25
Table 11 Rooftop PV contribution during periods of maximum underlying peak demand 26
Table 12 Rooftop PV generation (% of estimated capacity) during top 10% of peak demand periods 28
Table 13 South Australian rooftop PV penetration indices 29
Table 14 Total registered capacity and historical maximum variation outputs (MW) by area 34
Table 15 Total installed capacity and estimated historical maximum variation outputs (MW) 35
Table 16 Registered capacities of South Australian wind farms 45
Table 17 Financial year capacity factors of South Australian wind farms 46
Table 18 Key statistical characteristics of wind generation variation for 2015–16 47
Table 19 Key statistical characteristics of wind generation variation for 2014–15 47

FIGURES

Figure 1 South Australian wind generation, demand, rooftop PV, and wind penetration for 22 May 2016 5
Figure 2 Location and capacity of South Australian generating systems as at 18 November 2016 13
Figure 3 Location and capacity of proposed South Australian generation projects as 18 November 2016 14
Figure 4 Summer peak demand wind generation duration curve (% of registered wind capacity) 18
Figure 5 Winter peak demand wind generation duration curve (% of registered wind capacity) 18
Figure 6 Daily demand, wind generation, and penetration profile 20
Figure 7 South Australian wind generation, demand, rooftop PV, and wind penetration for 22 May 2016 21
Figure 8 Instantaneous wind penetration duration curves 22
Figure 9 South Australian rooftop PV installed capacity forecasts 24
Figure 10 Summer peak demand rooftop PV generation duration curve (% of estimated rooftop PV capacity) 27
Figure 11 Winter peak demand rooftop PV generation duration curve (% of estimated rooftop PV capacity) 27
Figure 12 Rooftop PV generation compared to total South Australian generation 28
Figure 13 South Australian wind generation, operational demand, and residual demand (variation distribution) 30

Figure 14 South Australian residual demand (variation distribution) 31
Figure 15 Five-minute and 10-minute absolute wind generation variation for 2015–16 32
Figure 16 Absolute wind variation as percentage of registered capacity 33
Figure 17 Daily estimated rooftop PV generation profile 35
Figure 18 Normalised mean absolute error of AWEFS forecasts for South Australia from FY12 to FY16 37
Figure 19 South Australian average wind generation and spot prices (30-minute data for 2011–12 to 2015–16) 38
Figure 20 South Australian estimated rooftop PV generation and spot prices (30-minute data for 2011–12 to 2015–16) 39
Figure 21 South Australian 30-minute spot prices and average wind generation (positive market prices) 40
Figure 22 South Australian 30-minute spot prices and estimated rooftop PV generation (positive market prices) 41
Figure 23 South Australian 30-minute spot prices and average wind generation (negative market prices) 42
Figure 24 South Australian 30-minute spot prices and estimated rooftop PV generation (negative market prices) 43
Figure 25 Negative South Australian spot price, average wind and rooftop PV generation by time of day (2015–16) 44

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 2011–12 to 2015–16.

This annual report supersedes the *South Australian Wind Study Report* (SAWSR), produced by AEMO since 2013, and broadens the focus to other renewable sources.

- **Chapter 1 − Introduction** provides an overview of the report, generation sites, and an update on recent relevant developments.
- **Chapter 2 − South Australian wind generation performance** provides information about capacity, maximum instantaneous generation, contribution to demand, total generation and share, penetration, and short-term generation variation. This chapter also provides analyses of historical generation and the relationship between wind generation and price in South Australia, and a brief discussion on performance of wind forecasting.
- **Chapter 3 − Rooftop PV** provides capacity, annual generation by residential and commercial, and contribution of rooftop PV to demand
- **Appendix A − Wind farm statistics** provides the name, geographic area, scheduling type, and registered capacity of the wind farms considered in this report, and their capacity factors and generation variation metrics.

South Australian demand refers to the as-generated operational demand met by local scheduled, semi-scheduled, and significant non-scheduled generating systems[5] plus interconnector imports from Victoria, and excludes demand supplied by rooftop PV generation.

Operational demand refers to electricity used at a specific point in time (typically at a five-minute or 30-minute interval, measured in megawatts (MW)), while operational consumption is the electricity used over a period of time (typically over one year, measured in gigawatt hours (GWh)).

Due to changes in their 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.

Underlying demand refers to electricity consumed by customers at their premises, supplied from both the grid and rooftop PV combined, but it does not include contribution from small non-scheduled generation (SNSG). In this report, it is estimated to be the sum of operational demand plus rooftop PV generation.

All time references in this report are to National Electricity Market (NEM) Standard Time.[6]

Summer has been defined as the period from 1 November to 31 March, and winter from 1 June to 31 August.

1.1 Information sources and assumptions

The SARER reports on electricity generated by South Australian generating systems that operate in the NEM. These wind farms are typically greater than or equal to 30 MW registered capacity, and are described in Appendix A.1.

[5] Significant non-scheduled generating units in South Australia are all non-scheduled wind farms. It does not include the output of small non-scheduled generating systems, typically less than 30 MW capacity. Note, in early 2016, Snowy Hydro altered the registration of its Angaston, Port Stanvac 1, and Port Stanvac 2 plants from non-scheduled to semi-scheduled. Angaston was scheduled from 2004 to 2012, was then non-scheduled but still reportable, and became a scheduled generator again on 27 May 2016. Lonsdale and Port Stanvac became scheduled generators on 12 January 2016.

[6] NEM Standard Time is equivalent to Australian Eastern Standard Time and is not altered during daylight saving.

Historical estimates of rooftop PV installed capacity and generation output are taken from the 2016 *National Electricity Forecasting Report* (NEFR)[7], to illustrate its impact on operational consumption and pricing.[8]

Analysis displaying generator outputs, operational demand, and interconnector flows, whether as duration curves, peak output, or daily averages, uses five-minute generation or power flow data, measured in MW, to give a representation of peaks and changes over time. For generator output or interconnector flow analysed over a financial year or season, five-minute power generation or flow data has been aggregated and converted to an equivalent energy amount (measured in GWh).

Table 2 summarises the data sources used in the reporting presented in the 2016 SARER, and any changes from reporting in 2015.[9]

Table 2 SARER data sources summary and comparison to previous reports

Data reported	Data source(s) in 2016 reports	Change from 2015 reports
Reporting on: • **Generation output (including for capacity factor and volume-weighting of average prices)** • **Interconnector flows** • **Demand**	Five-minute averages of as-generated SCADA metering. When not available, five-minute SCADA snapshots or the last known good SCADA value were used instead.	Previous reports generally used five-minute cleared generation dispatch targets for scheduled and semi-scheduled generators, or SCADA snapshots for non-scheduled generators. (There is no change to the as-generated nature of the data).
Rooftop PV capacity and generation estimates – annual totals	As provided in 2016 NEFR.	Not reported in 2015 SAWSR.
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, which takes into account data on rooftop PV installed capacity from the Clean Energy Regulator (CER).[10]	Not reported in 2015 SAWSR.
Pricing	Average of 6 x five-minute dispatch prices over a 30-minute trading interval.	N/A

Table 2 identifies a key change in the 2016 SARER data source, as five-minute average supervisory control and data acquisition (SCADA) metering data has been used to report generator output, interconnector flow, and demand. Earlier reports used cleared generation dispatch targets and SCADA snapshot values.

The new data inputs are more representative of actual electrical performance of the generating systems being analysed, and are now consistent across all generation and interconnector sources. However, in some cases, the 2016 reported analysis is noticeably different to the analysis presented in previous years. Trends and insights generally have not changed, some historical numbers reported are different. Where AEMO believes the difference is material, supplementary commentary is provided.

[7] AEMO. *2016 National Electricity Forecasting Report*. Available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/National-Electricity-Forecasting-Report.

[8] 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.

[9] Previous editions of the report were known as the *South Australian Wind Study Report* (SAWSR).

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. 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.[11] 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:
  - Demand.
  - 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
  - Capacity penetration and maximum possible instantaneous penetration.
- Wind farms in their commissioning period are excluded from any capacity calculations of wind variation analysis but are included in the generation calculations.
- Wind farms in their commissioning period are excluded from the capacity and generation calculations of wind contribution during peak demand analysis (but included in the demand calculations, as stated above).

For the 2016 SARER, the South Australian wind farms that are affected by the above methodology, in various analyses throughout the report, are Hallet 5 (The Bluff), Snowtown Stage 2, and Hornsdale Stage 1.[12]

1.3 Generating systems maps

Figure 2 shows the location and nameplate capacity of the South Australian scheduled, semi-scheduled, and significant non-scheduled generating systems, and Figure 3 shows the location and capacity of publicly announced generation projects as at November 2016.[13]

Table 3 summarises the capacity mix of fuel types for all registered generation in South Australia as at 30 June 2016, excluding the permanently closed coal-fired power plants currently being decommissioned.

Table 3 South Australian registered capacity by fuel type as at 30 June 2016

Fuel Type	Registered capacity (MW)	% of total capacity including rooftop PV
Gas	2,668	51%
Wind	1,576	30%
Rooftop PV*	679	13%
Diesel + SNSG**	289	6%
Total	5,212	100%

* Rooftop PV installations are not registered with AEMO, but are included here given their material contribution to generation in 2015–16. Rooftop PV capacity and generation estimates as listed build on those presented in the 2016 NEFR, but incorporate nine months of input data instead of six months.

** Diesel + SNSG includes small and large diesel, and small landfill methane and hydro generating systems.

11 Capacity factor calculations would especially be distorted if no consideration was made for the commissioning period.

12 Several non-South Australian wind farms are also affected in terms of the wind contribution during peak demand analysis summaries for other NEM regions, as presented in Section 2.2.

13 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.

Figure 2 Location and capacity of South Australian generating systems as at 18 November 2016

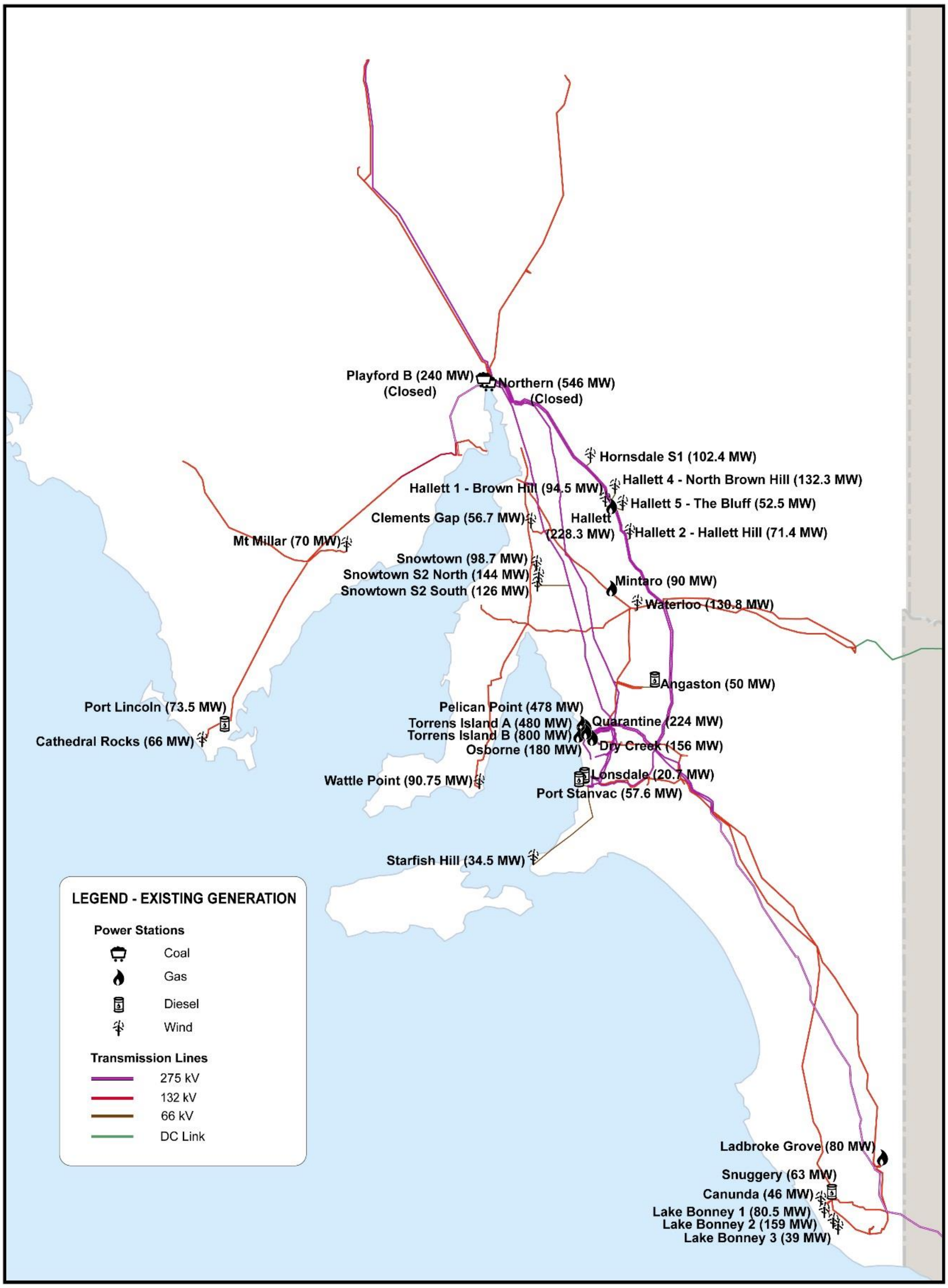
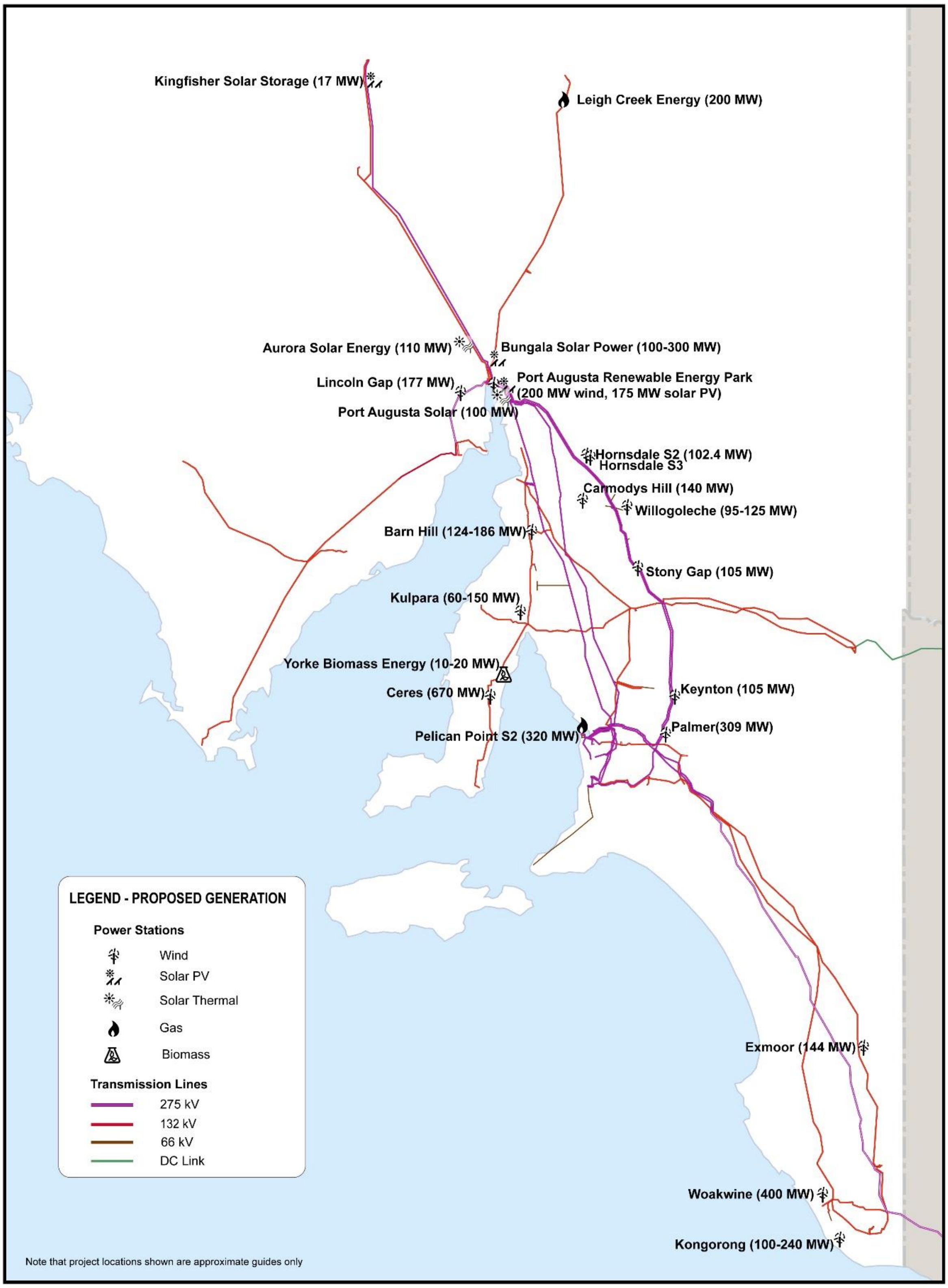


Figure 3 Location and capacity of proposed South Australian generation projects as 18 November 2016



1.4 Recent generation and network developments

The supply capacity and generation mix in South Australia has continued to evolve in recent years. There have been increases in wind farm and rooftop PV capacity, the ongoing upgrade to Heywood Interconnector import and export capability, and permanent closure of coal generation in May 2016. This report focuses on renewable generation development in the region. For information on changes in the supply mix more generally, refer to the *2016 South Australia Electricity Report* (SAER).[14]

1.4.1 New renewable generating systems

Generation investment interest in South Australia continues to be focused largely on renewable energy proposals. As at 18 November 2016, AEMO was aware of about 20 publicly announced renewable electricity generation developments in South Australia, totalling 3,775 MW. Table 4 aggregates the new developments by energy source.

Table 4 Publicly announced and committed renewable generation projects by energy source as at 18 November 2016[15]

Energy source	Number of projects	Capacity (MW)	Capacity (%)
Solar	5*	702	18.6
Biomass	1	20	0.5
Wind	15*	3,053	80.9
Total	**20**	**3,775**	**100.0**

* 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.

The largest wind farm projects under consideration are:

- Ceres (up to 670 MW).
- Woakwine (400 MW).
- Palmer (309 MW).
- Kongorong (up to 240 MW).

In the Port Augusta area, several large solar proposals have also been announced since the 2015 SAWSR:

- Port Augusta Solar – solar thermal plant with graphite block energy storage (100 MW).
- Aurora Solar Energy – solar thermal plant with molten salt energy storage (110 MW).
- Port Augusta Renewable Energy Park – combined wind and solar PV farm (175 MW solar and 200 MW wind, totalling 375 MW).
- Bungala Solar Power – solar PV farm (100–300 MW).

Hornsdale Stage 1 Wind Farm (102.4 MW) was reported as committed in the 2015 SAWSR and is now completed and undergoing commissioning tests. The second stage of Hornsdale Wind Farm (102.4 MW) became committed in July 2016, with full operation expected by June 2017. An additional 19.8 MW of capacity for the existing 111 MW Waterloo Wind Farm is now completed and undergoing commissioning tests.

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 2016 SAER.[16]

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

2. WIND FARMS

2.1 Summary

This chapter presents an 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).

The table below summarises annual wind generation and its annual change from 2011–12 to 2015–16. For further information on wind farm generation and capacity factors, please refer to the 2016 *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*
2011–12	3,563		34%
2012–13	3,475	-2%	33%
2013–14	4,088	18%	32%
2014–15	4,223	3%	33%
2015–16	4,322	2%	33%**

* Capacity factor is based on the annual generation in this table compared to theoretical maximum possible assuming the annual capacity reported.
** Capacity factor theoretical maximum possible generation calculation does not include Hornsdale Stage 1 wind farm, which was only registered in June 2016.

Other key observations include:

- With reduced consumption and higher wind generation, 2015–16 saw higher or equal wind penetration indices compared to 2014–15. Maximum instantaneous penetration reached 119% in 2015–16, and wind supplied 32% of the region's consumption from the grid, similar to 2014–15.
- Average wind penetration was highest between 3.00 am and 5.00 am, though typically maximum instantaneous penetration and minimum demand tends to occur in the middle of the day.
- Increased wind speeds contributed to the 2% growth in annual wind generation in 2015–16.
- Annual capacity factors for individual wind farms can vary by up to 5% year on year, though in aggregate the variation is no more than 2%.

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

[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.

periods, wind generation contributes at least 9.4% of its registered capacity (and for winter, 7.0%). The wind contribution factor is generally higher in summer than in winter.

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

Summer peak period	% of registered capacity	Winter peak period	% of registered capacity
2011–12	9.2%	2011	8.8%
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%
Five-year summer average	9.4%	Five-year winter average	7.0%

South Australia has the highest expected contribution factor during regional summer and winter peak demand in the NEM (9.4% and 7.0% of registered capacity, respectively). Table 7 compares the minimum expected contribution of wind generation during peak demand across different NEM regions.[20]

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

Minimum expected wind contribution during peak demand*	South Australia	Victoria	Tasmania	New South Wales
five-year summer average	9.4%	7.5%	8.5%	3.0%
five-year winter average	7.0%	6.8%	4.9%	4.2%

* 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 52–61% of its registered capacity, and for 50% of summer peak demand periods, it contributes about 22–27% of its registered capacity.
- For 10% of winter peak demand periods, wind generation contributes about 77–84% of its registered capacity, and for 50% of winter peak demand periods, it contributes about 29–39% 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)

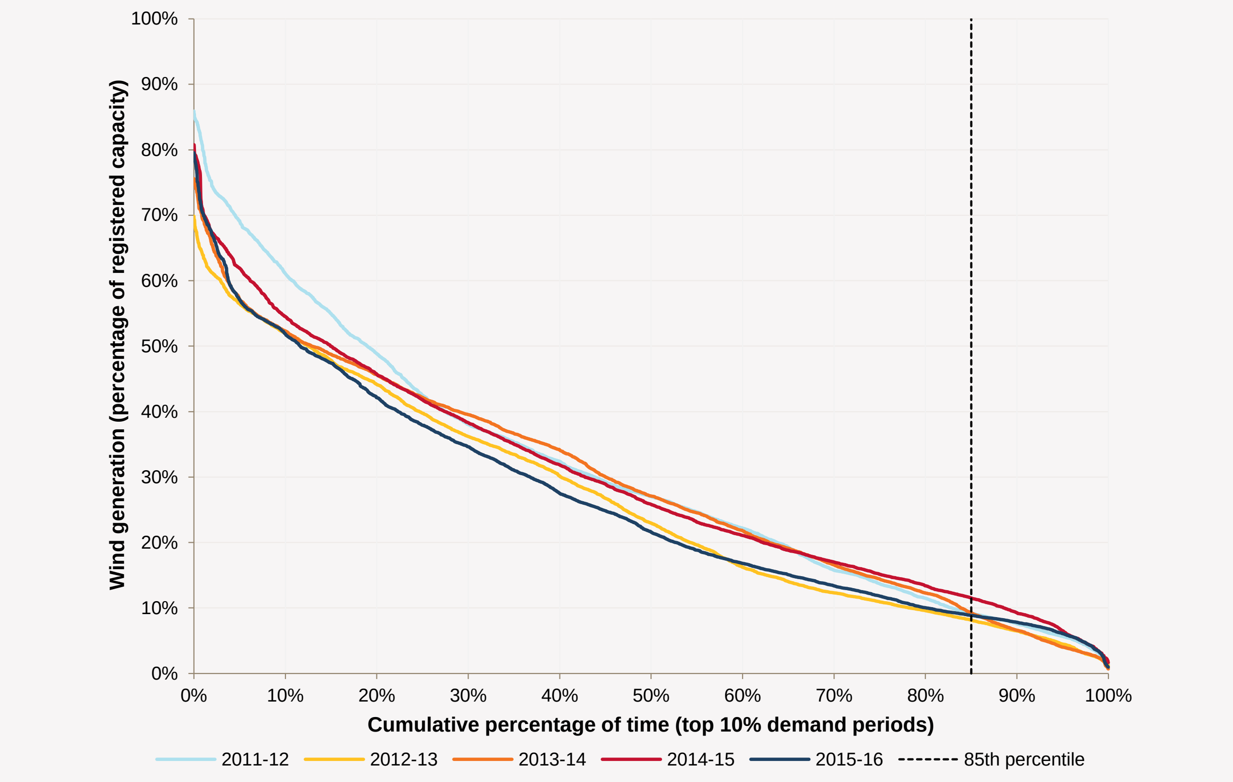
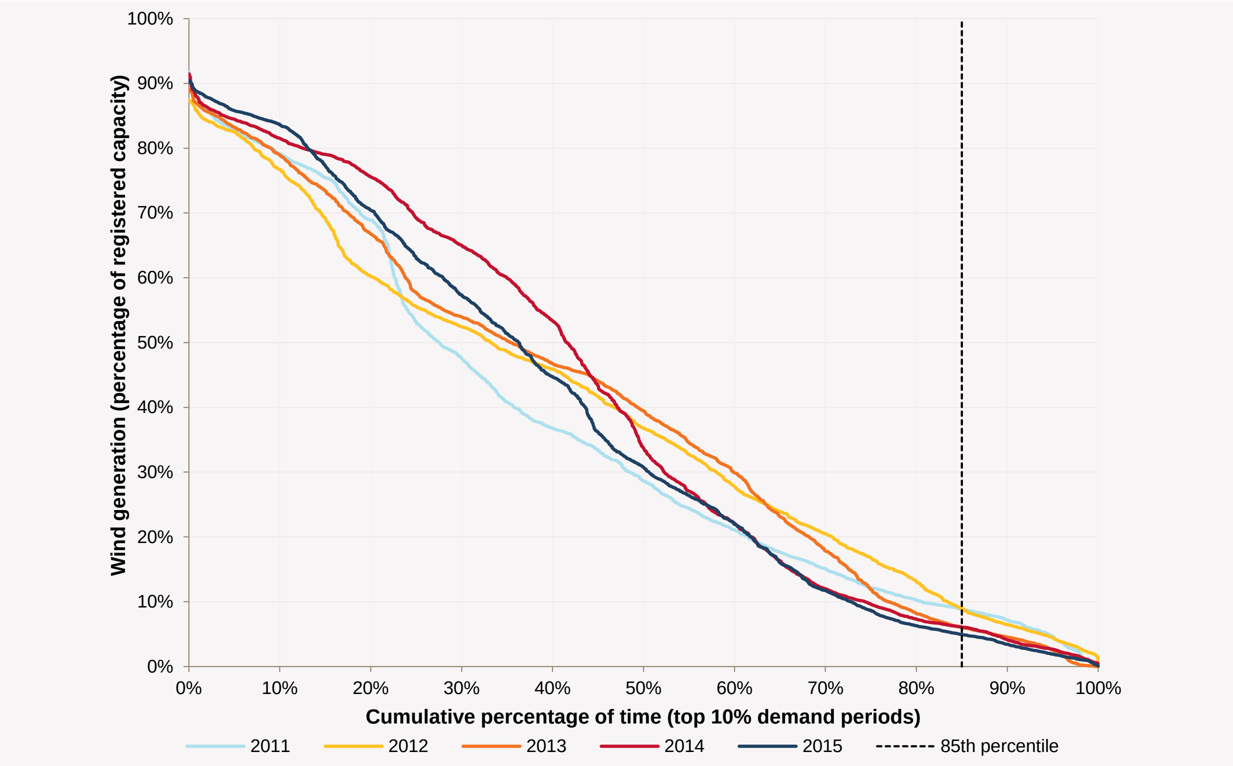


Figure 5 Winter peak demand wind generation duration curve (% of registered wind capacity)



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 following:

- 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

Description	South Australian value				
	2011–12	2012–13	2013–14	2014–15	2015–16
Capacity penetration: installed capacity as a percentage of total installed generation*	24%	26%	30%	30%	31%
Energy penetration: ratio of annual wind energy to annual total energy consumption	25%	25%	31%	32%	32%
Maximum instantaneous penetration (excluding exports): maximum observed ratio of wind energy to demand at any instant in time during the year	85%	87%	99%	109%	119%
Maximum possible instantaneous penetration: the ratio of installed capacity to minimum demand	113%	116%	126%	189%	170%

* 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.

In 2015–16, the maximum instantaneous wind penetration reached 119% on 22 May 2016 at around 4:45 am. Wind penetration was over 100% on 10 separate days across the year, with the majority of instances occurring early in the morning between about 2.00 am and 5:00 am or in the afternoon between 1:00 pm to 5:00 pm. 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 24 hours in 2015–16, compared to 32 hours in 2014–15.

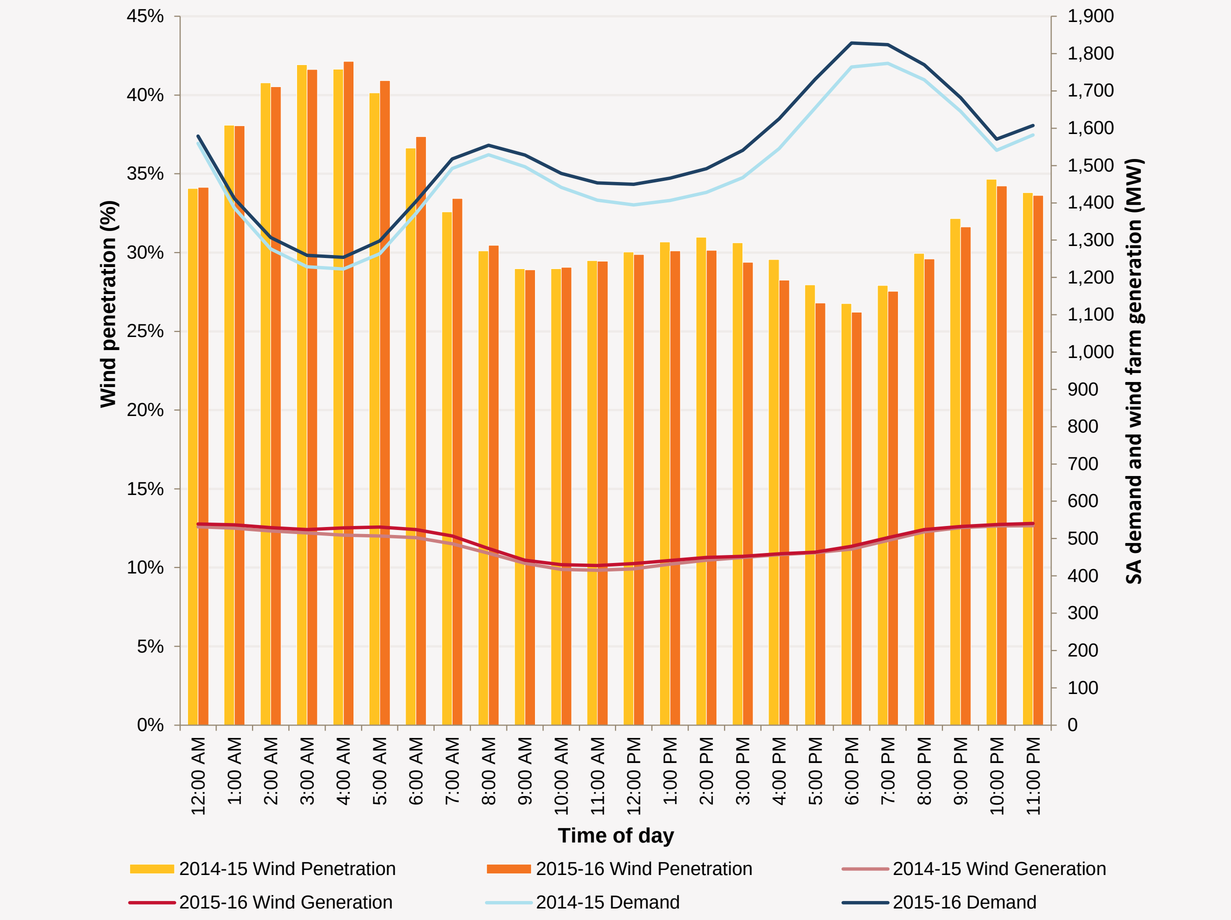
2.3.2 Daily demand, wind generation, and penetration profile

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 2014–15 and 2015–16. It indicates that:

- The average daily demand profile increased in 2015–16 relative to 2014–15, 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).
- While total wind generation increased in 2015–16, it 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 3.00 am to 5.00 am, when average demand was lowest.

Figure 6 Daily demand, wind generation, and penetration profile



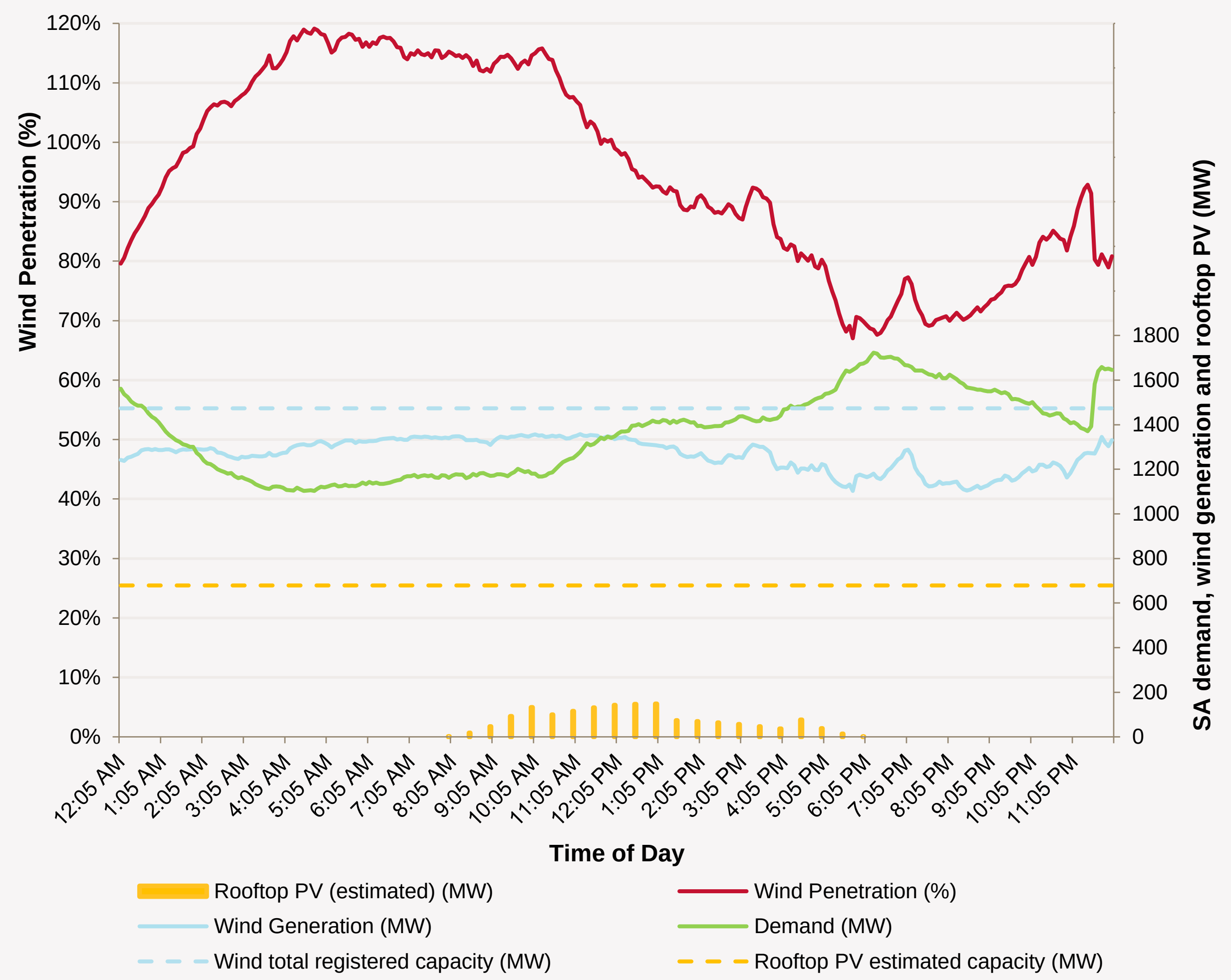
Maximum wind penetration occurred at 4:45 am on 22 May 2016.

Figure 7 shows the South Australian estimated rooftop PV, wind generation, wind penetration and demand from the grid, for 22 May 2016 (the day when maximum instantaneous wind penetration occurred). Also shown in this figure is an estimation of South Australian rooftop PV generation output at half hourly intervals.[21]

The 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 penetration. In 2015–16, maximum wind instantaneous penetration occurred in the early hours of the morning when wind was very high and demand low. By contrast, in 2014–15, it occurred in the middle of the day during low demand and corresponding high generation of rooftop PV and wind.

[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.

Figure 7 South Australian wind generation, demand, rooftop PV, and wind penetration for 22 May 2016



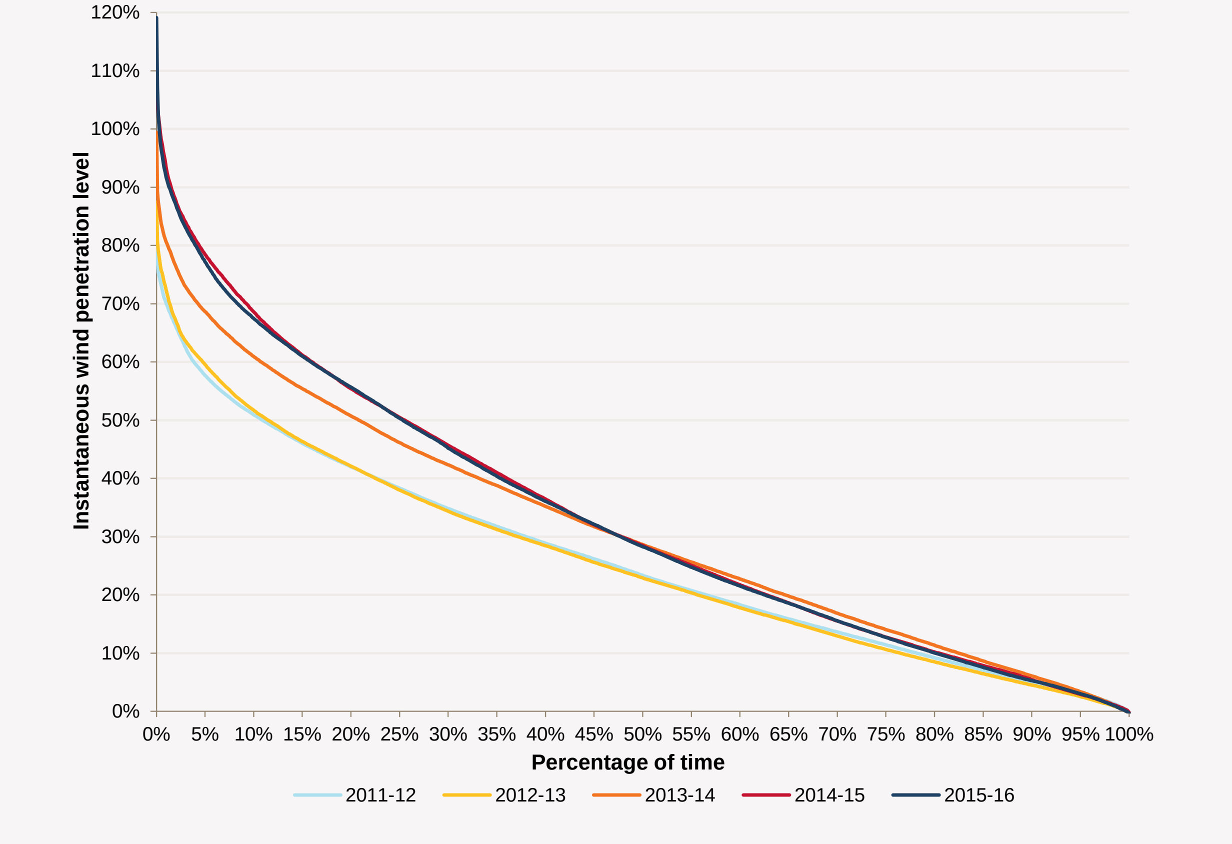
2.3.3 Wind penetration duration curves

Figure 8 provides wind penetration duration curves for the past five financial years, indicating that high penetration levels have increased over time. This is due to a combination of increasing wind generation with declining operational consumption and minimum demand.[22] The level of penetration over time has recently slowed down, as there were no new wind farms contributing to total wind penetration for any material portion of 2015–16 compared to 2014–15.[23] Also, despite there being 2.3% more total wind generation in 2015–16 compared to 2014–15 (due to seasonal variations), there was also increased total consumption in South Australia over the same period.

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. In 2015–16, penetration values below 78% were observed for 95% of the time.

[22] Details of operational consumption and minimum demand trends can be found in the 2016 SAER. Available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/South-Australian-Advisory-Functions.
[23] Hornsdale Stage 1 Wind Farm only began generating a small amount of its total capacity for the last few days of 2015–16.

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.[24] More than 29% of South Australian dwellings in now have rooftop PV systems installed.[25]

In South Australia, the uptake of residential rooftop PV systems is forecast[26] to decline as saturation levels are reached in some regions, however the business sector is forecast to have steady growth. By 2035–36, the total capacity of systems installed is forecast to be almost 2,100 MW. 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 economic viability of rooftop PV.

  Additionally, declining installation costs has improved economic viability for residential rooftop PV and Integrated PV and Storage Systems (IPSS). For rooftop PV systems, in the short term cost reductions are expected to come mainly in non-hardware "soft costs", including marketing and customer acquisition, system design, installation labour, permitting 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.
- 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.

The breakdown of rooftop PV installed generation capacity by sector with estimated actuals and forecasts for South Australia are shown in Figure 9 and broken down by sector in Table 9.

[24] 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.

[25] Analysis taken from: Australian PV Institute (APVI) Solar Map, funded by the Australian Renewable Energy Agency, accessed from pv-map.apvi.org.au on 24 June 2016.

[26] 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: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/National-Electricity-Forecasting-Report.

Figure 9 South Australian rooftop PV installed capacity forecasts

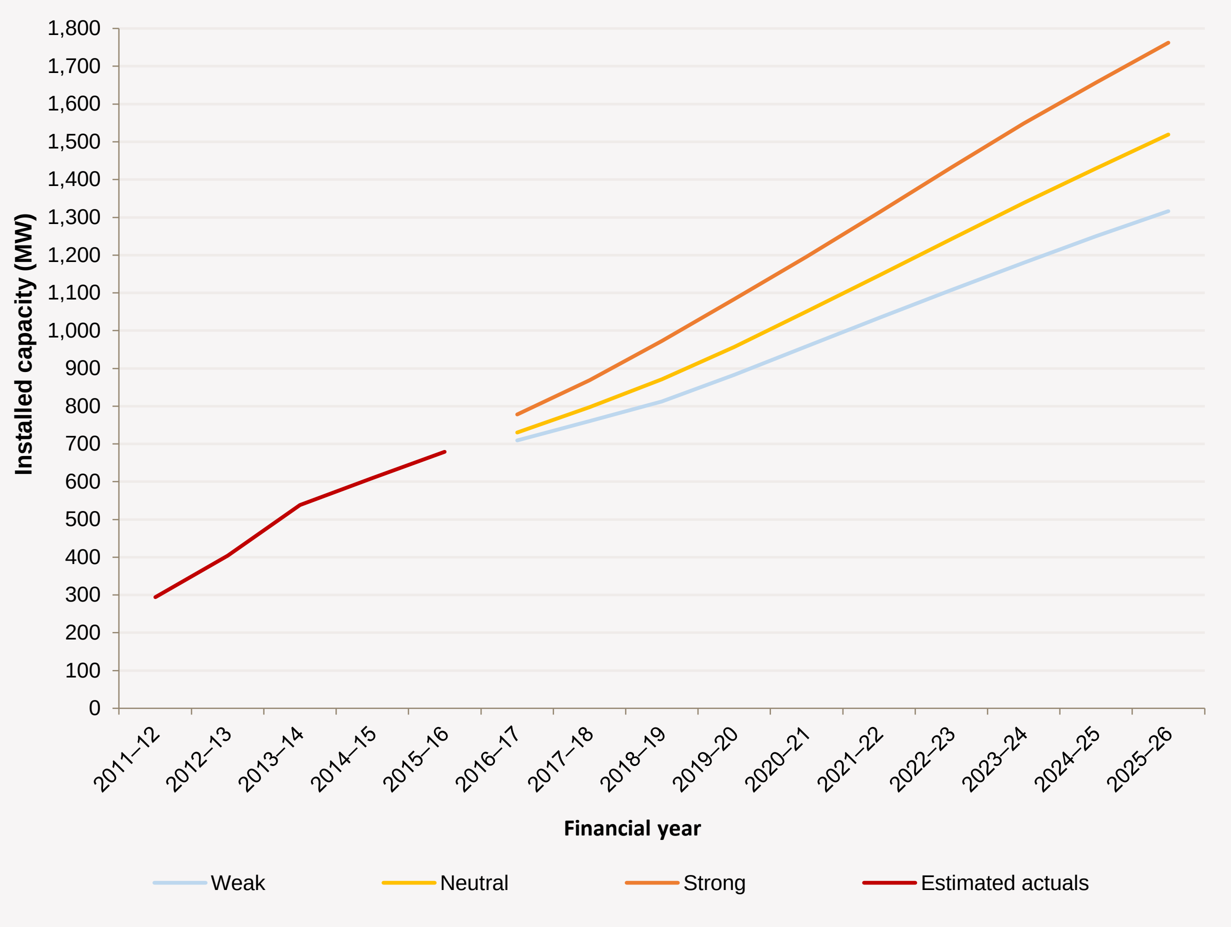


Table 9 South Australian rooftop PV installed capacity forecasts

Year	Installed capacity (MW)					
	Residential		Business		Total	
	Estimated Actual	Neutral sensitivity	Estimated Actual	Neutral sensitivity	Estimated Actual	Neutral sensitivity
2011–12	289		5		294	
2012–13	390		14		404	
2013–14	503		35		538	
2014–15	558		51		610	
2015–16	610		70		679	
2016–17		649		82		731
2017–18		697		100		797
2018–19		748		123		871
2019–20		805		152		957
2020–21		861		189		1,050
2021–22		917		230		1,146
2022–23		970		273		1,242
2023–24		1,020		319		1,338
2024–25		1,067		363		1,430
2025–26		1,110		410		1,520

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
2011–12	5	290	294
2012–13	12	480	492
2013–14	34	644	678
2014–15	66	806	872
2015–16	95	843	938

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 1.36% 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).[27]

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

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

Year	Contribution of rooftop PV*	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)
2011–12	4.49%	23/01/2012 15:30	294	139
2012–13	5.17%	18/02/2013 16:30	404	168
2013–14	7.36%	16/01/2014 16:30	538	256
2014–15	8.14%	07/01/2015 14:30	610	251
2015–16	9.93%	17/12/2015 16:30	679	322

* 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).

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.

Table 12 provides the 85th percentile level of expected rooftop PV generation across summer and winter peak periods over the past five years. On average, for 85% of summer underlying peak demand periods, rooftop PV generation contributes at least 4.9% of its estimated capacity[28].

As expected, the contribution in winter is 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 is no contribution from rooftop PV.

[28] 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 10 Summer peak demand rooftop PV generation duration curve (% of estimated rooftop PV capacity)

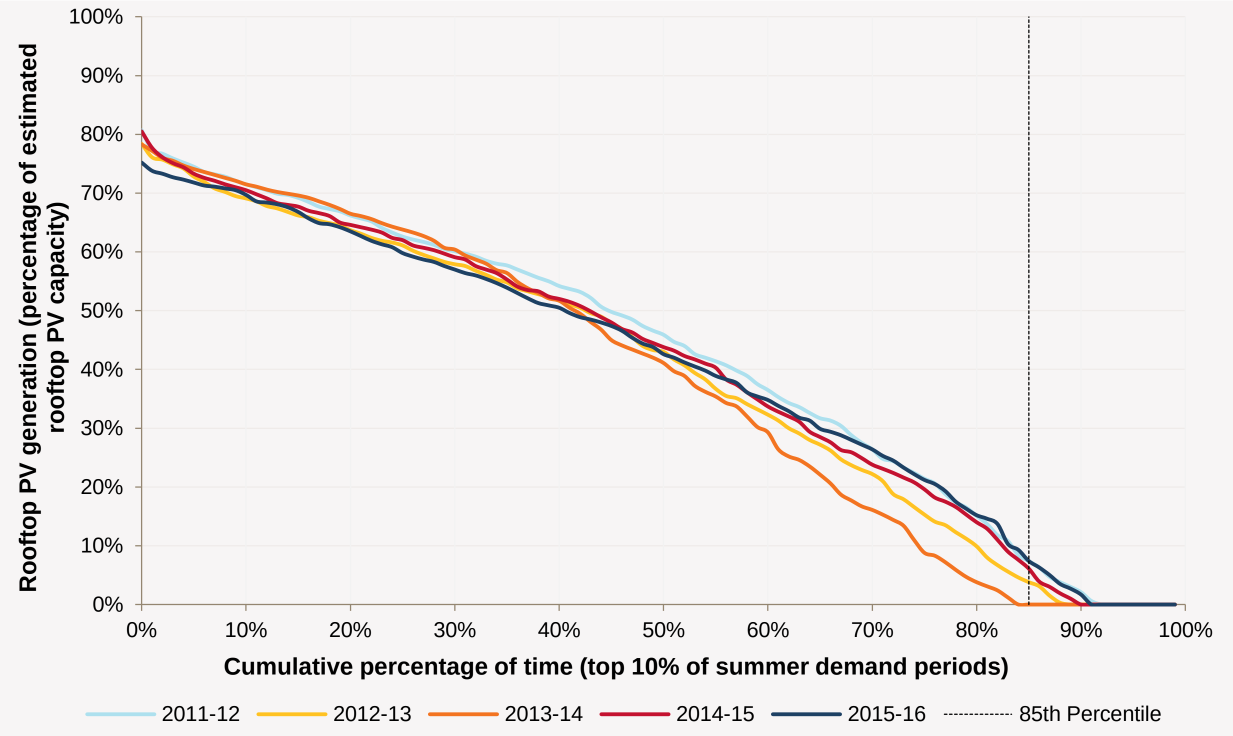


Figure 11 Winter peak demand rooftop PV generation duration curve (% of estimated rooftop PV capacity)

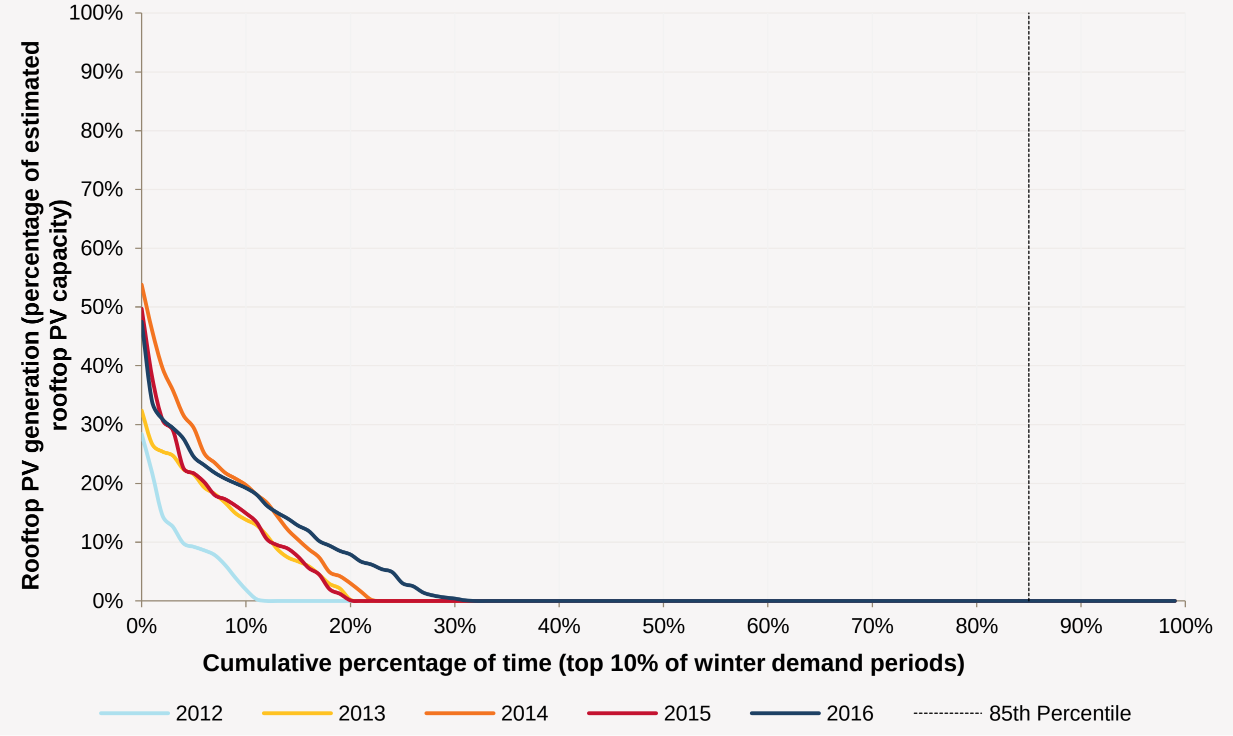


Table 12 Rooftop PV generation (% of estimated capacity) during top 10% of peak demand periods

Summer peak period	% of estimated capacity at the 85th percentile for summer
2011–12	7.4%
2012–13	3.8%
2013–14	0.0%
2014–15	6.1%
2015–16	7.4%
five-year summer average	4.9%

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 its fuel source is only available during daylight hours, about 50% of the time there is no generation output.

Figure 12 Rooftop PV generation compared to total South Australian generation

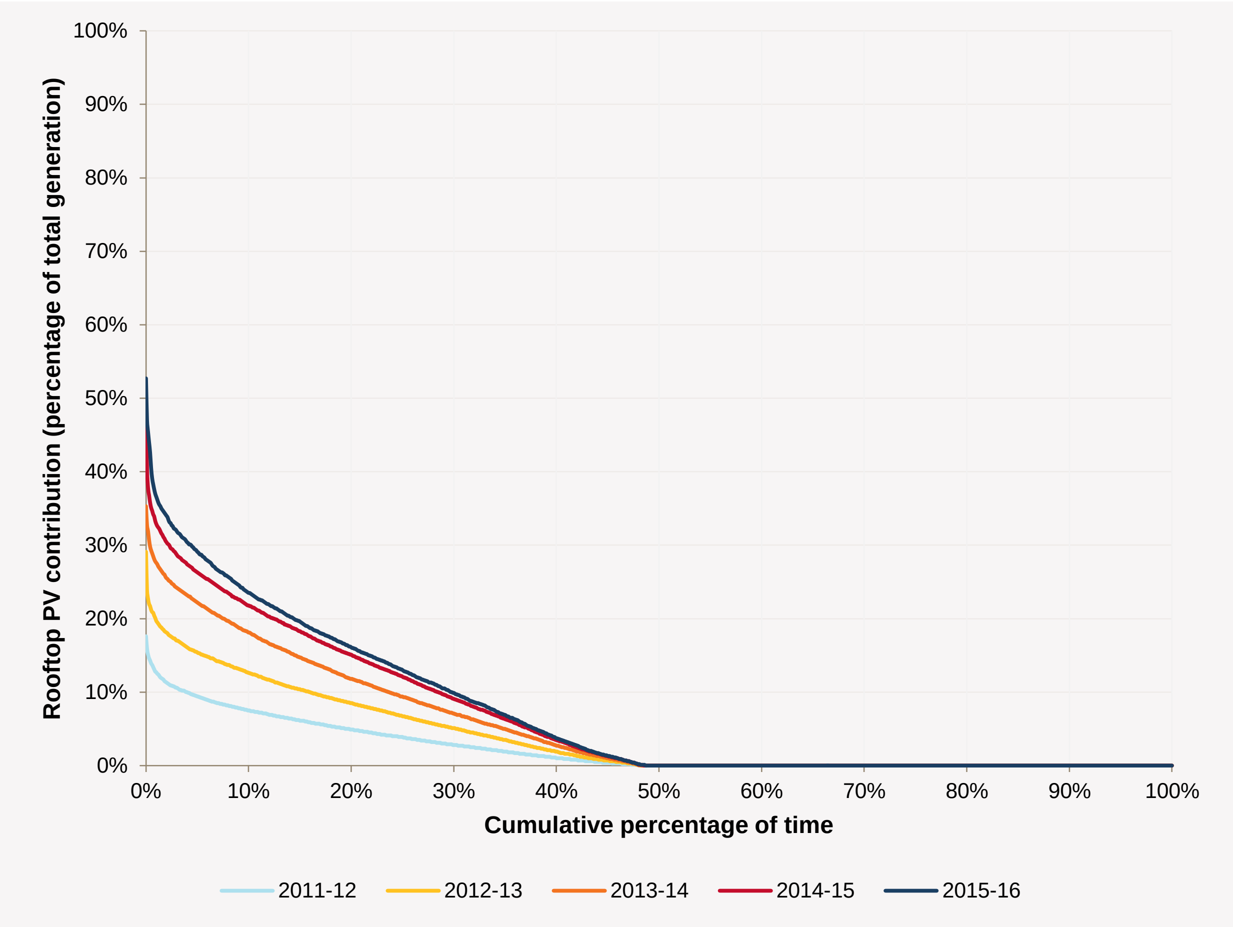


Table 13 sets out the calculations for South Australian estimated rooftop PV penetration using three indices. Corresponding with increases in installed rooftop PV generation capacity, all indices have tended to increase over time.

Table 13 South Australian rooftop PV penetration indices

Description	South Australian value				
	2011–12	2012–13	2013–14	2014–15	2015–16
Capacity penetration: installed capacity as a percentage of total installed generation*	6%	8%	10%	11%	13%
Energy penetration: ratio of annual rooftop PV energy to annual total energy consumption	2%	3%	5%	6%	7%
Maximum instantaneous penetration (excluding exports): maximum observed ratio of rooftop PV energy to demand at any instant in time during the year	14%	21%	30%	38%	38%

* 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 2016 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.

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).

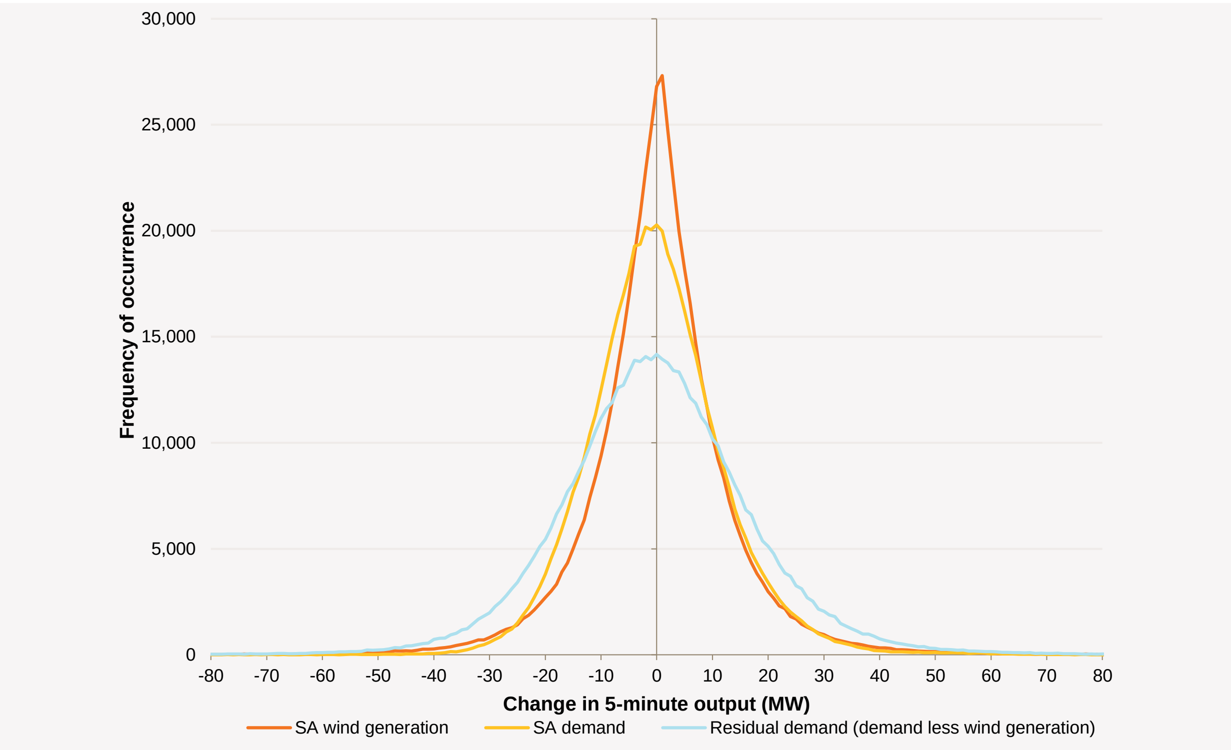
The intermittency of wind and rooftop PV generation, leading to sudden changes in the supply and demand balance, makes managing the power system more challenging.

In terms of power system operation, aggregate wind farm generation variation is considered rather than individual wind farm variation. Aggregation 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: mid-north[29], 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 2011–12 to 2015–16. 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 (variation distribution)

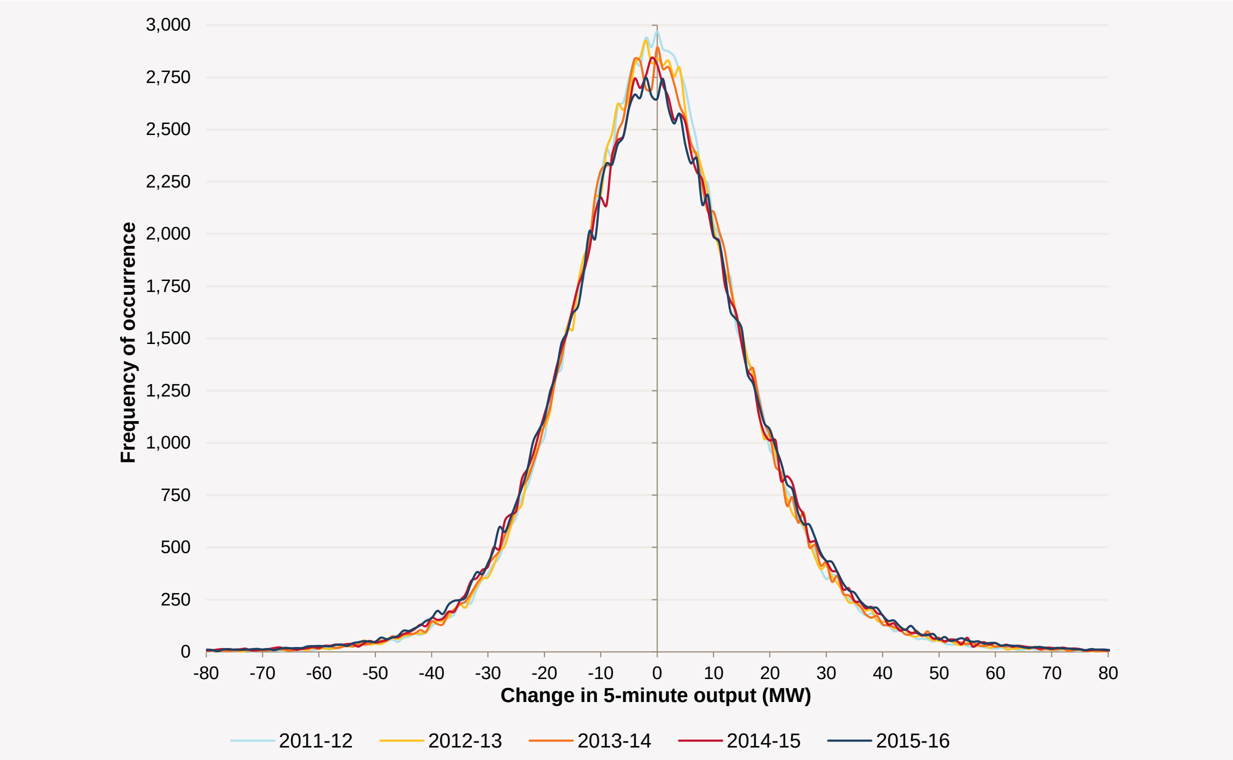


[29] Analysis for the Mid-north area now includes Mount Millar Wind Farm. This is due to a re-assessment of wind farm generation over the last five financial years, which considered correlation between wind farm 5-min generation outputs amongst the areas. In earlier (South Australian Wind Study) reports, 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, 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 2011–12 to 2015–16 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[30], south-east, and coastal peninsula areas in South Australia, and all South Australian wind farms in aggregate, for 2015–16. Appendix Section A.3 shows tables of the statistics for 2014–15 and 2015–16. In 2015–16, the mean five-minute variation for all South Australian wind farms in aggregate was 9.4 MW and the maximum variation was 264 MW.

Key observations from Figure 15 are:

- Wind generation variation differs by area. For 90% of the time, the variation across a 10-minute period for south-east and coastal peninsula areas is no more than 5.2% and 5.0% of registered

[30] 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.

capacity respectively, whereas total South Australian absolute wind generation variation is no more than 2.5%.

- The mean is higher than the median for all areas and all South Australian wind farms, indicating that while occurrences are skewed toward the lower values, larger fluctuations (though less frequent) do exist.

Figure 15 Five-minute and 10-minute absolute wind generation variation for 2015–16

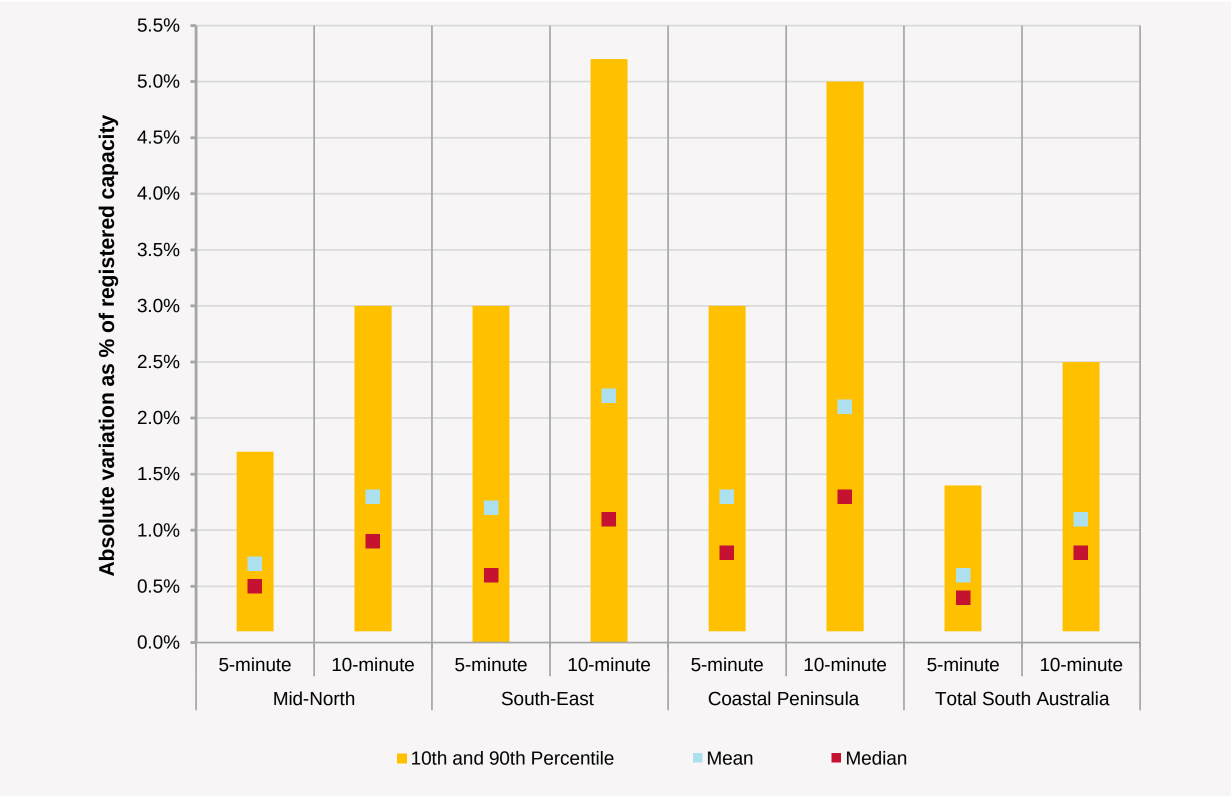
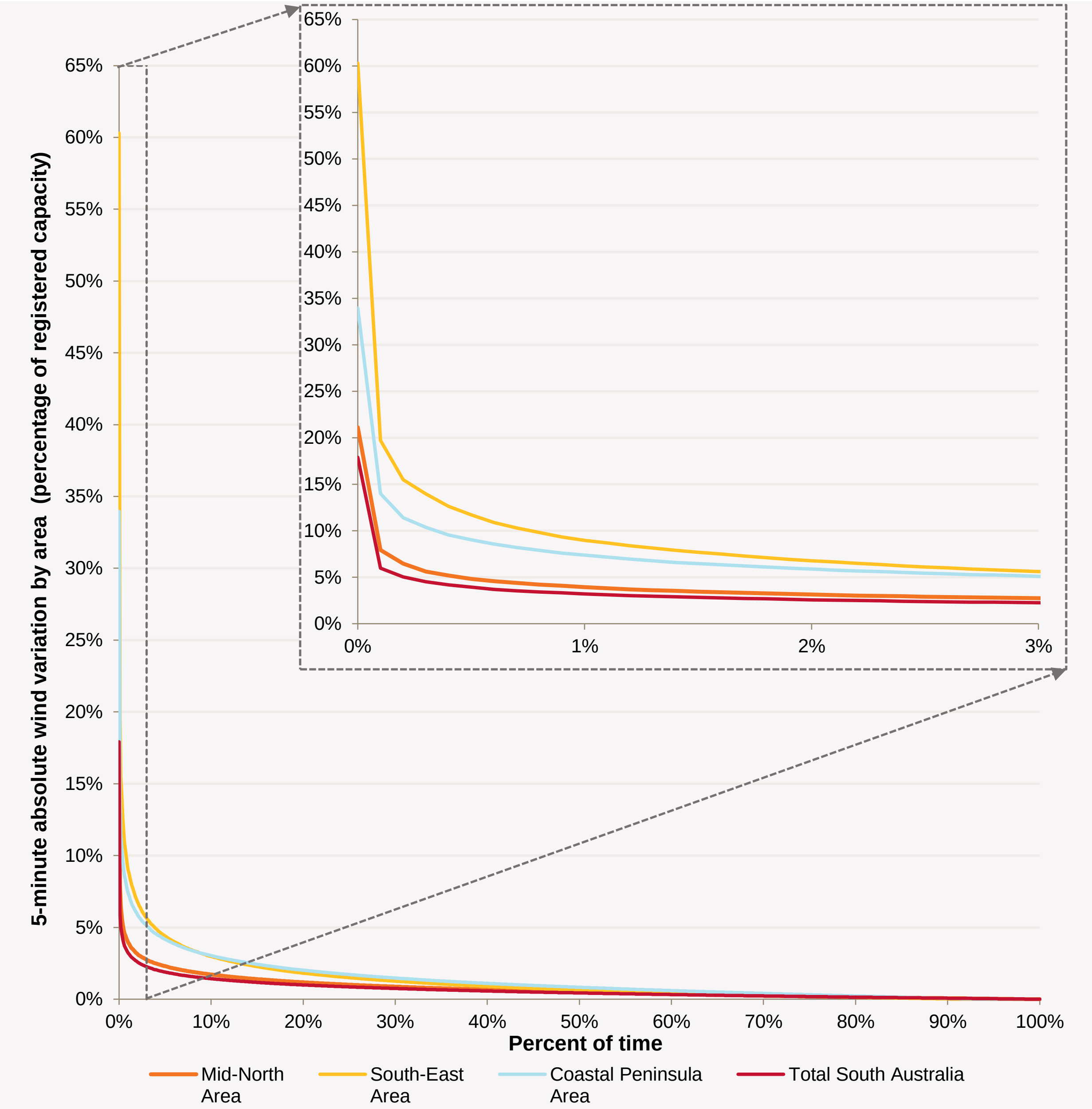


Figure 16 shows the full distribution of the five-minute absolute wind generation variation for the mid-north, south-east, and coastal peninsula areas, and all South Australian wind farms, for 2015–16.

Key observations are:

- South Australian wind farms in aggregate have lower absolute wind variation than the individual areas, indicating that greater wind generation geographical diversity leads to lower absolute wind variation.
- The coastal peninsula has the highest absolute wind variation of the three areas for around 81% of the time. The south-east has the highest absolute wind variation around 9% of the time.
- In the south-east area, a maximum wind farm variation of 60% 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 2011–12 to 2015–16.

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

South Australian wind farm variations from 2011–12 to 2015–16 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

Financial Year	2011–12	2012–13	2013–14	2014–15	2015–16	Area
Registered capacity	688	688	958	958	958	Mid-north area
Max. 5-minute increase	143	117	140	170	202	
Max. 5-minute decrease	167	122	129	248	200	
Max. 30-minute increase	359	275	367	410	366	
Max. 30-minute decrease	375	223	381	381	373	
Max. 60-minute increase	436	404	434	539	483	
Max. 60-minute decrease	417	279	449	416	466	
Registered capacity	325	325	325	325	325	South-east area
Max. 5-minute increase	109	142	166	169	196	
Max. 5-minute decrease	108	158	149	148	174	
Max. 30-minute increase	258	275	273	291	294	
Max. 30-minute decrease	257	264	268	266	253	
Max. 60-minute increase	282	278	268	297	294	
Max. 60-minute decrease	294	286	277	287	302	
Registered capacity	191	191	191	191	191	Coastal peninsula area
Max. 5-minute increase	60	47	65	57	51	
Max. 5-minute decrease	56	74	70	61	65	
Max. 30-minute increase	80	94	119	93	89	
Max. 30-minute decrease	88	136	103	89	104	
Max. 60-minute increase	113	104	126	113	110	
Max. 60-minute decrease	89	136	132	91	117	
Registered capacity	1,203	1,203	1,473	1,473	1,473	All South Australia
Max. 5-minute increase	202	152	162	177	236	
Max. 5-minute decrease	218	193	166	215	264	
Max. 30-minute increase	375	369	406	408	461	
Max. 30-minute decrease	402	325	442	400	534	
Max. 60-minute increase	455	489	566	548	571	
Max. 60-minute decrease	507	414	490	456	506	

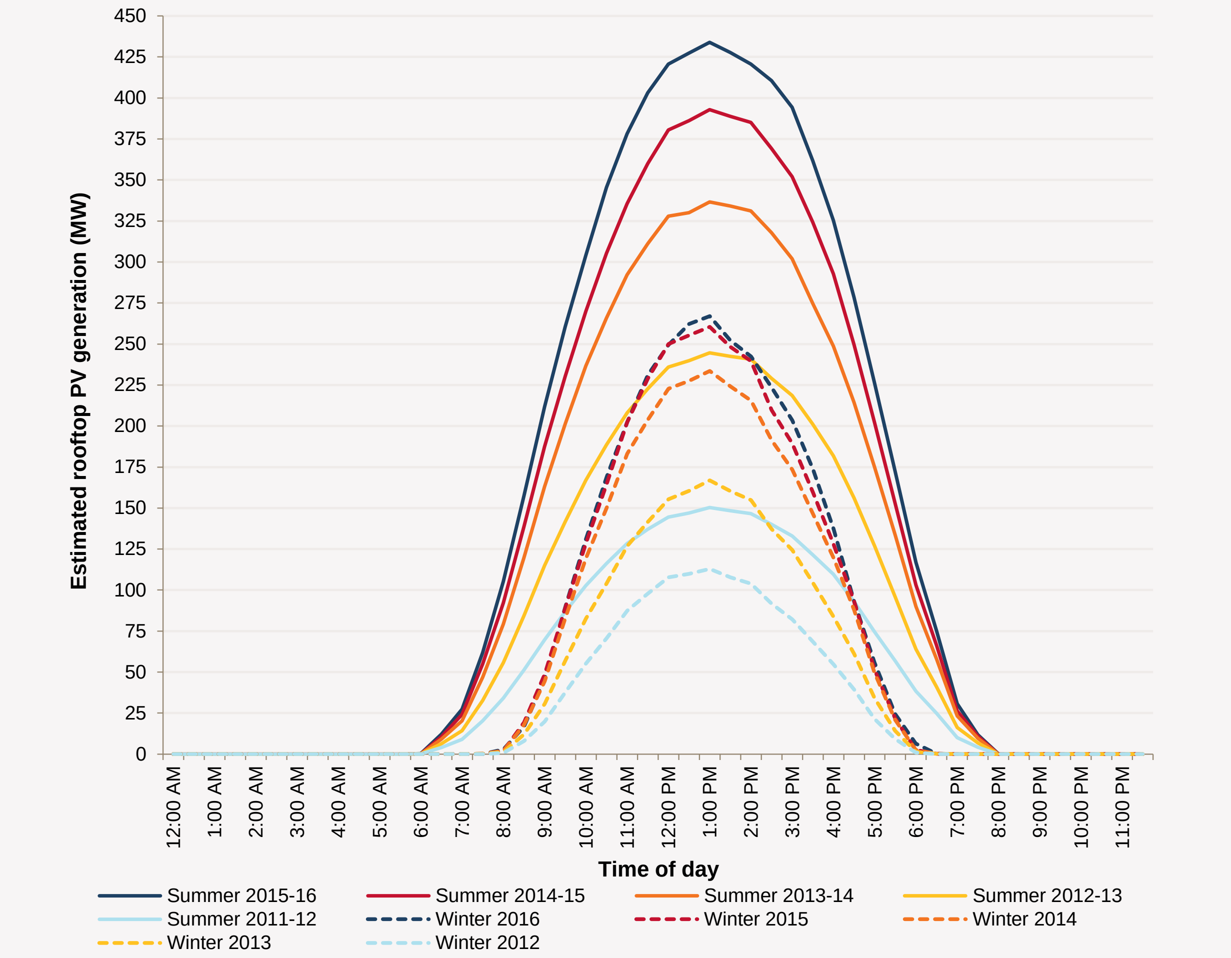
4.2 Rooftop PV variation

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 is greater generation in the summer months due to longer daylight hours and greater solar irradiance. When comparing the maximum summer capacity against output, the average capacity factor in summer is slightly above 30% compared to 15% to 18% during 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 2015–16, South Australian estimated rooftop PV generation varied by up to 176 MW (25.9% of estimated capacity) across 30-minute periods.

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

Financial Year	2011–12	2012–13	2013–14	2014–15	2015–16
Installed capacity	294	404	538	610	679
Max. 30-minute increase	82	66	240	115	152
Max. 30-minute decrease	81	99	236	142	176

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 to schedule sufficient generation in the dispatch process. 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 wind farms above or equal to 30 MW, for all NEM forecasting timeframes as follows:

- 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).[31]

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.

AWEFS accuracy is monitored for compliance with AEMO's internal performance standards on an 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. Forecast accuracy decreases as the forecast horizon extends, corresponding with the decreasing accuracy of the input weather models.

AEMO is currently conducting a formal Consultation[32] on amendments to the Energy Conversion Model (ECM) Guidelines for Wind and Solar farms. The ECM Guidelines define the static and dynamic information that Semi-Scheduled Generators provide to AEMO for use in AWEFS and ASEFS. The amendments aim to increase the accuracy of the AWEFS dispatch forecast by:

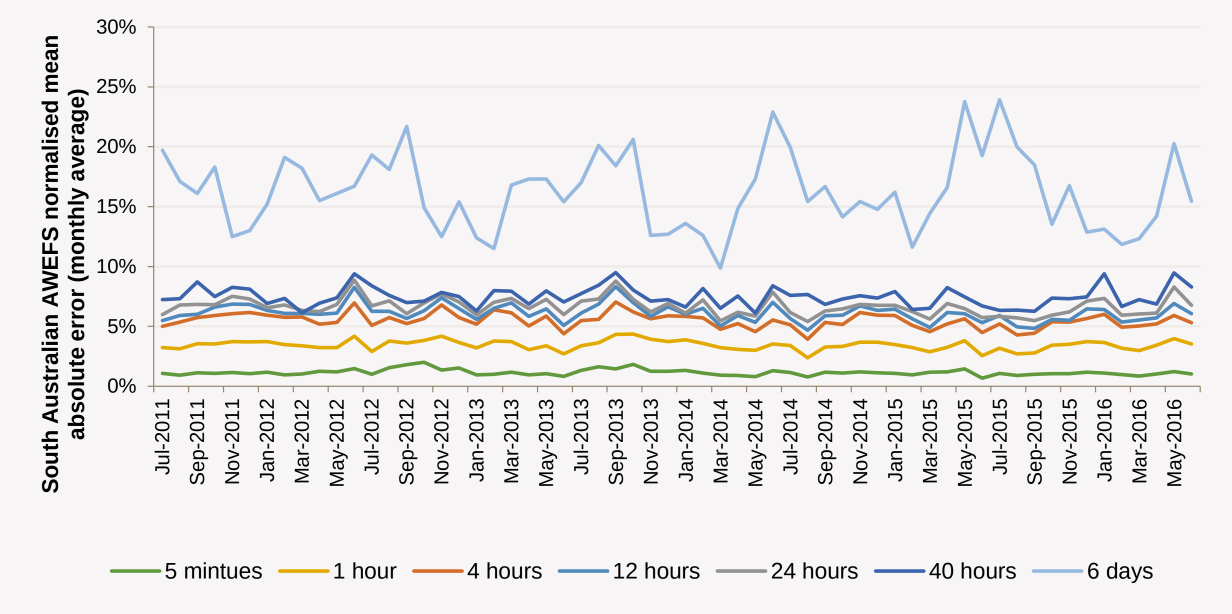
- Adding a new SCADA signal for generators to inform of local limitations to their capacity.
- Refining the definition of the Wind Speed SCADA signal to recommend an average of all turbine nacelle wind speed readings.
- Defining an optional SCADA signal "Estimated Power" for generators to provide a signal for use in dispatch forecasting that incorporates all technical factors affecting the wind farm's capacity.

In addition, AEMO is commencing a review of AWEFS performance and opportunities for improvement across all forecasting timeframes, and will be engaging with stakeholders during this process.

[31] Further information available at: https://www.aemo.com.au/Datasource/Archives/Archive1075.

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

Figure 18 Normalised mean absolute error of AWEFS forecasts for South Australia from FY12 to FY16



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 2016 SAHMIR. Renewable generation and spot market prices

Figures 19 and 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, with the market price cap increasing over the five-year period.

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 2011–12 to 2015–16)

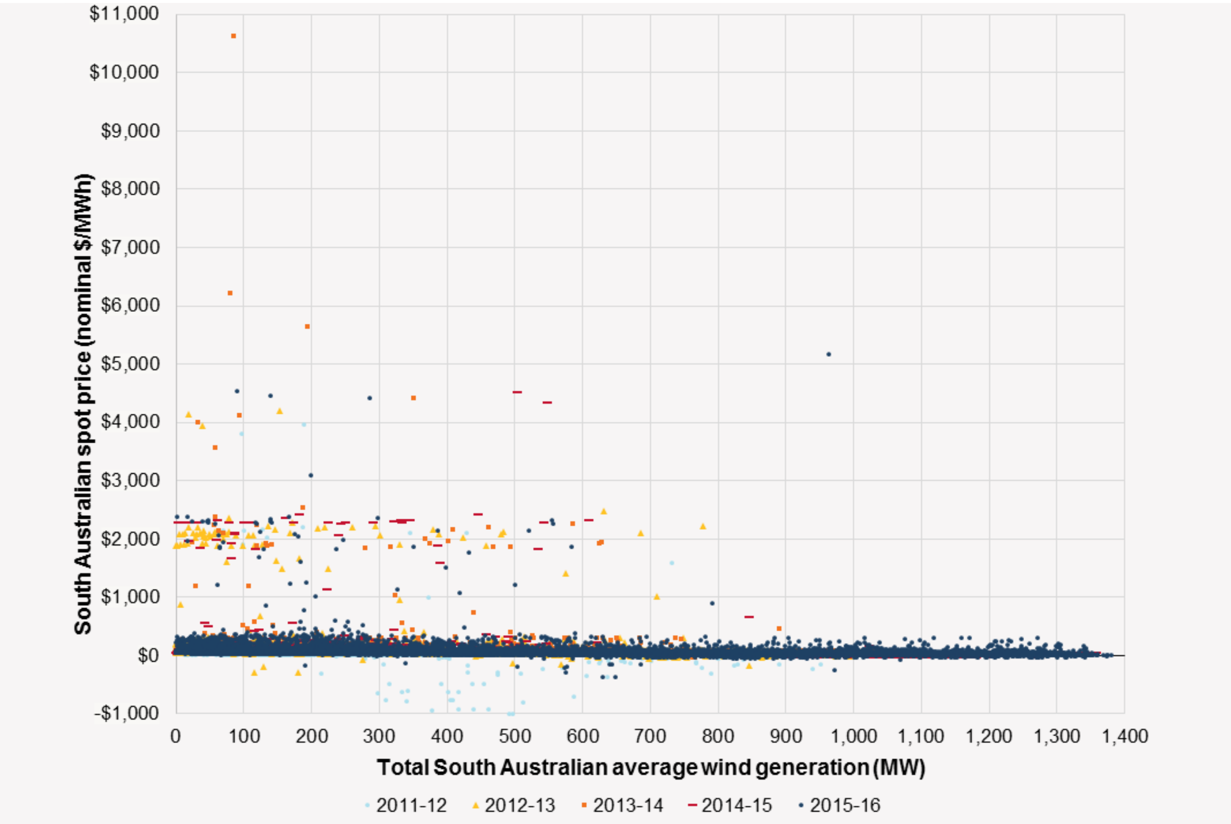
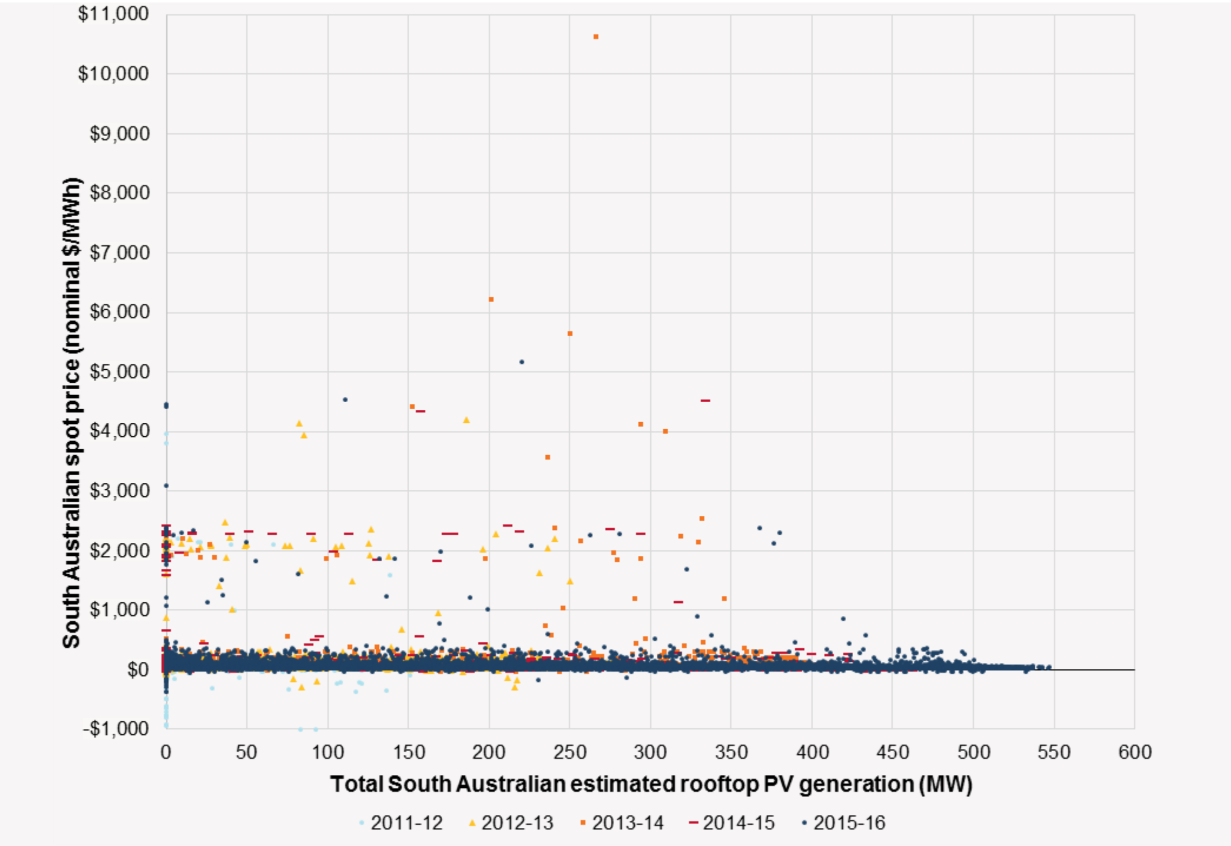


Figure 20 South Australian estimated rooftop PV generation and spot prices (30-minute data for 2011–12 to 2015–16)



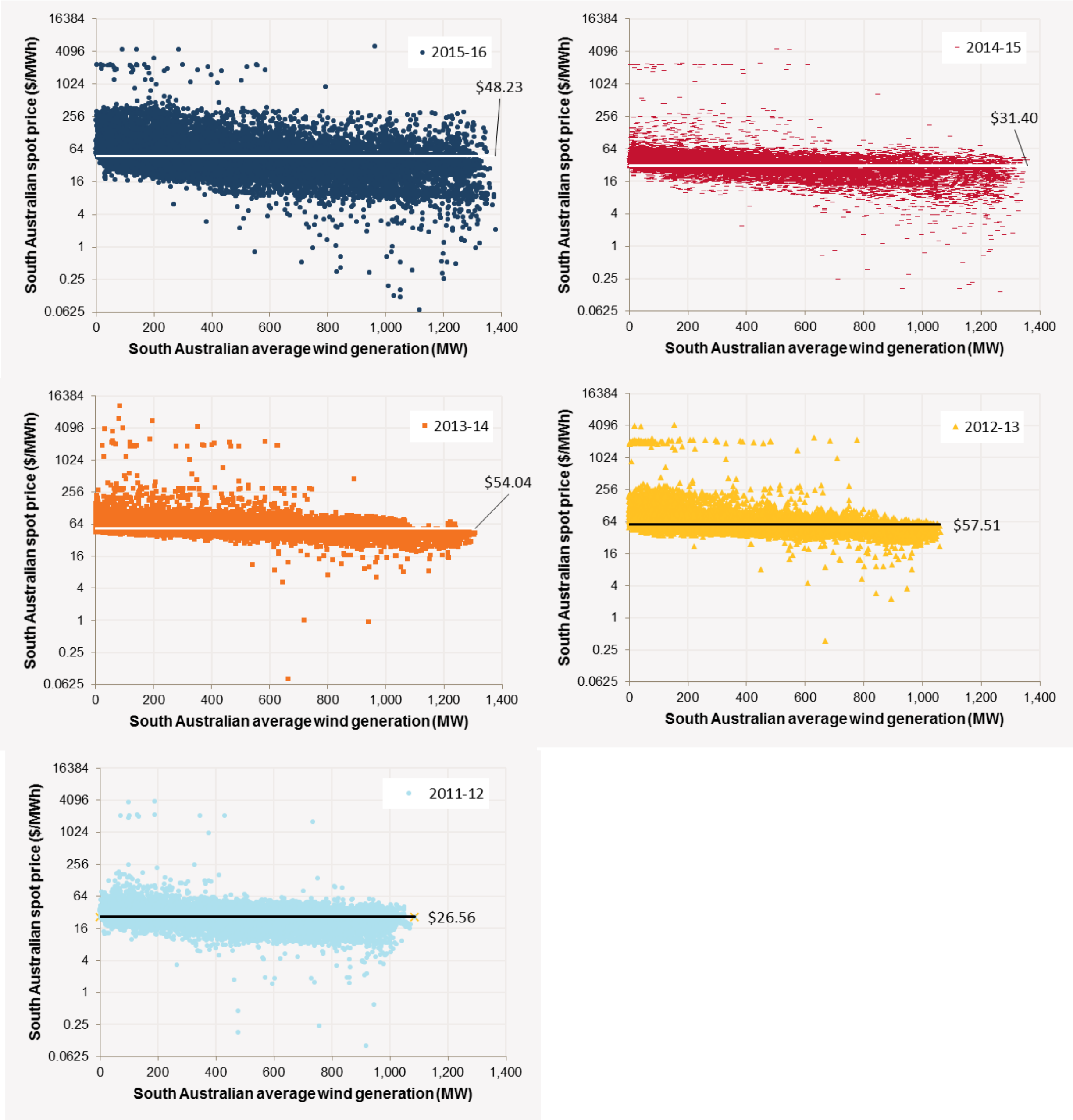
5.1.1 Positive spot price trading intervals

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 2011–12 to 2015–16. 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.

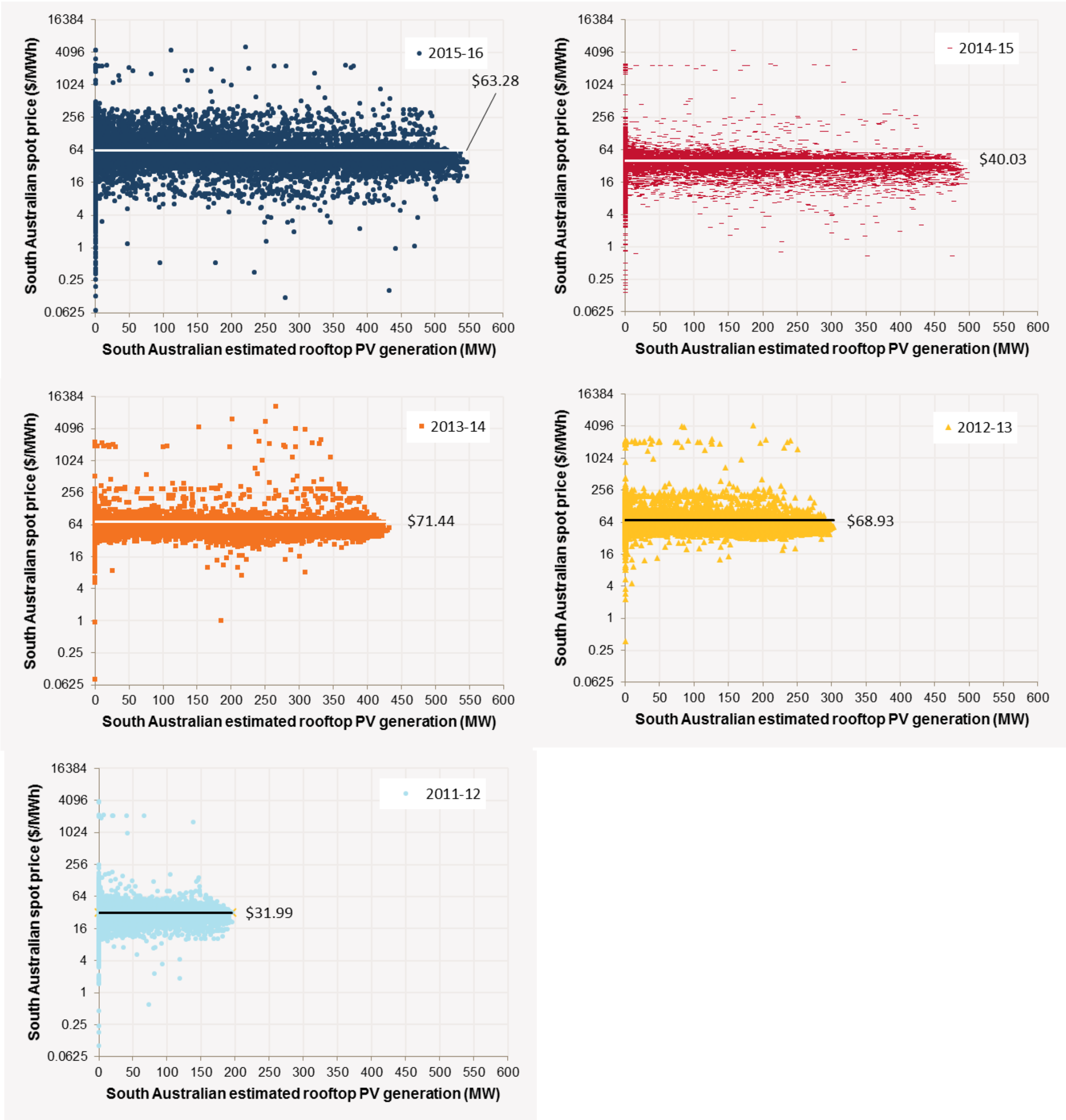
Excluding very high and very low prices, Figure 21 illustrates that most prices cluster around the mean, and decrease as wind generation output increases. Very high prices tend to occur when wind generation is low, while low prices tend to occur when wind generation is high. In contrast, Figure 22 does not show any correlation between price and rooftop PV generation level.

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)



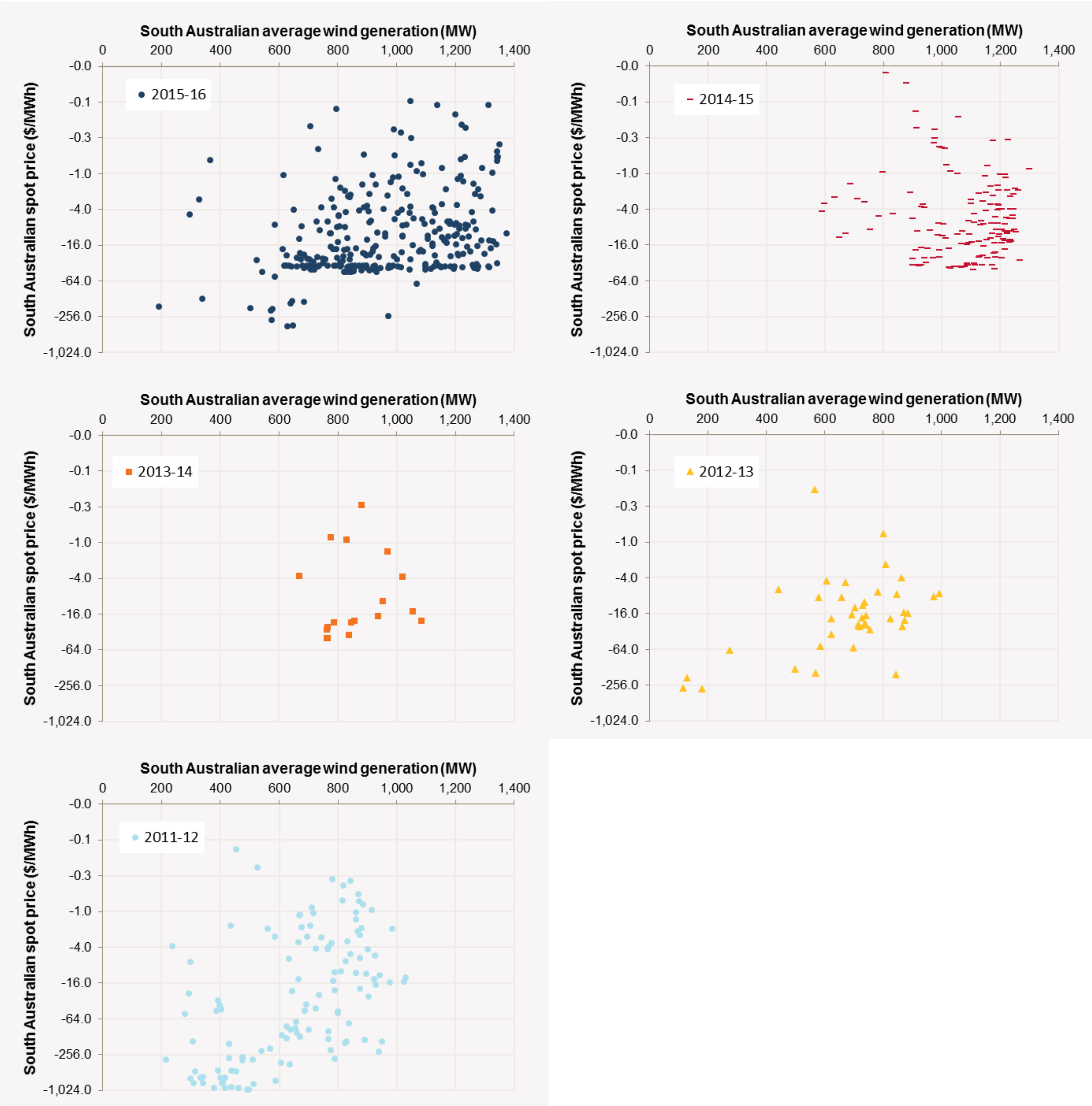
Note: Logarithmic axis

5.1.2 Negative spot price trading intervals

Figures 23 and 24 shows 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 2011–12 to 2015–16. Spot prices are plotted on a logarithmic axis to better represent the variance.

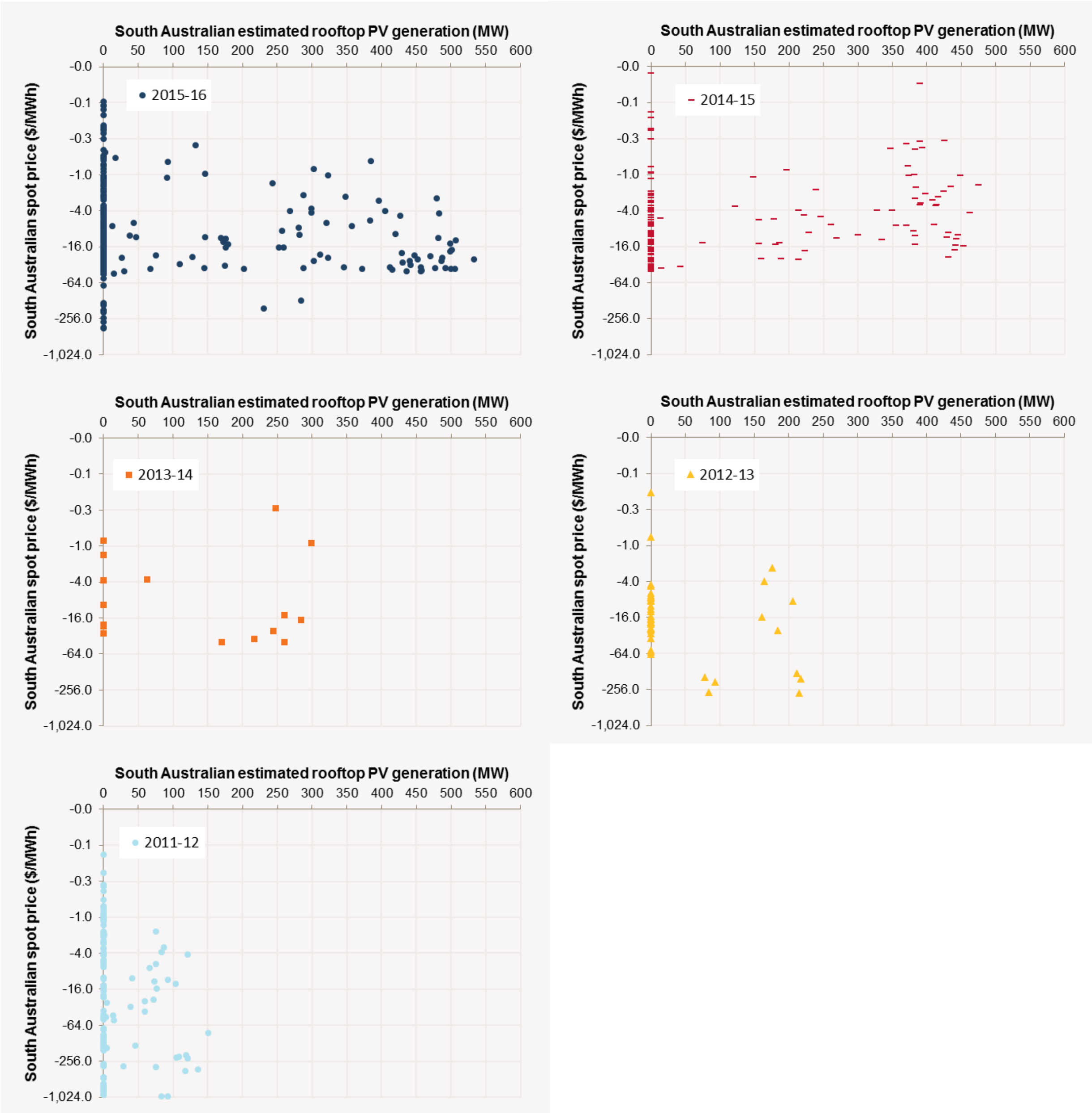
Of note is the number of negative spot prices, which has increased in both 2014–15 and 2015–16. A correlation is observed between the occurrences of negative prices at times of higher levels of wind generation. Negative prices are also often occurring overnight when there is no rooftop PV generation, as discussed in the next section.

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

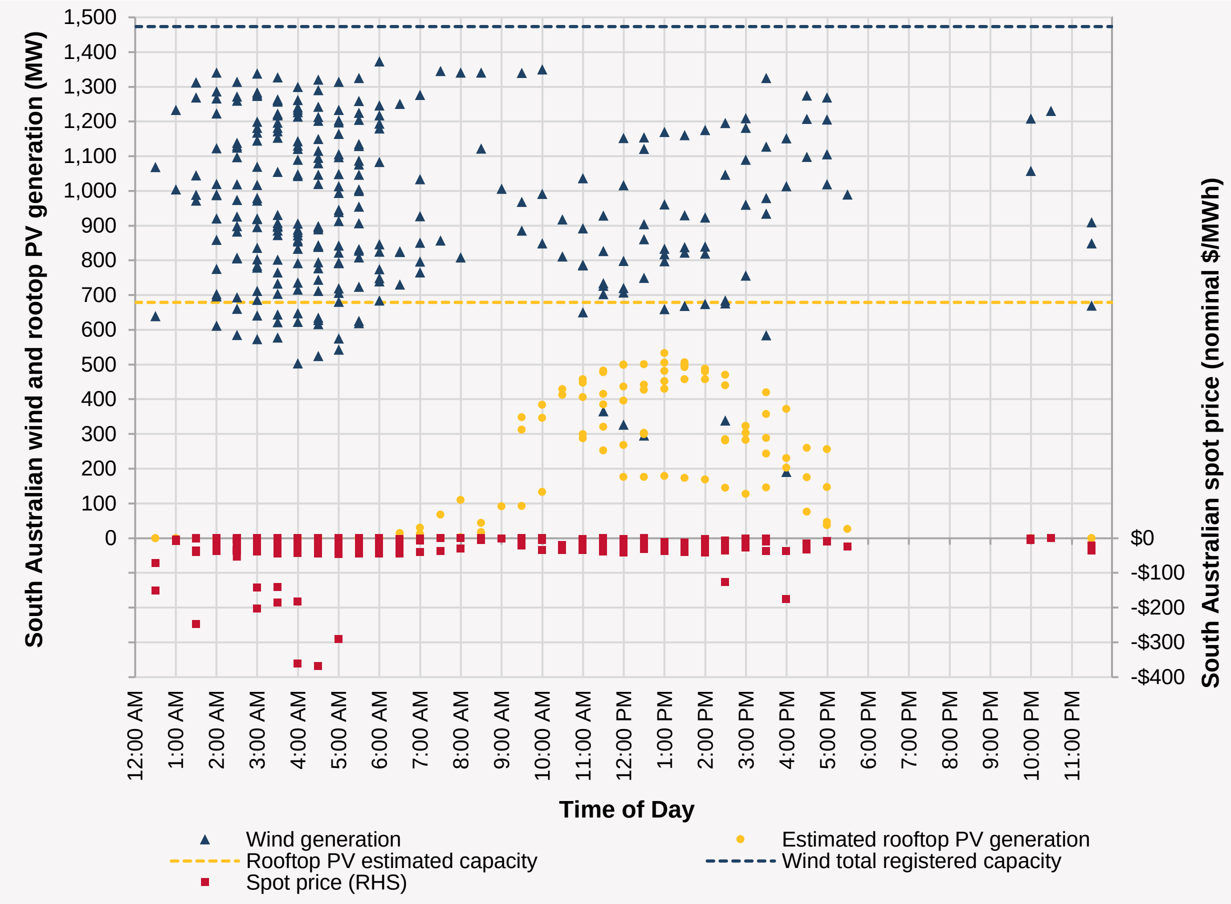
Negative spot prices by time of day

Figure 25 shows the time of day and wind generation level[33] for negative spot prices in 2015–16.

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.

[33] 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 (2015–16)



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 AND ROOFTOP PV STATISTICS

A.1 Wind farm capacities

Table 16 Registered capacities of South Australian wind farms

Wind farm	Dispatchable unit identifier (DUID)	Registered capacity (MW)*	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
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**
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	111	Semi-scheduled	Mid-north
Wattle Point Wind Farm	WPWF	90.75	Non-scheduled	Coastal peninsula

* Registered capacity sourced from AEMO's NEM Registration and Exemption List, 11 August 2016. Available: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Participant-information/Current-participants/Current-registration-and-exemption-lists.
** 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*.
*** Excludes the Waterloo Stage 2 expansion of +19.8 MW, which is now completed and undergoing commissioning, but was not registered during the period of analysis considered in this report.

A.2 Wind farm capacity factors

Table 17 Financial year capacity factors of South Australian wind farms[34]

Wind farm	Schedule Type	DUID	2011–12 Capacity factor (%)	2012–13 Capacity factor (%)	2013–14 Capacity factor (%)	2014–15 Capacity factor (%)	2015–16 Capacity factor (%)
Canunda	Non-scheduled	CNUNDAWF	30.8%	28.2%	31.0%	29.3%	27.9%
Hallett 5 (The Bluff)	Semi-scheduled	BLUFF1	32.5%	33.8%	36.4%	29.6%	32.6%
Cathedral Rocks	Non-scheduled	CATHROCK	31.9%	30.3%	34.0%	29.4%	29.1%
Clements Gap	Semi-scheduled	CLEMGPWF	35.0%	33.4%	36.0%	33.8%	34.6%
Hallett 1 (Brown Hill)	Semi-scheduled	HALLWF1	39.9%	40.1%	42.2%	37.2%	37.8%
Hallett 2 (Hallett Hill)	Semi-scheduled	HALLWF2	40.7%	41.0%	40.9%	37.3%	38.7%
Lake Bonney	Non-scheduled	LKBONNY1	28.5%	27.0%	29.2%	27.2%	25.8%
Lake Bonney Stage 2	Semi-scheduled	LKBONNY2	27.5%	27.2%	29.7%	28.4%	27.4%
Lake Bonney Stage 3	Semi-scheduled	LKBONNY3	25.3%	27.8%	29.0%	27.4%	27.1%
Mount Millar	Non-scheduled	MTMILLAR	30.6%	30.2%	33.3%	30.5%	29.8%
Hallett 4 (North Brown Hill)	Semi-scheduled	NBHWF1	39.4%	36.7%	40.8%	36.2%	38.3%
Snowtown Stage 2*	Semi-scheduled	SNOWNTH1 and SNOWSTH1	-	-	-	34.9%	37.0%
Snowtown	Semi-scheduled	SNOWTWN1	42.9%	43.1%	44.7%	38.4%	39.2%
Starfish Hill	Non-scheduled	STARHLWF	28.3%	22.6%	31.3%	28.4%	28.5%
Waterloo**	Semi-scheduled	WATERLWF	31.9%	32.0%	34.8%	30.1%	30.7%
Wattle Point	Non-scheduled	WPWF	34.0%	31.2%	37.0%	33.3%	33.8%

* Snowtown Stage 2 capacity factor is calculated for Snowtown Stage 2 North and Snowtown Stage 2 South wind farms combined.
** Waterloo capacity factor is based on a capacity of 111 MW, as was registered during the period of analysis.

[34] Data taken from the 2016 SAHMIR. Available at: http://aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/South-Australian-Advisory-Functions.

A.3 Wind generation variation

Table 18 Key statistical characteristics of wind generation variation for 2015–16

FY 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%

Table 19 Key statistical characteristics of wind generation variation for 2014–15

FY 2014–15	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%	1.2%	1.3%	2.3%	1.3%	2.1%	0.6%	1.1%	2.4%
Median	0.5%	0.8%	0.6%	1.1%	0.8%	1.3%	0.4%	0.8%	1.7%
Standard deviation	0.8%	1.4%	2.1%	3.5%	1.6%	2.6%	0.7%	1.2%	2.4%
Key statistical characteristics of absolute variation (megawatt equivalent)									
Mean	6.9	12.0	4.3	7.4	2.5	4.0	9.3	16.2	35.4
Median	4.6	8.0	2.1	3.6	1.5	2.5	6.3	11.1	25.2
Standard deviation	7.8	13.4	6.8	11.5	3.1	5.0	10.2	17.3	35.0
Absolute variation									
90th percentile	0.1%	0.1%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.3%
10th percentile	1.6%	2.8%	3.2%	5.6%	3.0%	5.0%	1.4%	2.5%	5.4%
5th percentile	2.2%	3.8%	4.8%	8.4%	4.2%	6.9%	1.9%	3.3%	7.0%
1st percentile	3.7%	6.4%	10.0%	17.4%	7.5%	12.4%	3.3%	5.6%	11.2%
Maximum	25.9%	30.3%	52.1%	82.0%	32.1%	43.6%	14.6%	18.6%	27.7%

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
ASEFS2	Australian Solar Energy Forecasting System Phase 2
AWEFS	Australian Wind Energy Forecasting System
DUID	Dispatchable unit identifier
ECM	Energy Conversion Model
MT PASA	Medium-term Projected Assessment of System Adequacy
NEM	National Electricity Market
NEFR	National Electricity Forecasting Report
NER	National Electricity Rules
NMAE	Normalised Mean Absolute Error
PV	Photovoltaic
RRP	Regional Reference Price
SAER	South Australian Electricity Report
SAEMETR	South Australian Electricity Market Economic Trends 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
VWAP	Volume-weighted average price

GLOSSARY

The 2016 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 2016 SARER are listed below.

Term	Definition
Absolute variation	The total variation, regardless of whether it is positive (an increase) or negative (a decrease).
ASEFS2	Australian Solar Energy Forecasting System Phase 2 (Small scale PV Forecasting). An in-development AEMO system that will produce forecasts up to 8 days ahead of distributed rooftop PV generation.
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.
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.