SOUTH AUSTRALIAN WIND STUDY REPORT

SOUTH AUSTRALIAN ADVISORY FUNCTIONS

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AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

IMPORTANT NOTICE

Purpose

The purpose of this publication is to provide information about wind generation in South Australia.

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EXECUTIVE SUMMARY

South Australian electricity supply and demand is evolving, with:

- Withdrawal of coal and gas-fired generation.
- Increases in wind generation.
- Increasing rooftop photovoltaics (PV), contributing to declining operational electricity consumption and minimum demand levels.

Alinta Energy's recent announcement to withdraw the Northern and Playford coal-fired power stations by 31 March 2016, means that South Australia will rely heavily on interconnection with Victoria for reliable and secure power supply in future.

When levels of instantaneous wind penetration are high, frequency control and network support services need to be sourced from Victoria to maintain power system security. And 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 generation in South Australia is key to managing operational risks in maintaining system security and reliability.

This report focuses on the performance of wind generation in South Australia over the last five financial years. Key insights include:

- Instantaneous wind penetration (ratio of wind energy to demand), continues to increase over time. Wind generation exceeded demand from the grid for around 30 hours in 2014–15, with surplus wind generation available for export to Victoria. In 2013–14, 100% of demand was met by wind generation for the first time, and for less than one hour.
- In 2014–15, maximum instantaneous wind penetration occurred in the middle of the day, when rooftop PV generation was high and operational demand was low. In contrast, in 2013–14 maximum instantaneous wind penetration occurred at around 4.30 am.[1]
- South Australia has 1,473 MW of registered wind capacity, more than any other region in the National Electricity Market (NEM). At least 9.9% of installed wind capacity has been available during summer peak demand periods (85% of the time in the past five years).
- The geographic diversity of wind across the state helps to reduce the aggregate variability of wind. As more wind farms come online, however, the residual demand (demand less wind generation) changes in South Australia are becoming more variable.
- The volume-weighted average spot price for wind generation continues to be lower than the volume-weighted average spot price for thermal generation in the state, with negative prices typically coinciding with high instantaneous wind penetration levels.

Instantaneous wind penetration

The maximum instantaneous wind penetration in 2014–15 reached 110% on 29 December 2014 at around 1.20 pm. Wind penetration was over 100% on 12 separate days (about 30 hours) between August and May.

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 4.00 am, when average demand is lowest. In contrast to daily averages, both minimum demand for South Australia (driven by rooftop PV generation) and maximum instantaneous wind penetration, occurred around midday in 2014–15, although on different days.

Table 1 summarises the change in maximum instantaneous penetration, along with a number of other internationally-recognised wind generation indices, from 2013–14 to 2014–15.

[1] All times reported are National Electricity Market (NEM) Standard Time, which is equivalent to Australian Eastern Standard Time and is not altered during daylight saving time.

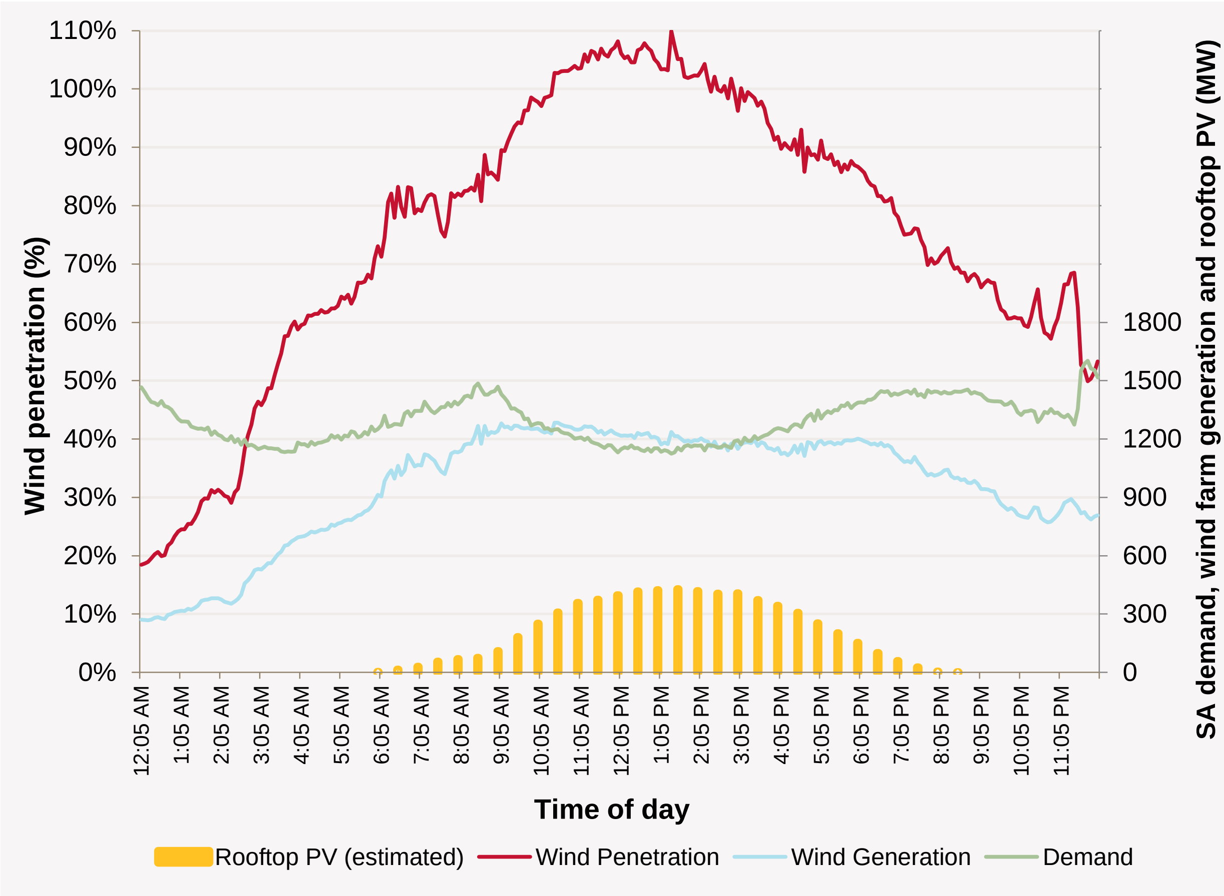
Table 1 South Australian wind generation indices

Description	Value for South Australia	
	2013–14**	2014–15
Capacity penetration: installed capacity as a percentage of total installed generation*	30%	30%
Energy penetration: ratio of annual wind energy to annual total energy consumption	31%	33%
Maximum instantaneous penetration (excluding exports): maximum observed ratio of wind energy to demand at any instant in time during the year	100%	110%
Maximum possible instantaneous penetration: the ratio of installed capacity to minimum demand	127%	191%
Periods of 100% (or greater) instantaneous wind penetration	<1 hour	30 hours

* Capacity penetration analysis for these years excludes the mothballed Playford B power station.
** Values for some indices are different to those published in the 2014 SAWSR due to improved time-alignment between non-scheduled and semi-scheduled wind farm data. For the maximum possible instantaneous penetration, the approach taken in 2015 better reflects the actual wind capacity at time of minimum demand.

Figure 1 shows 5-minute wind generation, demand from the grid, and instantaneous wind penetration, for 29 December 2014, when maximum wind penetration occurred. It also shows a trace of estimated 30-minute rooftop PV generation during this period, which highlights that rooftop PV is influencing the timing of maximum penetration observed, by lowering demand during the middle of the day.[2]

Figure 1 South Australian wind generation, demand and wind penetration for 29 December 2014



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

Wind generation and contribution to peak demand

Total installed wind generation capacity remained at 1,473 MW in 2014–15, with no new wind farms registered in South Australia. Total wind farm generation in South Australia for the year was 4,219 GWh. This was 3% higher than in 2013–14, largely driven by Snowtown Stage 2 Wind Farm's availability for the full financial year in 2014–15.

Analysis of the contribution of wind generation to the top 10% of summer peak demand periods in the past five years shows that more than 9.9% of South Australia's registered wind capacity was generating 85% of the time. In winter, the 85th percentile wind contribution is 6.8%. These contribution factors are the highest in the NEM for summer peak demand, and equal highest (alongside Victoria) for winter peak demand.

Wind generation variation

Due to the intermittent nature of wind, there is potential for sudden variations in generation from wind farms. Analysis of output in 2014−15 shows that for 90% of the time, South Australian total wind generation varies by no more than 24 MW (1.6% of registered capacity) across five-minute periods, and by no more than 38 MW (2.6% of registered capacity) across 10-minute periods. This variability in wind generation means the residual demand 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, larger residual demand changes in South Australia are observed more often.

Of the three South Australian geographical areas, the mid-north shows lower variation than the south-east and coastal peninsula areas. The aggregated South Australian variation is lower than any single area, reflecting the smoothing effect of multiple generating units in different areas across the state.

Wind generation and electricity price

In 2014–15, there was a continuing link between times of high wind generation and low spot prices for the region. Very high spot prices tended to occur when wind generation was low, while low spot prices occurred when wind generation was high.

Negative spot prices were observed in 154 price intervals in 2014–15, the second highest level in five years. Negative spot prices typically coincided with high wind energy penetration during the trading interval.

CONTENTS

EXECUTIVE SUMMARY **3**

1. INTRODUCTION **9**
1.1 Generating systems maps 9
1.2 Recent generation and network developments 12

2. SOUTH AUSTRALIAN WIND GENERATION PERFORMANCE **14**
2.1 Summary 14
2.2 Data and methodology 14
2.3 Registered capacity and maximum wind generation 14
2.4 Wind contribution during maximum demand 15
2.5 Total wind generation 17
2.6 Wind penetration 21
2.7 Short-term wind generation and demand variations 25

3. WIND GENERATION AND THE NATIONAL ELECTRICITY MARKET **30**
3.1 Data and methodology 30
3.2 Wind generation and market prices 30
3.3 Positive spot price trading intervals 33
3.4 Negative spot price trading intervals 34
3.5 Wind forecast performance 39

APPENDIX A. WIND FARM STATISTICS **41**
A.1 Wind farm capacities 41
A.2 Wind farm capacity factors 42
A.3 Wind generation variation 43

MEASURES AND ABBREVIATIONS **44**
Units of measure 44
Abbreviations 44

GLOSSARY **45**

TABLES

Table 1	South Australian wind generation indices	4
Table 2	South Australian registered capacity by fuel type	9
Table 3	Publicly announced generation withdrawals	12
Table 4	Registered wind generation capacity and maximum five-minute wind generation	15
Table 5	85th percentile wind contribution (% of registered capacity) of top 10% seasonal peak demand	15
Table 6	Expected wind contribution at peak demand (% of registered wind capacity)	16
Table 7	Total South Australian wind generation	18
Table 8	South Australian wind penetration indices	21
Table 9	Total registered capacity and historical maximum variation outputs (MW) by area	29
Table 10	Frequency of occurrence of spot prices for South Australia	31
Table 11	Volume-weighted average spot prices for wind generation (real Q4 2014–15 dollars)	32
Table 12	Registered capacities of South Australian wind farms	41
Table 13	Capacity factors of South Australian wind farms	42
Table 14	Key statistical characteristics and five- and 10-minute wind generation variation for 2014–15	43
Table 15	Key statistical characteristics and five- and 10-minute wind generation variation for 2013–14	43

FIGURES

Figure 1	South Australian wind generation, demand and wind penetration for 29 December 2014	4
Figure 2	Location and capacity of South Australian generating systems	10
Figure 3	Location and capacity of proposed South Australian generation projects	11
Figure 4	Summer peak demand wind generation duration curve (% of registered wind capacity)	16
Figure 5	Winter peak demand wind generation duration curve (% of registered wind capacity)	17
Figure 6	South Australian total monthly wind energy output and average monthly contribution	18
Figure 7	South Australian wind generation capacity factors	19
Figure 8	Annual South Australian wind generation duration curves	20
Figure 9	Daily demand, wind generation and penetration profile	22
Figure 10	South Australian wind generation, demand and wind penetration for 29 December 2014	23
Figure 11	Instantaneous wind penetration duration curves	24
Figure 12	South Australian wind generation, demand, and residual demand (variation distribution)	25
Figure 13	South Australian residual demand (variation distribution)	26
Figure 14	Five- and 10-minute absolute wind generation variation for 2014–15	27
Figure 15	Absolute wind variation as percentage of registered capacity	28
Figure 16	South Australian average wind generation and spot prices (30-minute data for 2010–11 to 2014–15)	31
Figure 17	South Australian 30-minute spot prices and average wind generation (positive market prices)	33
Figure 18	South Australian 30-minute spot prices and average wind generation (negative market prices)	34

Figure 19	Negative South Australian spot price and average wind generation by time of day (2014-15)	35
Figure 20	Count of negative price trading intervals per year	36
Figure 21	South Australian spot price duration curves, negative values only	37
Figure 22	Supply summary at selected times of negative South Australian spot price during 2014–15	38
Figure 23	Normalised mean absolute error of AWEFS forecasts for South Australia 2014-15	40

1. INTRODUCTION

The South Australian Wind Study Report (SAWSR) analyses the state's historical wind farm performance, including electricity market pricing insights, over the five years 2010–11 to 2014–15.

- **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 capacity, maximum instantaneous generation, contribution to demand, total generation and share, penetration, and short-term generation variation.
- **Chapter 3 − Wind generation and the National Electricity Market** provides analyses of historical generation, the relationship between wind generation and price in South Australia, and a brief discussion on performance of wind forecasting.
- **Appendix A − Wind farm statistics** provides the name, geographic area, scheduling type, and registered capacity of the wind farms considered in this report, as well as their capacity factors and generation variation metrics.

South Australian demand refers to the operational demand met by local scheduled, semi-scheduled and selected non-scheduled generating systems plus interconnector imports from Victoria, and excludes demand supplied by rooftop photovoltaic (PV) generation.

Operational demand refers to electricity used at a specific point in time (typically at a 5 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)). [3]

South Australian generating systems included in operational reporting are shown in Figure 2. For this report, however, demand or consumption analysed is always operational demand or consumption, less output from Angaston, Port Stanvac 1 and Port Stanvac 2 generating systems.

All time references in this report are to National Electricity Market (NEM) Standard Time.[4]

1.1 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 October 2015.[5]

Table 2 summarises the capacity mix of fuel types for all registered generation in South Australia as at October 2015.

Table 2 South Australian registered capacity by fuel type

Fuel Type	Registered Capacity (MW)
Wind	1,473
Coal*	770
Gas	2,668
Diesel	270
Other	28

* Coal capacity includes Playford B power station, but the power station has been mothballed since 2012.

3 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.

4 NEM Standard Time is equivalent to Australian Eastern Standard Time and is not altered during daylight saving time.

5 AEMO Generation Information for South Australia. 2015, October 26. Available at: http://www.aemo.com.au/Electricity/Planning/Related-Information/Generation-Information. Viewed: 26 October 2015.

Figure 2 Location and capacity of South Australian generating systems

Figure 3 Location and capacity of proposed South Australian generation projects

1.2 Recent generation and network developments

The South Australian generation mix is changing. Current and announced withdrawals of synchronous coal and gas-fired generation within the state is leading to greater reliance on wind generation, rooftop PV and interconnector imports to meet South Australia's electricity consumption. This section outlines the recent generation and network developments in the state.

Since 2014, AEMO and ElectraNet have been undertaking power system security studies to understand the operational impacts of high levels of renewable generation (from wind farms and rooftop PV) and low levels of online synchronous generation in South Australia.

The key conclusion to date is that the South Australian power system can operate securely and reliably with a high percentage of wind and rooftop PV generation as long as the Heywood Interconnector is operational. Further information can be found in the 2015 South Australian Electricity Report (SAER)[6], and a new report updating the challenges is due to be published December 2015.

1.2.1 New wind farm generating systems

Operation of the Snowtown Stage 2 Wind Farm (270 MW) commenced in 2013–14, with commissioning completed in November 2014. The site consists of two separately metered wind farms: Snowtown 2 Stage 2 North (144 MW) and Snowtown 2 Stage 2 South (126 MW). Generation totals in this report include all output from Snowtown Stage 2 Wind Farm, unless otherwise indicated. For the SAWSR analysis, South Australia's wind farm capacity total is considered to have increased by 270 MW in June 2014, when Snowtown Stage 2 Wind Farm generation first reached 90% of registered capacity.

The first 102.4 MW of the Hornsdale wind farm project progressed to committed status on 21 August 2015 and is expected to be operating by November 2016.

1.2.2 Generating system withdrawals

A summary of existing and announced South Australian generation withdrawals is listed in Table 3.

Table 3 Publicly announced generation withdrawals

Station Name	Fuel Type	Capacity Change (MW)**	Change details
Northern	Coal	-546	Full retirement in March 2016
Playford B	Coal	-240	Full retirement in March 2016*
Torrens Island A	Gas	-480	Out of service from 2017
Pelican Point	Gas	-239	Operating at half capacity
	Total	**-1,505**	

* Playford B power station is currently mothballed.
** Capacity reported is nameplate capacity.

[6] AEMO. 2015 South Australian Electricity Report (SAER), Section 4.1.1. Available at: http://www.aemo.com.au/Electricity/Planning/South-Australian-Advisory-Functions/South-Australian-Electricity-Report. Viewed: 20 October 2015.

Northern and Playford B power stations

In 2014−15, Northern Power Station returned to normal service (from October 2014) and Playford B remained mothballed with a recall time of around 90 days.[7]

Alinta Energy has announced that both power stations will cease generation around 31 March 2016.[8] These are the last two operational coal-fired power stations in South Australia.

Torrens Island A power station

Torrens Island Power Station A is to be taken out of service indefinitely from winter 2017, subject to review if market conditions change materially.[9]

Pelican Point power station

Pelican Point Power Station has been available at half capacity from 1 April 2015, and shows 0 MW availability in the medium term projected assessment of system adequacy (MT PASA) for winter 2016, given the current dynamics and outlook in the electricity and gas markets.[10]

1.2.3 Heywood Interconnector upgrade

Completion of the Heywood Interconnector upgrade is scheduled for July 2016. The project increases the power transfer capacity of the interconnector from 460 MW to a nominal 650 MW. The staged delivery of sub-components of the upgrade is expected to deliver portions of the capacity increase before this date. More information on the Heywood Interconnector upgrade is available on AEMO's website.[11]

[7] Alinta Energy advised: Northern Power Station returned back to normal service in October 2014 (following periods of withdrawal from April to September in 2013 and 2014), and Playford B Power Station will be available with a recall time of around 90 days.
Source: AEMO Generation Information for South Australia. 2015, October 26. Available at: http://www.aemo.com.au/Electricity/Planning/Related-Information/Generation-Information. Viewed: 26 October 2015.

[8] AEMO Generation Information for South Australia. 2015, October 26. Available at: http://www.aemo.com.au/Electricity/Planning/Related-Information/Generation-Information. Viewed: 26 October 2015.

[9] Refer to Note 8.

[10] Refer to Note 8.

[11] AEMO. Heywood Interconnector Update. Available: http://www.aemo.com.au/Electricity/Planning/South-Australian-Advisory-Functions/Heywood-Interconnector-Update. Viewed: 1 October 2015.

2. SOUTH AUSTRALIAN WIND GENERATION PERFORMANCE

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 (as aggregated across a financial year), and wind generation and maximum demand (as measured at five-minute intervals). Key observations include:

- Overall, the maximum five-minute generation from South Australian wind farms increased by 2.4%, from 1,332 MW in 2013–14 to 1,364 MW in 2014–15. This increase was likely due to seasonal variations in wind.
- Total energy from wind generation increased by 3%, from 4,087 GWh in 2013–14 to 4,219 GWh in 2014–15, largely driven by Snowtown Stage 2 Wind Farm's availability for the full financial year in 2014–15.
- With reduced consumption and higher wind generation, 2014–15 saw higher or equal wind penetration indices. Maximum instantaneous penetration reached 110% in 2014–15, with wind supplying 33% of the state's consumption from the grid, up from 31% in 2013–14.
- Average wind penetration was highest between 3.00 am and 4.00 am, but maximum instantaneous penetration and minimum demand occurred in the middle of the day.

2.2 Data and methodology

AEMO used the following methodology with regard to data throughout this chapter:

- Cleared supply values (unless otherwise indicated) for all semi-scheduled wind generation totals, based on a five-minute dispatch interval. Non-scheduled wind generation is not dispatched so corresponding five-minute generation output is used instead.
- Wind generation (unless otherwise indicated) during commissioning periods is included.

2.3 Registered capacity and maximum wind generation

South Australia has the highest registered wind generation capacity of any state in Australia. Table 4 shows the total capacity for all South Australian semi-scheduled and non-scheduled wind farms registered by AEMO, together with the maximum five-minute generation output over the past five financial years from 2010–11 to 2014–15.

Changes in registered wind farm capacity do not always match changes in maximum five-minute generation, because small variations in maximum five-minute generation are attributed to seasonal variations in wind speed across the geographically diverse locations of the state's wind farms.

Table 4 Registered wind generation capacity and maximum five-minute wind generation

Financial year	Registered capacity (MW)*	Reason for increase in capacity	Maximum five-minute generation (MW)*
2010–11	1,151	N/A	1,061
2011–12	1,203	Hallett 5 (The Bluff) Wind Farm (52 MW)	1,082
2012–13	1,203	N/A	1,069
2013–14	1,473	Snowtown Stage 2 Wind Farm (270 MW)	1,332
2014–15	1,473	N/A	1,364

* Data is captured from when each wind farm was entered into AEMO systems, and includes the commissioning period. Values for some years are different to those published in the 2014 SAWSR due to improved time-alignment between non-scheduled and semi-scheduled wind farm data.

2.4 Wind contribution during maximum demand

Wind generation during peak demand depends on both wind speed and the operational limitations of wind turbines across the state. Wind is intermittent by nature, with periods of low wind (and in some cases very high wind[12]) resulting in low generation output.

When these situations arise in South Australia, excess demand must be met by other types of generation within the state or by imports from Victoria. Currently, non-renewable generation such as gas, coal, or diesel meets any shortfall. However, with the recent announcement that Northern Power Station will close by 31 March 2016, at times of high operational demand and low wind output, there will be greater reliance on imports from Victoria to maintain reliability.

To meet its medium-term projected assessment of system adequacy (MT PASA) reliability obligations, AEMO forecasts a minimum level of expected wind generation over the next two years, with a 90% probability of exceedance (POE). This conservatively assesses supply adequacy to cover anticipated consumption, especially during times of high or peak demand. Wind generation forecasts for MT PASA are taken from the Australian Wind Energy Forecasting System (AWEFS).

A review of wind generation performance for the top 10% of five-minute demand dispatch intervals, over a five year period, highlights that the contribution from wind generation is variable between seasons and across years. Table 5 provides the 85th percentile level of expected wind generation across summer and winter peak periods over the past five years.[13] The wind contribution is generally higher in summer than in winter.

Table 5 85th percentile wind contribution (% of registered capacity) of top 10% seasonal peak demand

Summer peak period	% of registered capacity	Winter peak period	% of registered capacity
2010–11	9.0%	2010	3.9%
2011–12	9.2%	2011	8.8%
2012–13	9.9%	2012	9.4%
2013–14	9.7%	2013	6.2%
2014–15	11.7%	2014	6.0%
5-year summer average	9.9%	5-year winter average*	6.8%

* Seasonal averages are calculated from non-rounded seasonal data for 2010 to 2014, which explains why the winter average does not exactly match the average of the rounded winter values for 2010 to 2014 which are shown in this table.

South Australia has the highest expected contribution factor to summer peak demand in the NEM (9.9% of registered capacity) and equal highest factor alongside Victoria for winter peak demand (6.8% of registered capacity). Table 6 compares the minimum expected contribution of wind generation to peak demand across different NEM regions.[14]

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12 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.
13 Analysis for wind contribution factors excludes wind generation from the period before a new wind farm first reached 90% of registered capacity.
14 Queensland region is not included in the analysis as there is insufficient historical data compared to other NEM regions.

Table 6 Expected wind contribution at peak demand (% of registered wind capacity)

Minimum expected wind contribution to peak demand*	South Australia	Victoria	Tasmania	New South Wales
5-year summer average	9.9%	7.0%	7.8%	1.2%
5-year winter average	6.8%	6.8%	3.5%	3.4%

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

Figures 4 and 5 illustrate the 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.

Figures 4 and 5 illustrate that:

- For 10% of summer peak demand periods, wind generation contributes about 49%–61% of its registered capacity, and for 50% of summer peak demand periods, it contributes about 20%–27% of its registered capacity.
- For 10% of winter peak demand periods, wind generation contributes about 77%–82% of its registered capacity, and for 50% of winter peak demand periods, it contributes about 23%–41% of its registered capacity.

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

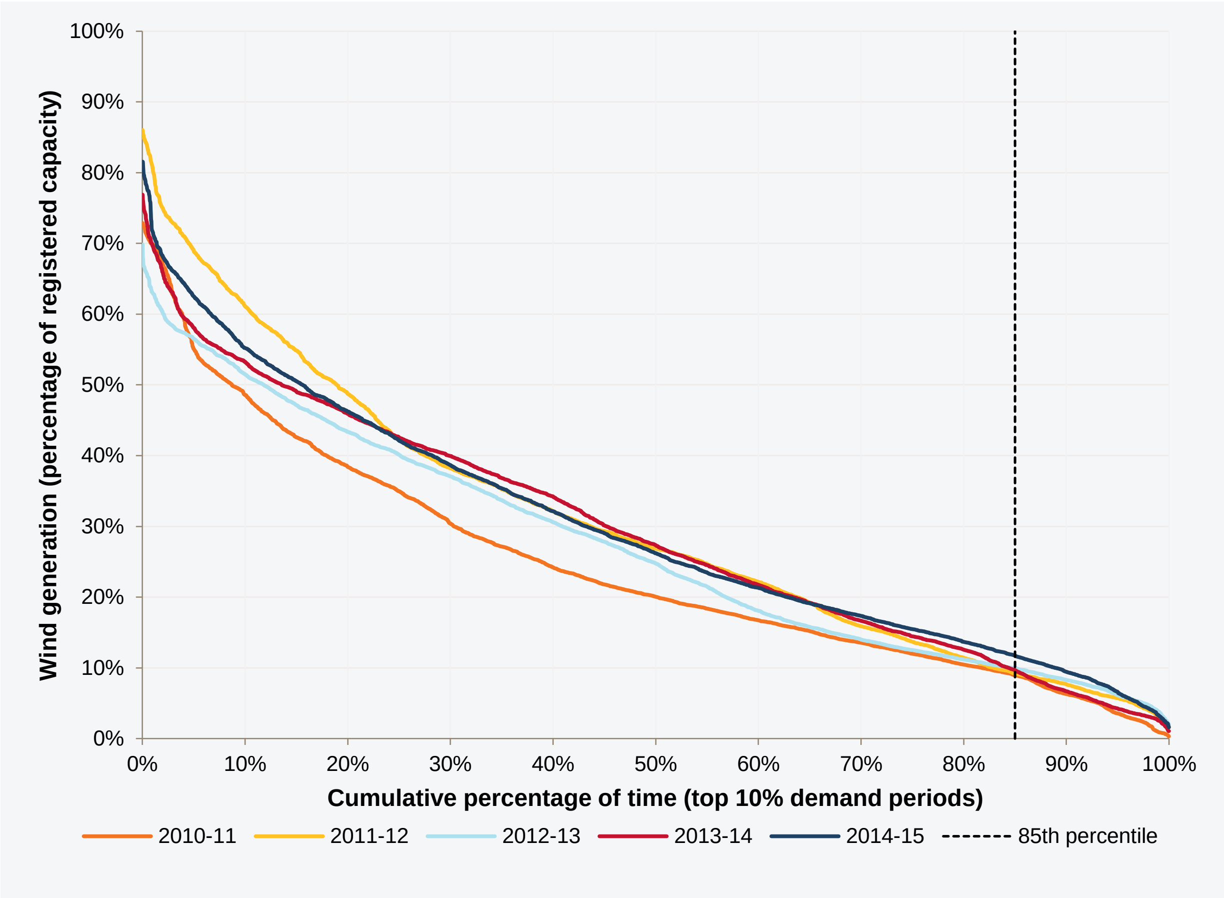
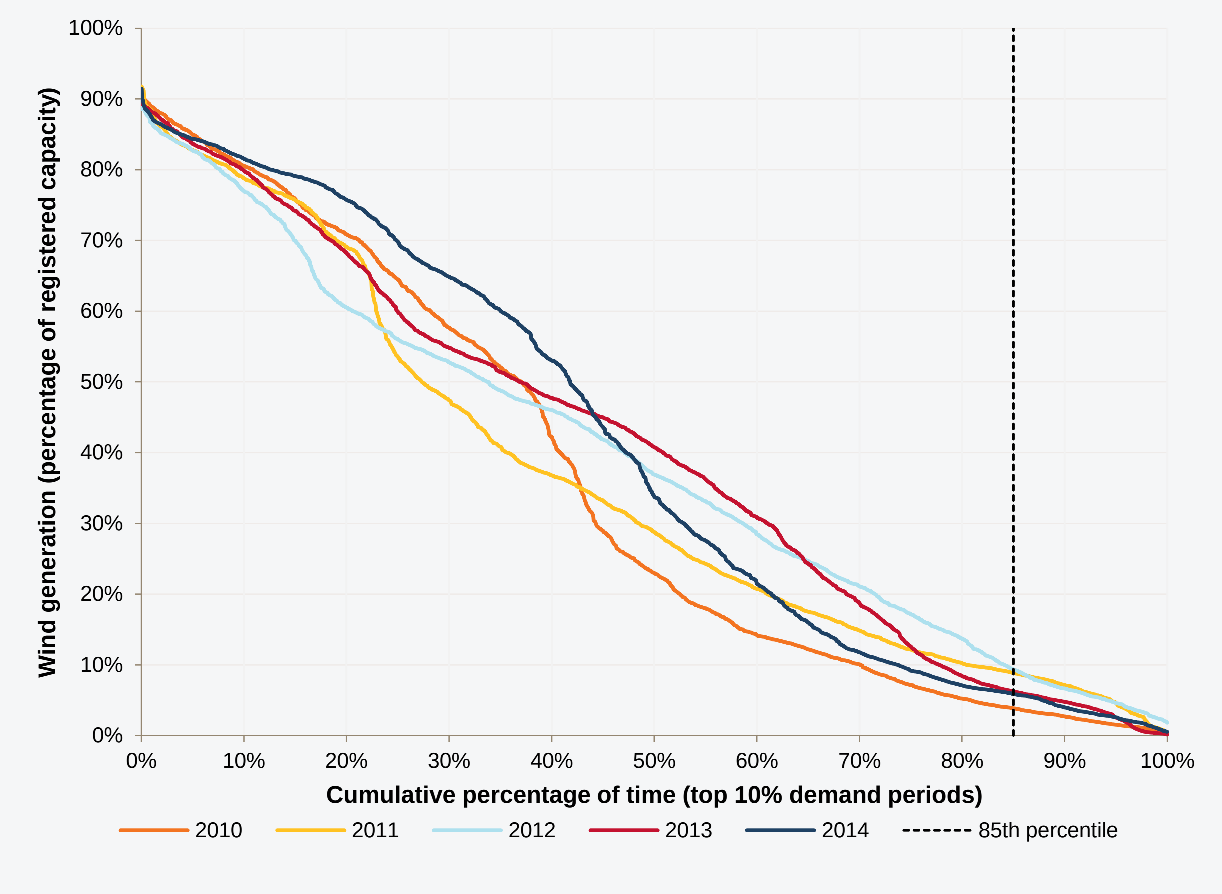


Figure 5 Winter peak demand wind generation duration curve (% of registered wind capacity)



2.5 Total wind generation

Annual energy from wind generation

Table 7 summarises annual wind generation and its annual change since 2010–11.

Key observations are:

- Annual wind generation in South Australia has increased in line with installed capacity increases since 2010–11. In 2012–13, when there was no new registered wind capacity and lower wind resources, a 2% reduction in annual output was observed.
- In 2013–14, Snowtown Stage 2 Wind Farm was brought online, and first reached 90% of its registered capacity in June 2014. Growth in wind generation in 2014–15 was largely driven by Snowtown Stage 2 Wind Farm's availability for the full financial year.

Table 7 Total South Australian wind generation

Financial year	Annual South Australian wind generation (GWh)*	Annual change in wind generation	Annual capacity factor**
2010–11	3,039		38%
2011–12	3,563	17%	34%
2012–13	3,474	-2%	35%
2013–14	4,087	18%	36%
2014–15	4,219	3%	35%

* Wind generation is calculated using 5-minute Supervisory Control and Data Acquisition (SCADA) readings for all wind farms, and differs from the use of cleared dispatch values used elsewhere for semi-scheduled wind farms.
** Capacity factor is simply the ratio of annual generation in this table to the annual capacity reported in Section 2.3, Table 4.

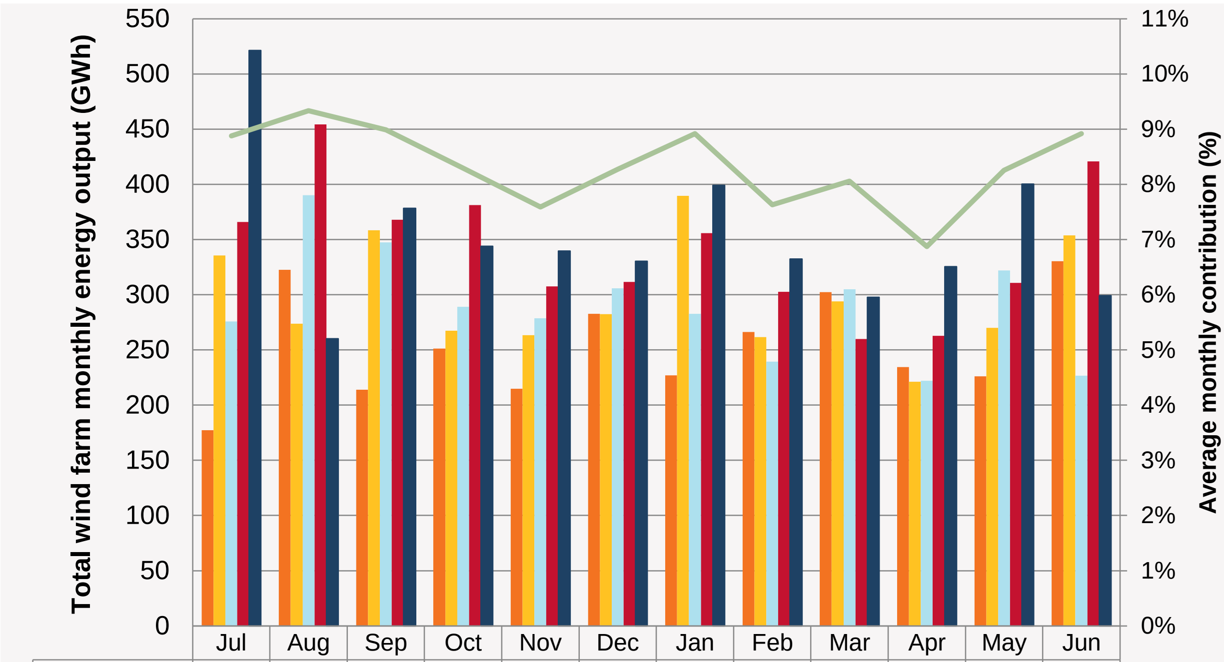
Monthly wind generation variability

Figure 6 shows the monthly South Australian wind generation in GWh over the last five financial years from 2010–11 to 2014–15. Also shown is the average monthly contribution to financial year totals.

Monthly totals show significant variation and some underlying seasonal deviations, with average contribution peaking in late winter and early spring, and some reduction of output in autumn.

Snowtown Stage 2 Wind Farm commenced generation in October 2013 and reached 90% of registered capacity in June 2014. Waterloo Wind Farm reached 90% of registered capacity in August 2010 and Hallet 5 (The Bluff) Wind Farm reached 90% of registered capacity in July 2011.

Figure 6 South Australian total monthly wind energy output and average monthly contribution



	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
2010-11	177	323	214	251	215	283	227	266	302	235	226	330
2011-12	335	274	358	267	263	282	390	262	294	221	270	354
2012-13	276	390	348	289	279	306	283	239	305	222	322	227
2013-14	366	454	368	381	307	312	356	303	260	263	311	421
2014-15	521	260	378	344	340	330	399	332	298	325	400	299
Avg %	8.9%	9.3%	9.0%	8.3%	7.6%	8.3%	8.9%	7.6%	8.1%	6.9%	8.3%	8.9%

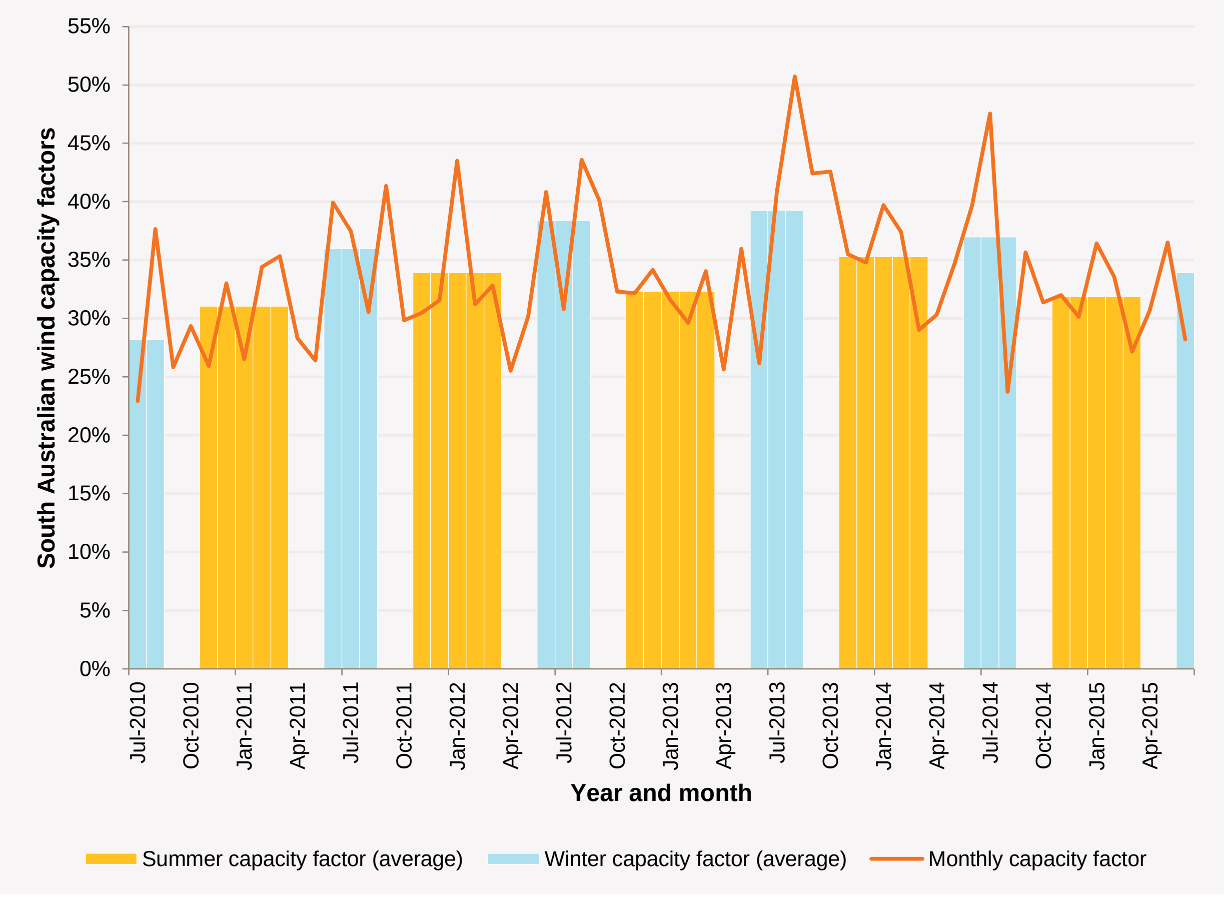
Seasonal capacity factors - conclusions

Figure 7 shows the capacity factors for South Australian wind generation, based on the total registered capacity for each month, over the last five financial years from 2010–11 to 2014–15.

Key observations are:

- Average winter capacity factors are usually higher than average summer ones.
- Capacity factors are usually highest in the winter months and lowest in the autumn months.
- There is variation across the years for any given month or season, which is attributable to seasonal changes in wind speeds across the state's wind farm sites.
- Capacity factors for 2014–15 are lower than for 2013–14, and this is also seen when examining individual wind farm capacity factors (refer to Appendix A.2). Less wind was measured at the wind farm locations in 2014–15.[15]

Figure 7 South Australian wind generation capacity factors



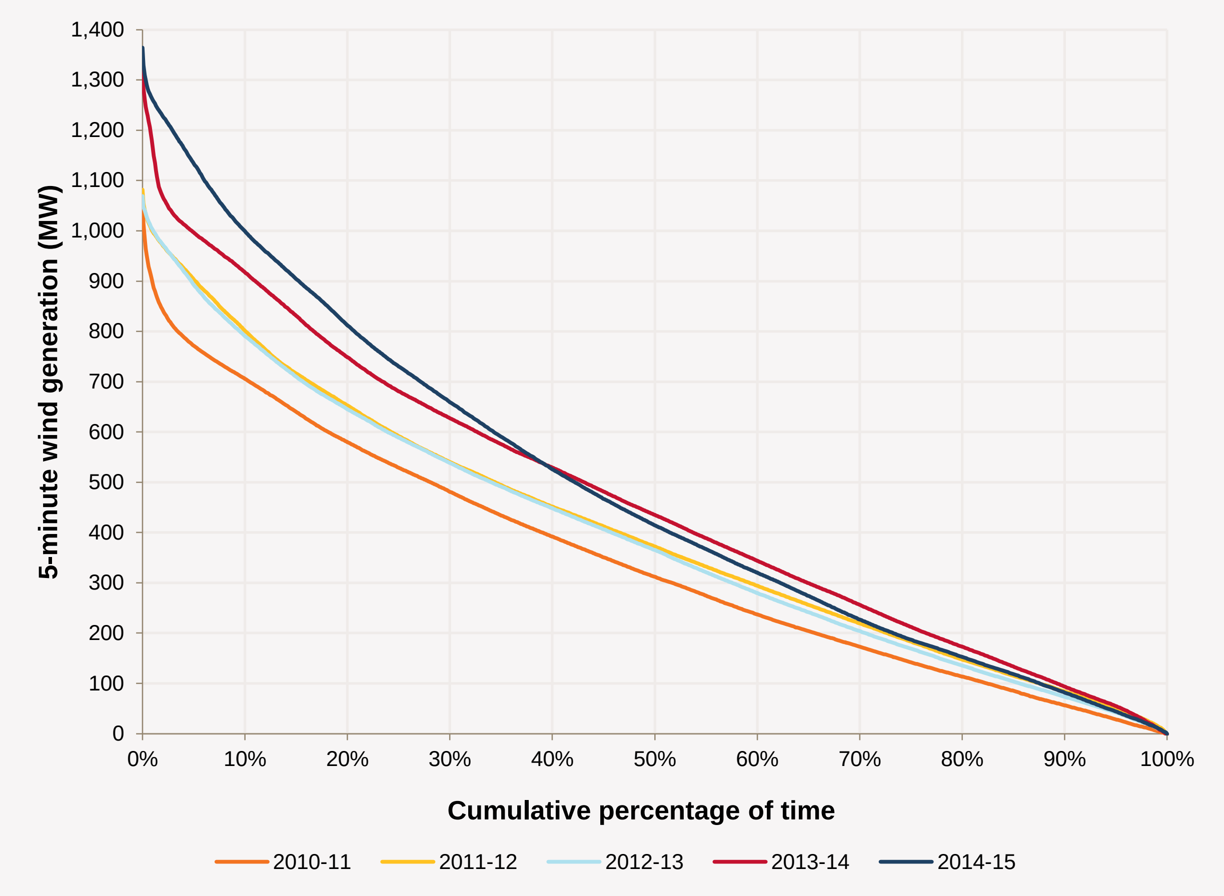
[15] Based on AEMO's analysis of average wind speed telemetry from wind farm sites across South Australia.

Wind generation duration curves

Figure 8 shows the wind generation duration curves for 2010–11 to 2014–15, indicating the percentage of time wind generation was at or above a given level for each financial year. Calculations are based on five-minute dispatch intervals and show:

- Increasing wind generation since 2010–11 (except in 2012–13 when no new capacity was registered).
- Increased wind generation for 2013–14 and 2014–15 following commencement of Snowtown Stage 2 Wind Farm.

Figure 8 Annual South Australian wind generation duration curves



2.6 Wind penetration

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. In line with increases in installed wind generation capacity, all other indices have tended to increase over time, with 2014–15 values the highest to date. The increasing trends in energy and instantaneous penetration are also partly attributable to the state's decreasing operational consumption and increasing rooftop PV generation.

Table 8 South Australian wind penetration indices

Description	South Australian value				
	2010–11	2011–12	2012–13	2013–14	2014–15
Capacity penetration: installed capacity as a percentage of total installed generation*	24%	24%	26%	30%	30%
Energy penetration: ratio of annual wind energy to annual total energy consumption	21%	25%	25%	31%	33%
Maximum instantaneous penetration (excluding exports): maximum observed ratio of wind energy to demand at any instant in time during the year	76%	83%	88%	100%	110%
Maximum possible instantaneous penetration: the ratio of installed capacity to minimum demand**	107%	115%	116%	127%	191%

* Calculations are based on AEMO registered capacity for all South Australian generating systems for any time during the financial year, but exclude generating units that are effectively mothballed for at least the last six months of the financial year. Wind farms can also qualify for inclusion when their output reaches 90% of registered capacity.
** Values for some years are different to those published in the 2014 SAWSR due to improved time-alignment between non-scheduled and semi-scheduled wind farm data. For the maximum possible instantaneous penetration, the approach taken in 2015 better reflects the actual capacity at time of minimum demand.

Maximum instantaneous wind penetration reached 100% for the first time in June 2013–14. This was a significant milestone, where South Australian demand (excluding exports) equalled total wind generation for a five-minute dispatch interval.

In 2014–15, the maximum instantaneous wind penetration reached 110% on 29 December 2014 at around 1.20 pm. Wind penetration was over 100% on 12 separate days between August and May, with instances occurring between about 2.00 am and 4.00 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 30 hours in 2014–15, compared to less than 1 hour in 2013–14.

When high levels of wind penetration occur, close assessment of network performance is required to ensure network security and reliability obligations are met. Refer to Section 1.2 for more information on renewable energy integration studies being undertaken by AEMO and ElectraNet.

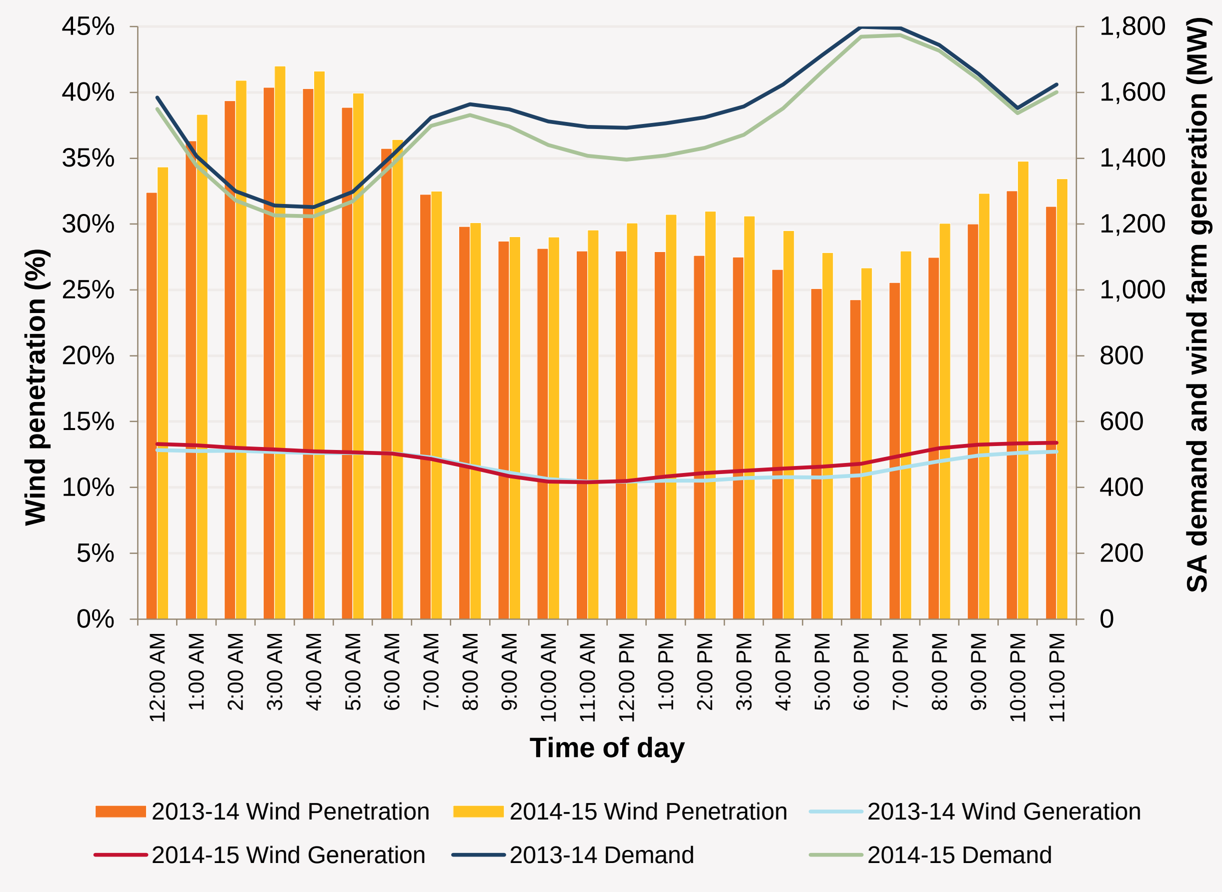
Daily demand, wind generation, and penetration profile

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 9 illustrates the average South Australian demand, wind generation, and wind penetration values throughout the day for 2013–14 and 2014–15. It indicates that:

- The average daily demand profile decreased in 2014–15, especially between 8.00 am and 6.00 pm (coinciding with periods of increasing rooftop PV generation during the middle of the day).
- While total wind generation increased in 2014–15, it maintained a similar daily profile, peaking overnight from around 10.00 pm through to 6.00 am the next day.
- Average wind penetration is highest around 3.00 am to 4.00 am, when average demand is lowest.

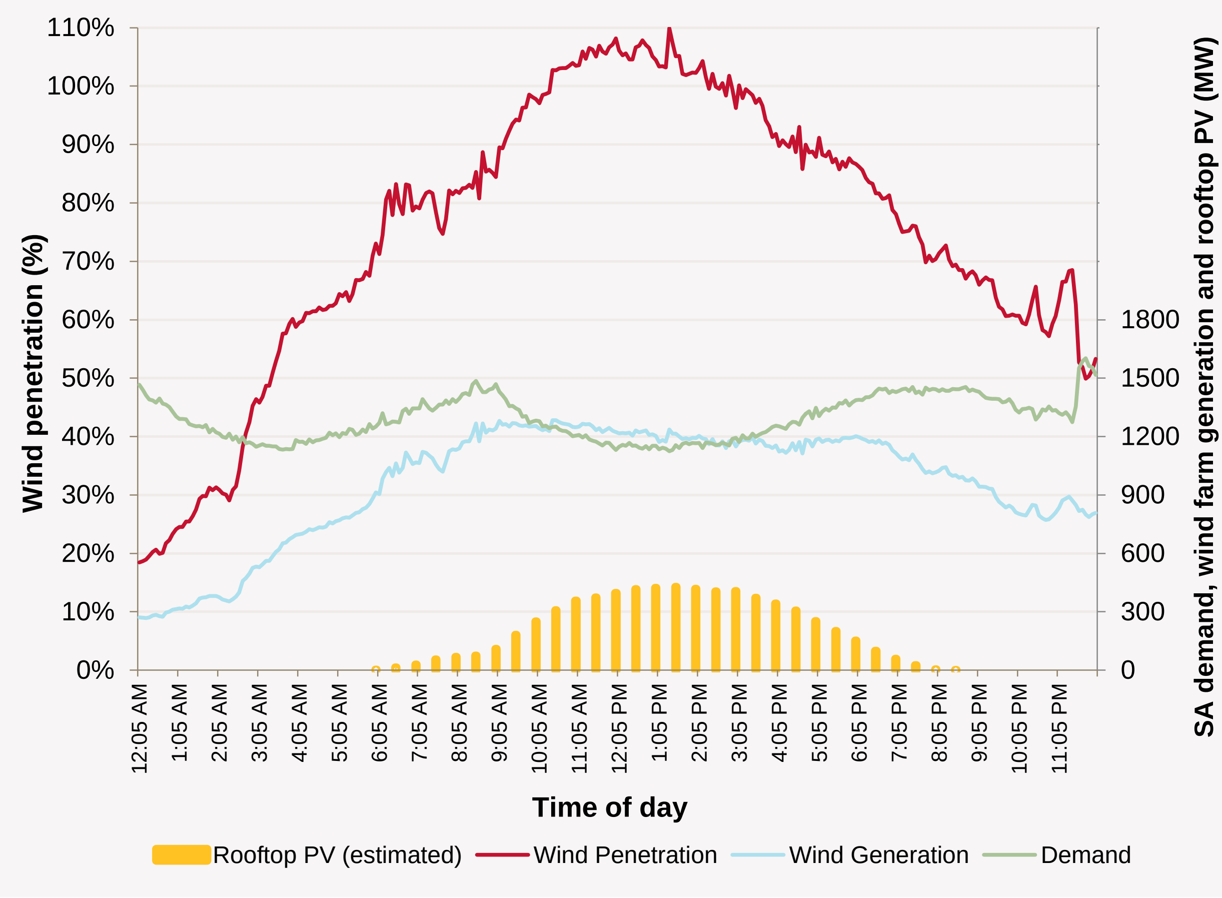
Figure 9 Daily demand, wind generation and penetration profile



While average wind penetration is highest at 3:00 am – 4:00 am, the maximum penetration occurred in the middle of the day. Figure 10 shows the South Australian demand, wind generation and wind penetration for 29 December 2014 (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[16], which indicates a correlation between low demand periods and high rooftop PV generation in South Australia. Figure 10 illustrates that maximum penetration is occurring around the middle of the day when rooftop PV generation is typically highest and hence demand lowest.[17]

Figure 10 South Australian wind generation, demand and wind penetration for 29 December 2014



[16] The estimated rooftop PV generation output is sourced from AEMO's in-development Australian Solar Energy Forecasting System Phase 2 (ASEFS2) which will be used to forecast rooftop PV generation in the NEM.

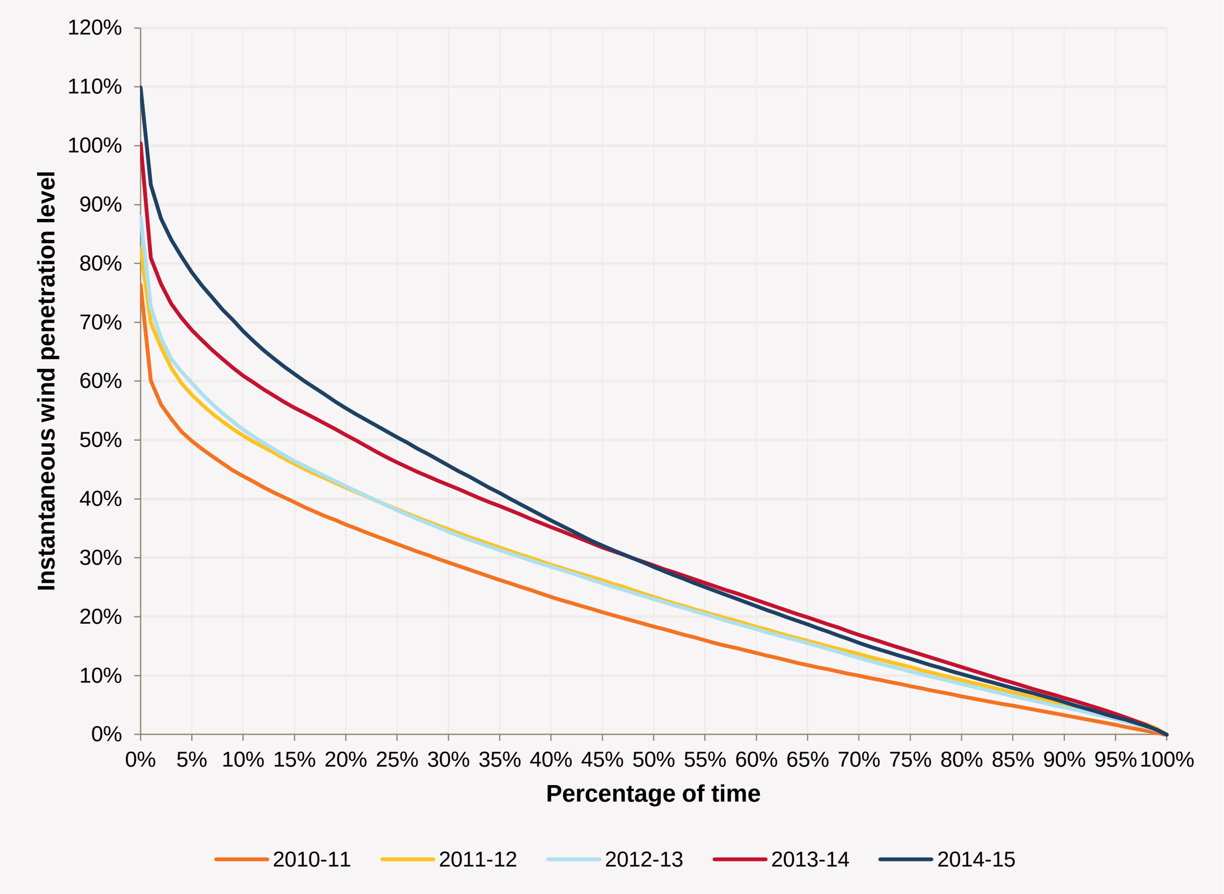
[17] Rooftop PV generation is seen as a reduction in demand, as it is not metered by AEMO.

Wind penetration duration curves

Figure 11 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.[18]

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 2014–15, penetration values below 80% were observed for 95% of the time.

Figure 11 Instantaneous wind penetration duration curves



[18] Details of operational consumption and minimum demand trends can be found in the 2015 SAER. Available at: http://www.aemo.com.au/Electricity/Planning/South-Australian-Advisory-Functions/South-Australian-Electricity-Report. Viewed: 13 October 2015.

2.7 Short-term wind generation and demand variations

This section provides statistical information on aggregate wind generation output variations occurring in response to changing wind conditions. Variation is calculated as the difference in generation between each five-minute dispatch interval.

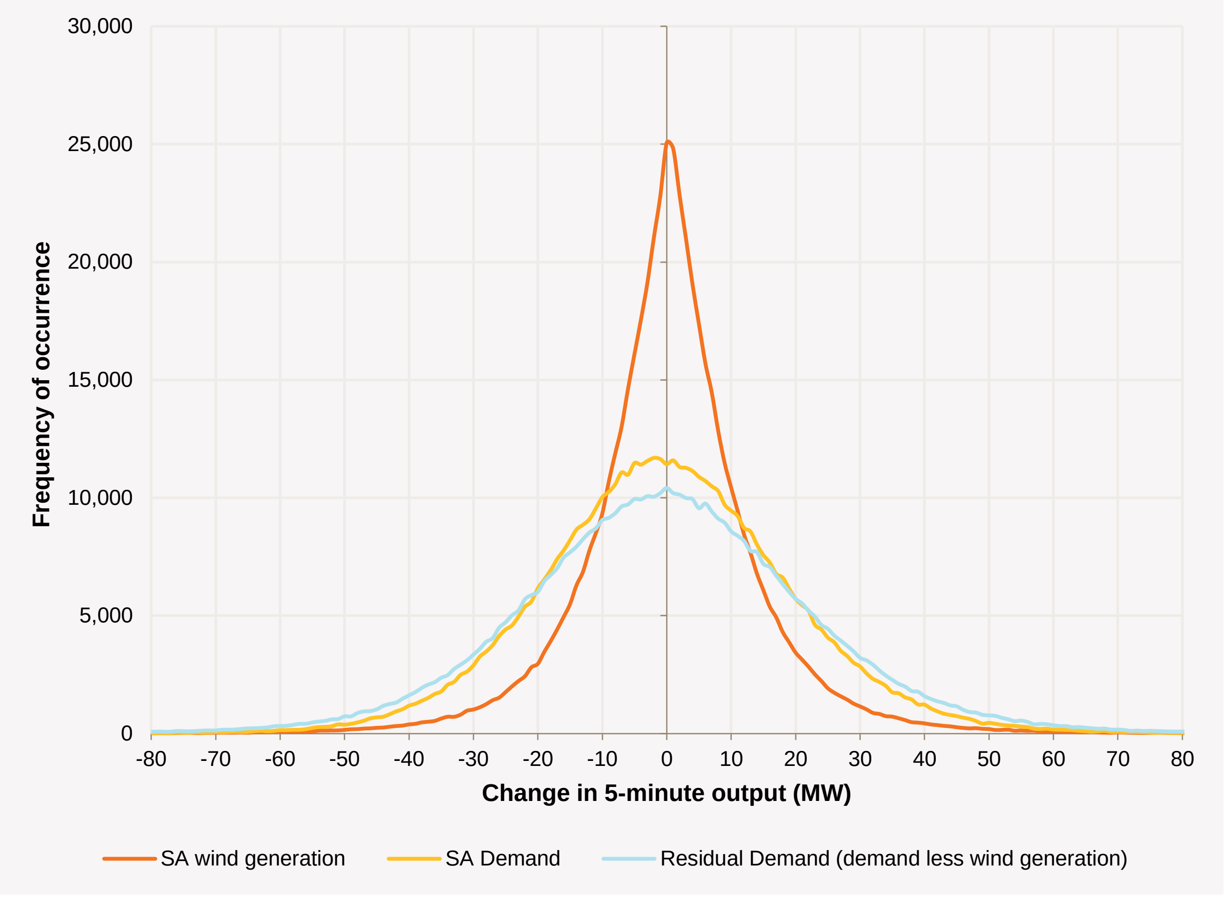
The intermittency of wind generation, leading to sudden changes in the supply and demand balance, makes managing the power system more challenging.

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, 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 state.

Wind and demand variation

Figure 12 shows the frequency-of-occurrence distributions for five-minute variations in South Australian wind generation, demand, and their combined effect (residual demand) from 2010–11 to 2014–15. Operationally this combined variation must be managed by AEMO and network service providers to ensure power system reliability.

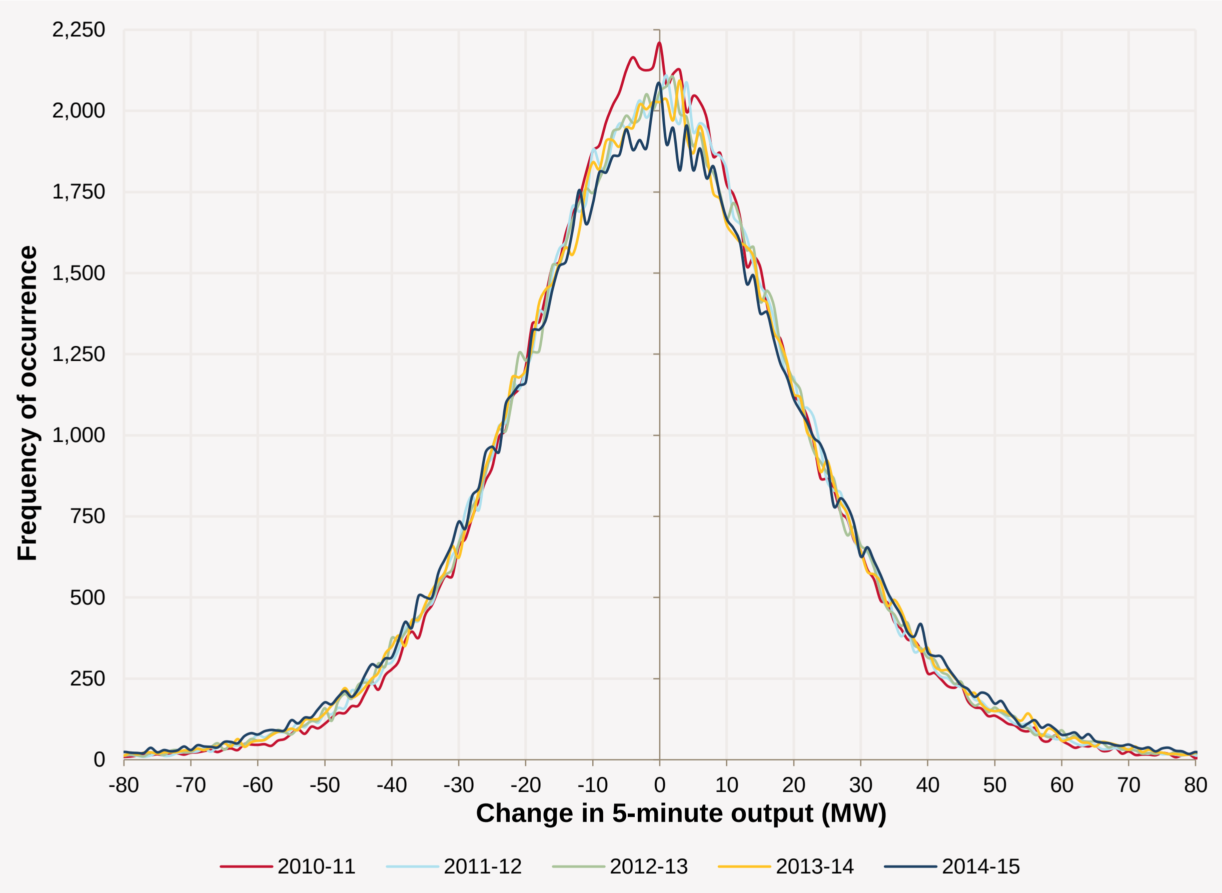
Figure 12 South Australian wind generation, demand, and residual demand (variation distribution)



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 less variable than South Australian demand, 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 units, able to manage large variations. Residual demand change can also be met by changes in power flow on the Heywood Interconnector.

Analysis of the residual demand each year from 2010–11 to 2014–15 in Figure 13 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, the residual demand changes in South Australia are becoming more variable.

Figure 13 South Australian residual demand (variation distribution)



Wind variation across geographical areas

Figure 14 presents key statistical information about five-minute and 10-minute wind generation variation for the mid-north, south-east, and coastal peninsula areas in South Australia, and all South Australian wind farms in aggregate, for 2014–15. Appendix Section A.3 shows tables of the statistics for 2013–14 and 2014–15. In 2014–15, the mean 5-minute variation for all South Australian wind farms in aggregate was 10.7 MW and the maximum variation was 240 MW.

Key observations from Figure 14 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 5.7% and 5.4% of registered capacity respectively, whereas, total South Australian absolute wind generation variation is no more than 2.6%.
- 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 14 Five- and 10-minute absolute wind generation variation for 2014–15

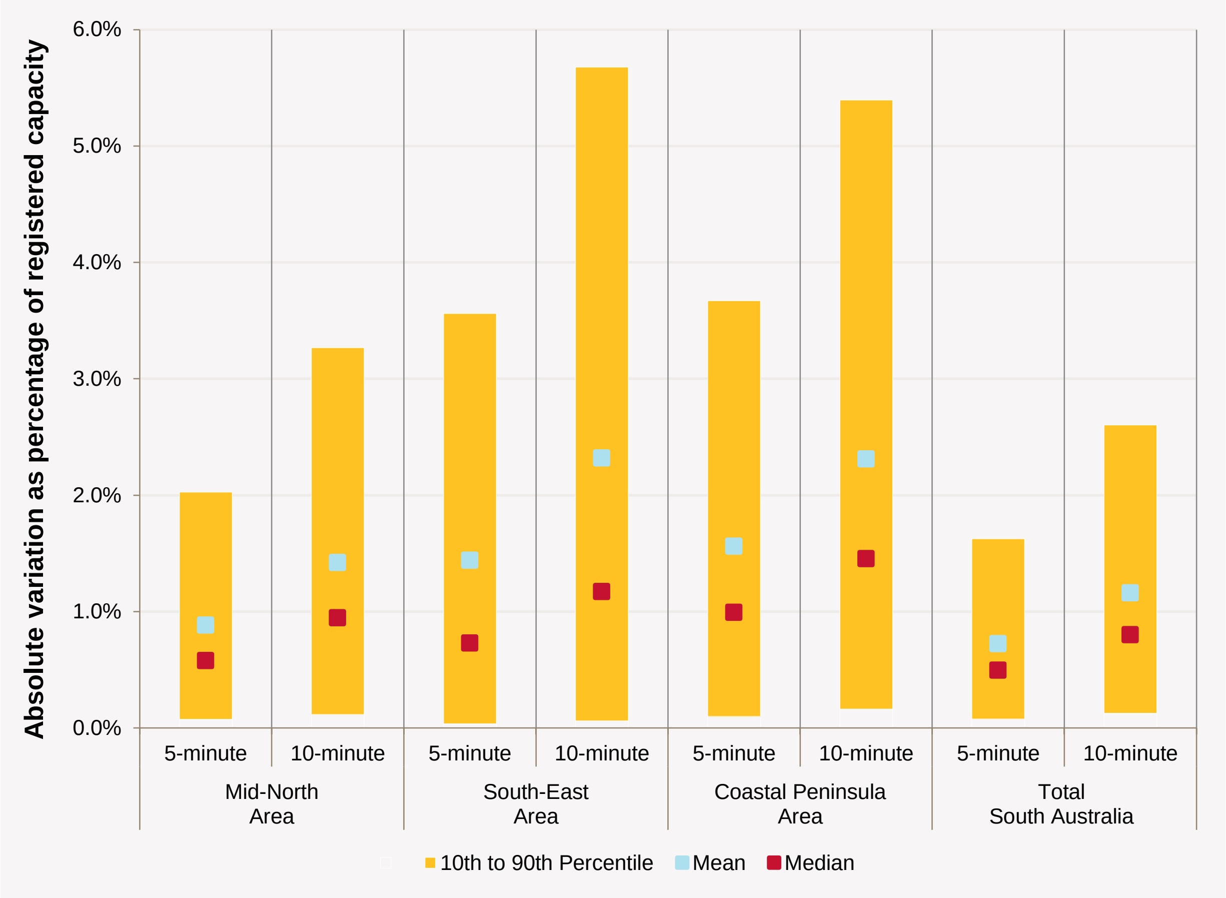
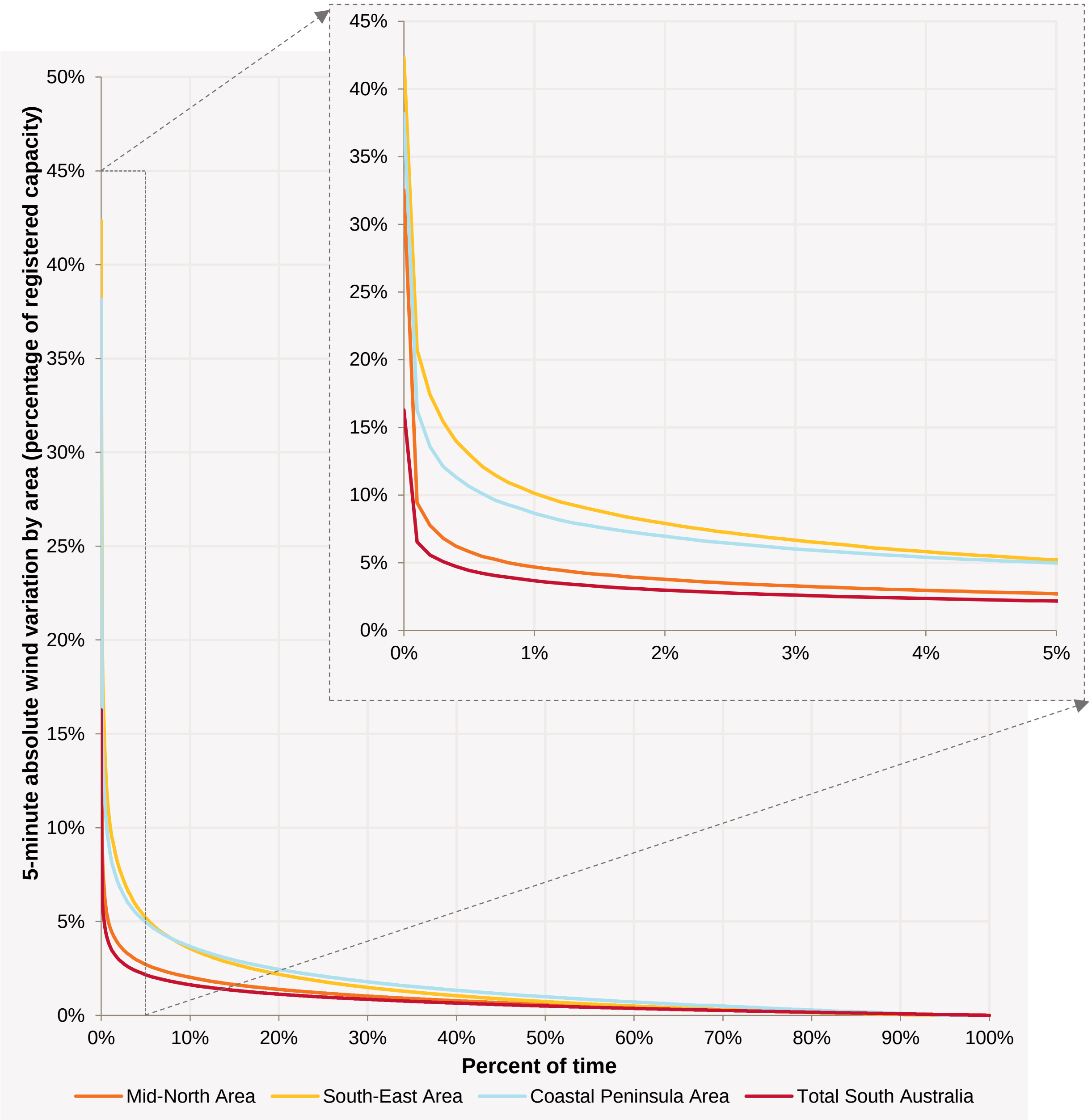


Figure 15 shows the full distribution of the five-minute absolute wind generation variation for the mid-north, south-east, and coastal peninsula areas, and all South Australian wind farms, for 2014–15.

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 80% of the time. The south-east has the highest absolute wind variation around 7% of the time.
- In the south-east area, a maximum wind farm variation of 42% was observed from one five-minute period to another.

Figure 15 Absolute wind variation as percentage of registered capacity



Maximum generation increase and decrease

Table 9 shows variations in wind generation for three operational timeframes (five-minutes, 30-minutes, and 60-minutes) for the three geographical areas and all South Australian wind farms in aggregate, from 2010–11 to 2014–15.[19]

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

South Australian wind farm variations from 2010–11 to 2014–15 show differences year on year. For the mid-north area and all South Australia, where capacity increased over the five year period, there is a general upward trend, particularly in the 30-minute and 60-minute variations.

Table 9 Total registered capacity and historical maximum variation outputs (MW) by area

Financial Year	2010–11	2011–12	2012–13	2013–14	2014–15	Area
Registered capacity	565	618	618	888	888	Mid-north area
Max. 5-minute increase	171	174	155	155	180	
Max. 5-minute decrease	173	257	206	179	289	
Max. 30-minute increase	257	372	279	367	371	
Max. 30-minute decrease	231	370	295	382	380	
Max. 60-minute increase	339	460	433	444	550	
Max. 60-minute decrease	273	437	293	479	442	
Registered capacity	325	325	325	325	325	South-east area
Max. 5-minute increase	103	84	125	131	137	
Max. 5-minute decrease	118	132	128	180	126	
Max. 30-minute increase	238	244	243	264	296	
Max. 30-minute decrease	223	249	266	247	257	
Max. 60-minute increase	282	284	268	273	299	
Max. 60-minute decrease	252	263	281	262	276	
Registered capacity	191	191	191	191	191	Coastal peninsula area
Max. 5-minute increase	57	62	63	63	61	
Max. 5-minute decrease	81	70	83	86	73	
Max. 30-minute increase	89	86	92	118	96	
Max. 30-minute decrease	106	93	136	105	89	
Max. 60-minute increase	122	113	106	125	116	
Max. 60-minute decrease	108	91	136	131	92	
Registered capacity	1,151	1,203	1,203	1,473	1,473	All South Australia
Max. 5-minute increase	145	230	154	194	180	
Max. 5-minute decrease	170	286	211	185	240	
Max. 30-minute increase	300	371	446	418	418	
Max. 30-minute decrease	336	435	360	415	393	
Max. 60-minute increase	375	478	479	556	589	
Max. 60-minute decrease	352	524	415	487	466	

19 Values for some years are different to those published in earlier SAWSRs due to improved time-alignment between non-scheduled and semi-scheduled wind farm data.

3. WIND GENERATION AND THE NATIONAL ELECTRICITY MARKET

This chapter provides information on wind generation and market prices in South Australia. Generation analysis in this chapter is restricted to the state's registered wind farms only.

Additional market pricing information is available in the 2015 South Australian Electricity Market Economic Trends Report (SAEMETR)[20], which demonstrates that wind generation receives a lower volume-weighted average price than thermal generation.[21]

Market prices are not typically set by wind generators, except during low demand periods, due to:

- Low marginal cost, and revenue from participation in the renewable energy target scheme, which results in most wind generation being bid near or below $0/MWh, and seldom being the marginal (price setting) generator.
- Average wind generation being higher overnight when demand is low, corresponding to periods when low bids are typically received for thermal generation to remain scheduled on.
- Wind generators depending on wind availability, which precludes them from increasing generation in response to high market prices.

AEMO has not undertaken a detailed investigation to further explore the relationship between wind generation and market prices. This would require consideration of demand, generator bidding strategies, network constraints, and interconnector capacity and spot prices in adjoining regions.

However, of note is the frequency and magnitude of negative pricing intervals, which had both generally been declining since 2010–11, until 2014–15, when more negative prices were observed than in the previous three years. This may be the result of a number of factors including increases in wind and rooftop PV generation, reducing demand, and the return to full-time service of Northern Power Station[22], all placing downward pressure on spot prices at these times.

3.1 Data and methodology

AEMO has used the following data inputs for the analysis in this chapter:

- Spot prices for South Australia for each 30-minute trading interval.
- Wind generation from cleared supply values measured in megawatts at the end of each 30-minute trading interval, based on a simple average of five-minute values.
- Historical data to 30 June 2015.

3.2 Wind generation and market prices

Figure 16 plots South Australian average wind generation 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.

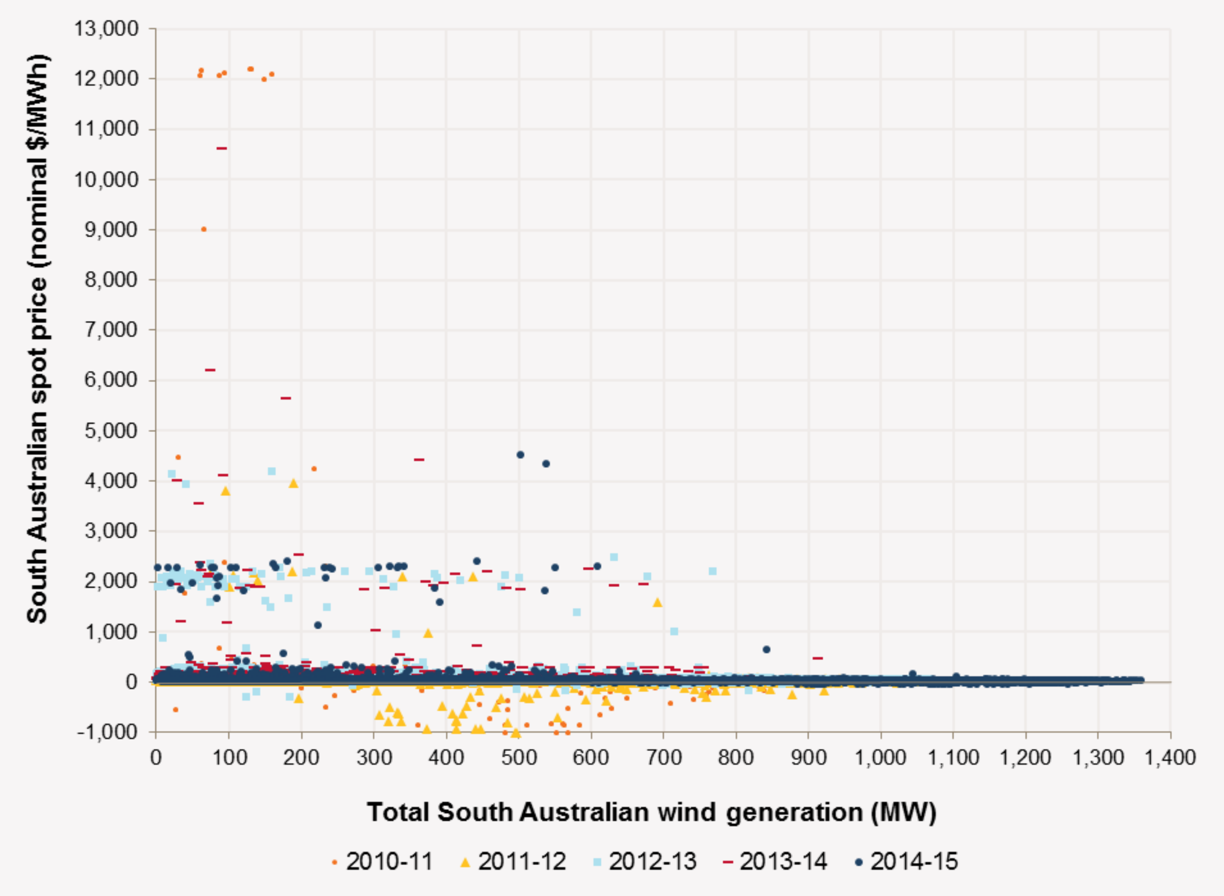
More information on positive and negative prices is provided in sections 3.3 and 3.4.

[20] AEMO. Available at: http://www.aemo.com.au/Electricity/Planning/South-Australian-Advisory-Functions/South-Australian-Electricity-Market-Economic-Trends-Report. Viewed: 12 October 2015.

[21] Volume-weighted average prices are calculated as earnings ($) divided by amount of generation (MWh) for a given trading period. The SAEMETR publishes both financial year and summer season volume-weighted average prices.

[22] Alinta Energy advised that Northern Power Station returned to normal service in October 2014. This followed periods of withdrawal from April to September in 2013 and 2014. Source: AEMO Generation Information for South Australia. 2015, October 26. Available at: http://www.aemo.com.au/Electricity/Planning/Related-Information/Generation-Information. Viewed: 26 October 2015.

Figure 16 South Australian average wind generation and spot prices (30-minute data for 2010–11 to 2014–15)



South Australian spot prices

Table 10 shows the relative occurrence of spot price bands for the South Australian region, ranging from negative prices (below $0/MWh) to prices above $300/MWh.

Key observations are:

- The occurrence of negative prices in 2014–15 is 0.9%, the second highest level in five years.
- The impact of carbon pricing is evident, with very little pricing below $25/MWh occurring in 2012–13 and 2013–14, and a greater proportion of pricing in the $50/MWh to $75/MWh price band.
- The occurrence of high prices above $300/MWh in 2014–15 is 0.3%, slightly below levels seen during carbon pricing years, but above 2010–11 and 2011–12 levels.

Table 10 Frequency of occurrence of spot prices for South Australia

Price band	2010–11	2011–12	2012–13	2013–14	2014–15
Below $0	1.0%	0.7%	0.2%	0.1%	0.9%
$0–$25	45.5%	29.6%	0.3%	0.5%	25.1%
$25–$50	51.6%	67.1%	36.2%	42.6%	63.1%
$50–$75	1.3%	2.0%	47.4%	46.9%	9.0%
$75–$100	0.3%	0.3%	9.9%	6.8%	0.7%
$100–$300	0.3%	0.2%	5.5%	2.7%	0.9%
Above $300	0.1%	0.1%	0.5%	0.4%	0.3%

Wind generation volume-weighted average prices

Table 11 shows volume-weighted average spot prices for South Australian wind generation each quarter over the past five years from 2010–11 to 2014–15. The values in Table 10 are based on 30-minute averaged dispatched volumes[23] and the corresponding spot price (in real fourth quarter (Q4) 2014–15 dollars).

Table 11 Volume-weighted average spot prices for wind generation (real Q4 2014–15 dollars)

Price ($/MWh)	2010–11	2011–12	2012–13	2013–14	2014–15
Q1 (Jul–Sep)	25.30	31.74	58.21	61.99	35.01
Q2 (Oct–Dec)	15.95	29.19	56.87	54.92	26.18
Q3 (Jan–Mar)	34.05	25.38	53.48	56.58	29.77
Q4 (Apr–Jun)	29.10	27.24	74.04	46.34	34.78
Annual (volume-weighted)	26.27	28.41	60.25	55.26	31.56

The impact of carbon pricing is evident in 2012–13 and 2013–14, with annual volume-weighted prices which are around $25 to $30 higher than the adjacent years. Ignoring these two years, the annual volume-weighted average spot prices for wind generation have been increasing over time (in real dollars), since 2010–11.

[23] Dispatched volumes refers to cleared supply data for semi-scheduled wind generation plus SCADA readings for non-scheduled wind generation. The latter does not participate in dispatch but is still considered in the analysis of South Australian wind generation volume-weighted average prices.

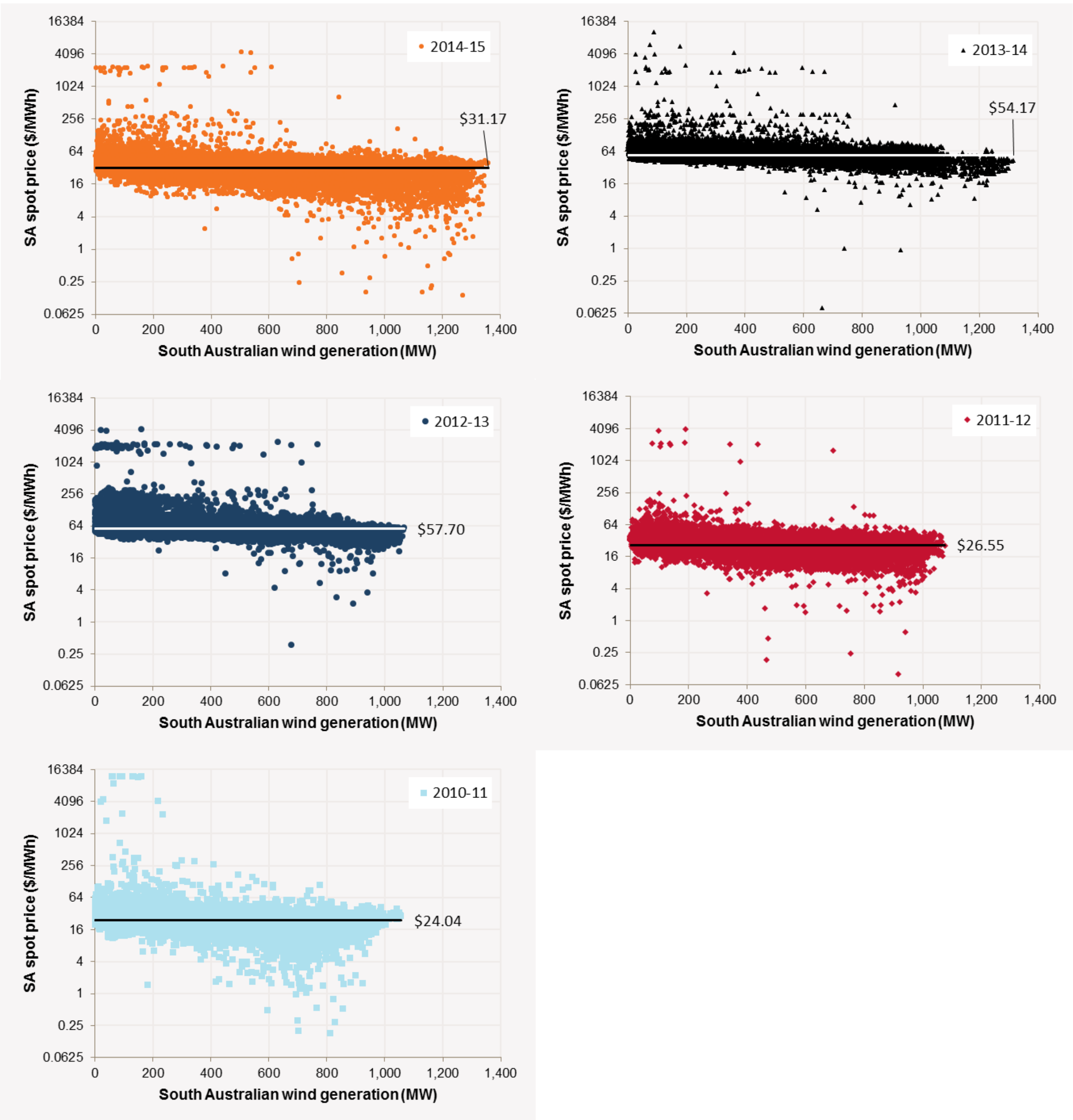
3.3 Positive spot price trading intervals

Figure 17 shows spot prices for the South Australian region and the corresponding average wind generation levels for each 30-minute dispatch interval from 2010–11 to 2014–15. 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, most prices cluster around the mean, and decrease as 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.

Figure 17 South Australian 30-minute spot prices and average wind generation (positive market prices)



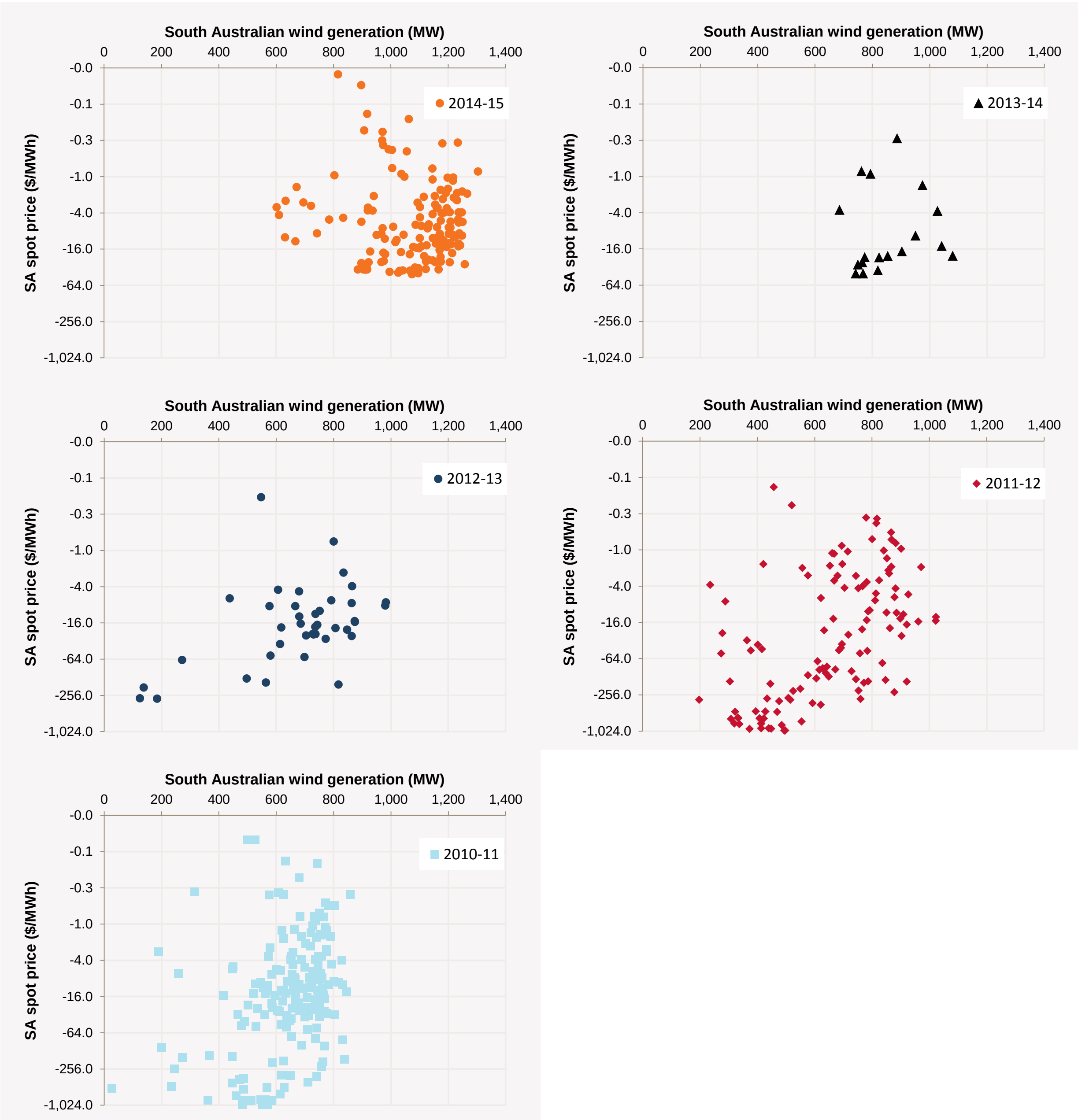
Note: Logarithmic axis

3.4 Negative spot price trading intervals

Figure 18 shows only the negative spot prices for the South Australian region and the corresponding average wind generation levels for each 30-minute dispatch interval from 2010–11 to 2014–15. 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 2014–15. A correlation is observed between the occurrences of negative prices and higher levels of wind generation.

Figure 18 South Australian 30-minute spot prices and average wind generation (negative market prices)



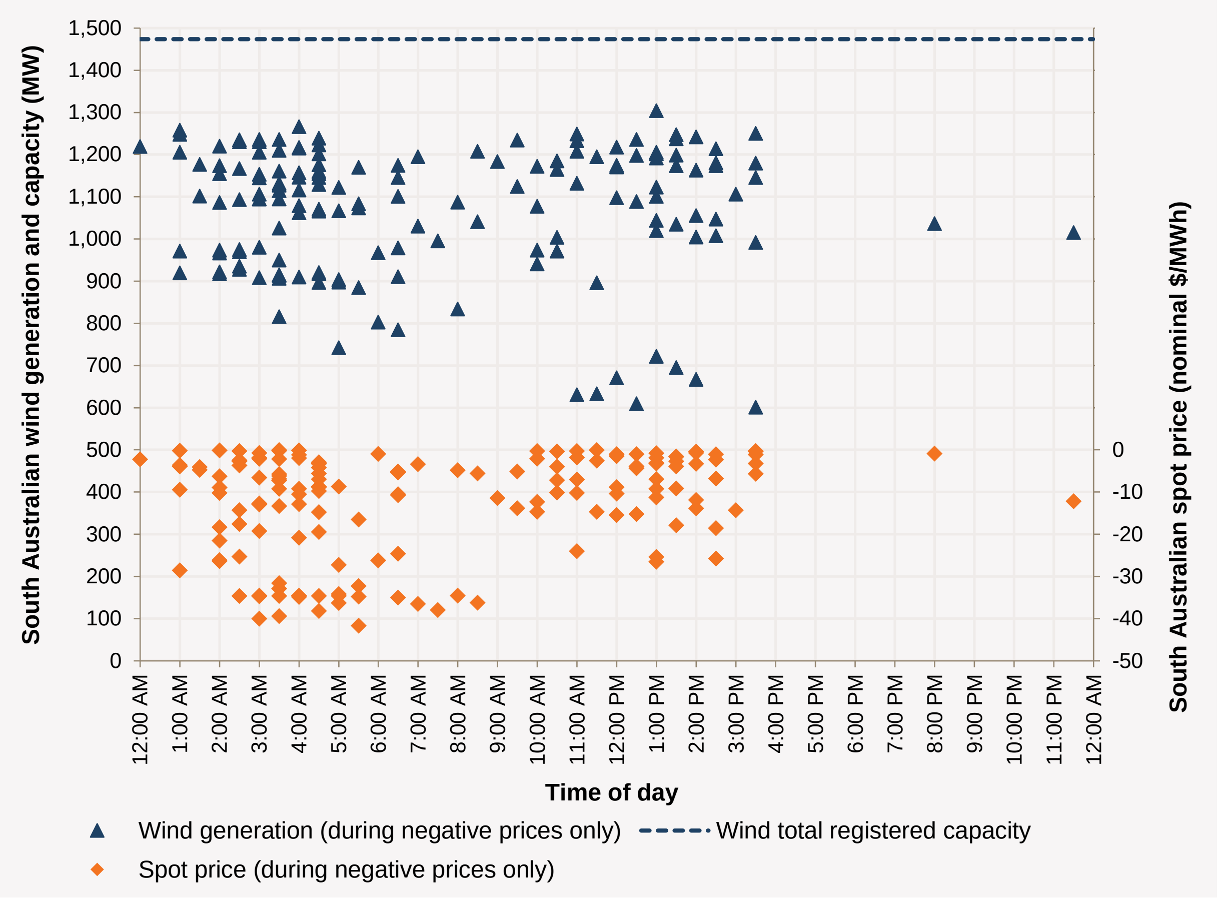
Note: Logarithmic axis

Negative spot prices by time of day

Figure 19 shows the time of day and average wind generation level for negative spot prices in 2014–15.

Most negative spot prices occurred either early in the morning or during the middle of the day, when wind generation was relatively high. As discussed in Section 2.6, highest average penetration values occur early in the morning and the maximum value in 2014–15 occurred during the middle of the day.

Figure 19 Negative South Australian spot price and average wind generation by time of day (2014-15)

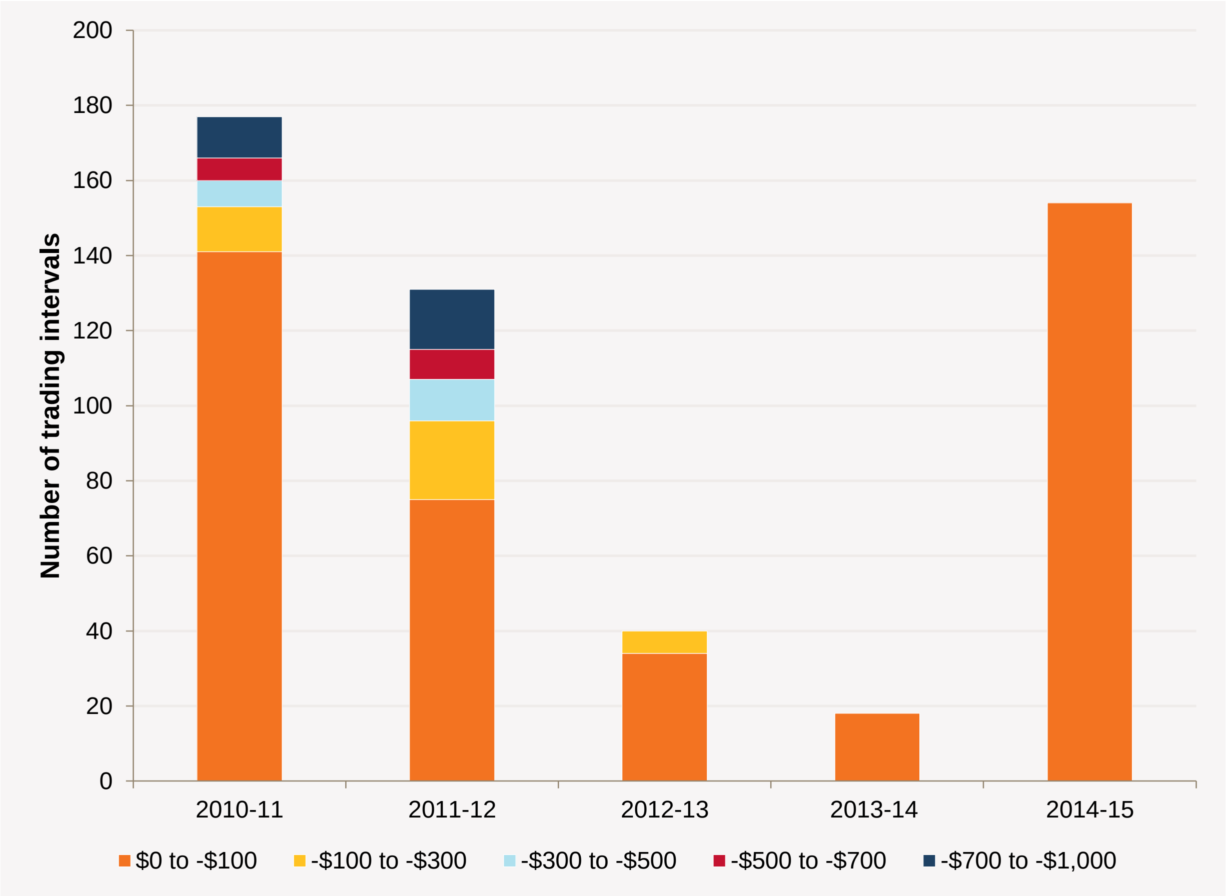


Frequency of negative pricing events

Figure 20 shows the frequency of negative South Australian market prices from 2010–11 to 2014–15. The magnitude of each event is also indicated by colour.

The number of negative price intervals for 2014–15 (at 154) is higher than the previous three years, but not as high as the total in 2010–11 (177). However 2014–15, as in 2013–14, saw the value of negative prices restricted to the $0/MWh to –$100/MWh band only.

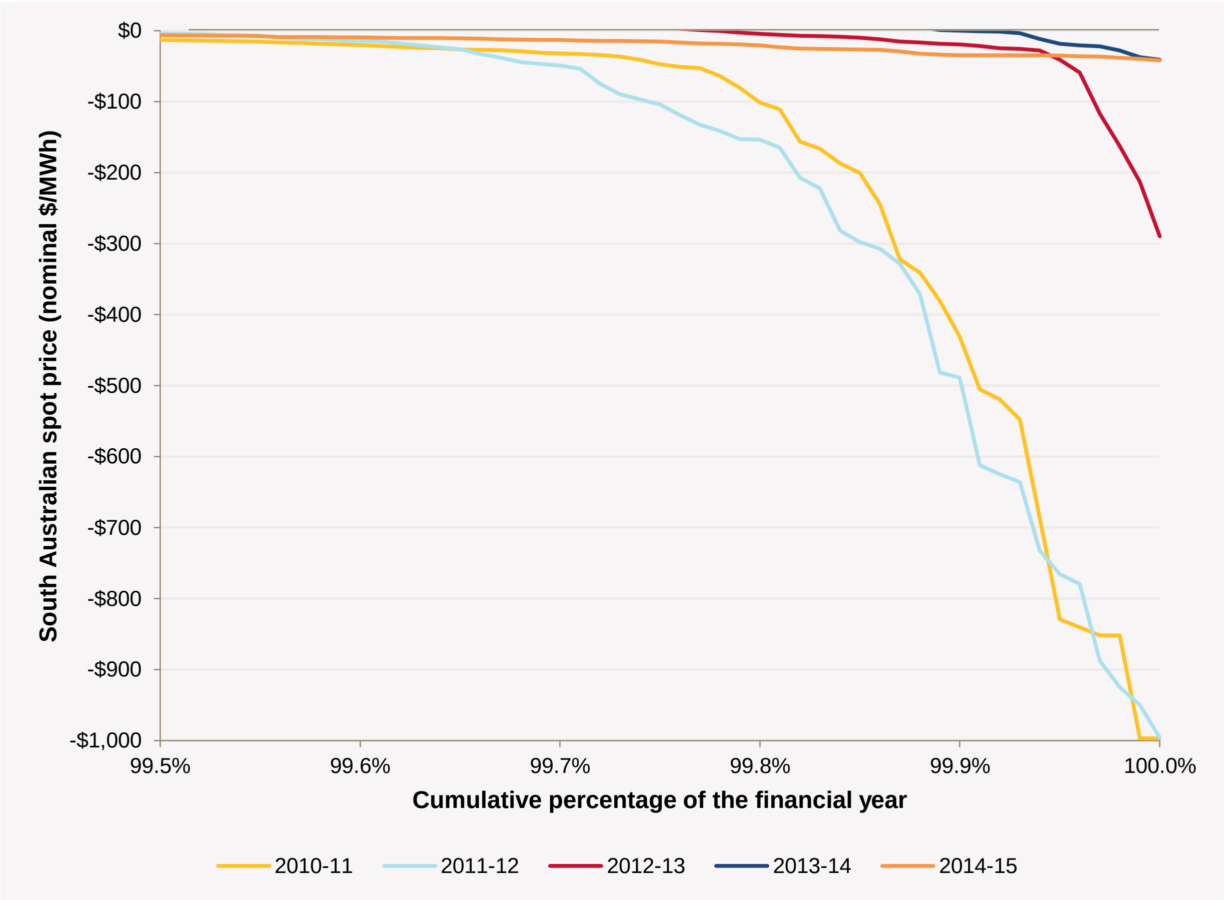
Figure 20 Count of negative price trading intervals per year



Negative price duration curves

Figure 21 shows the price duration curves for negative price events, indicating the increased frequency but similar magnitude of negative events in 2014–15, compared to 2013–14.

Figure 21 South Australian spot price duration curves, negative values only



Generation mix during negative spot price intervals

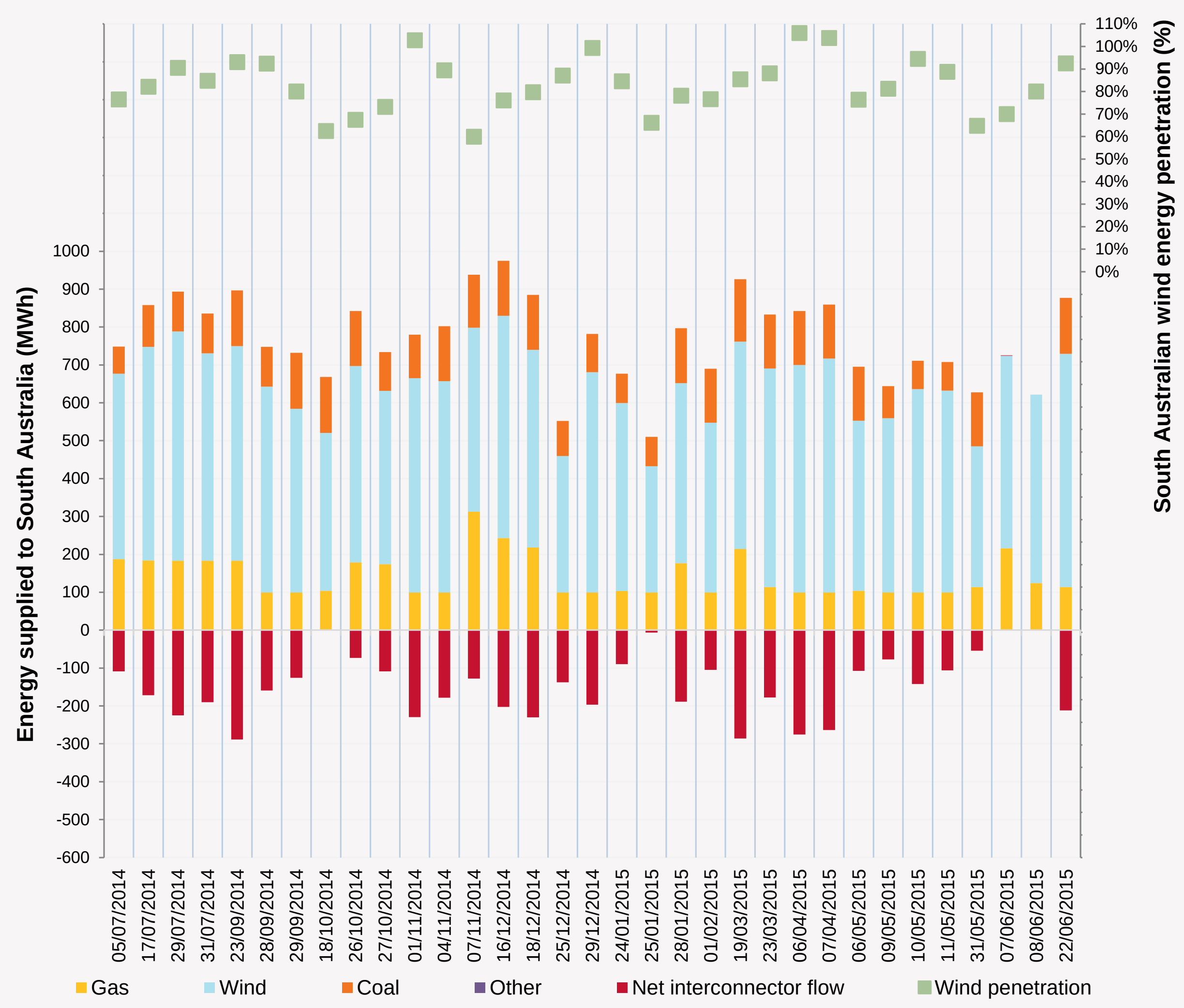
Historically, negative spot prices have occurred during periods of relatively low demand, periods of high wind, and restrictions on interconnector flow from South Australia to Victoria. At these times, negatively-priced generating capacity can exceed demand.

During 2014–15, negative spot prices for South Australia occurred for 154 trading intervals, with no events below –$100/MWh, as highlighted in Figure 20.

Figure 22 provides details on the mix and magnitude of South Australian generation and net interconnector import during 30-minute periods that had negative prices. As all 154 events occurred across 33 days, only the most extreme negative pricing event is shown for each day.

The negative pricing events analysed in Figure 22 suggest that in 2014–15, most negative prices occurred during times when wind energy penetration was above average (the annual value for the year being 33% as presented in Table 7), and typically when South Australia was net exporting electricity to Victoria.

Figure 22 Supply summary at selected times of negative South Australian spot price during 2014–15



3.5 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).
- ST PASA (30-minute resolution, seven days ahead).
- MT PASA (daily resolution, two years ahead).[24]

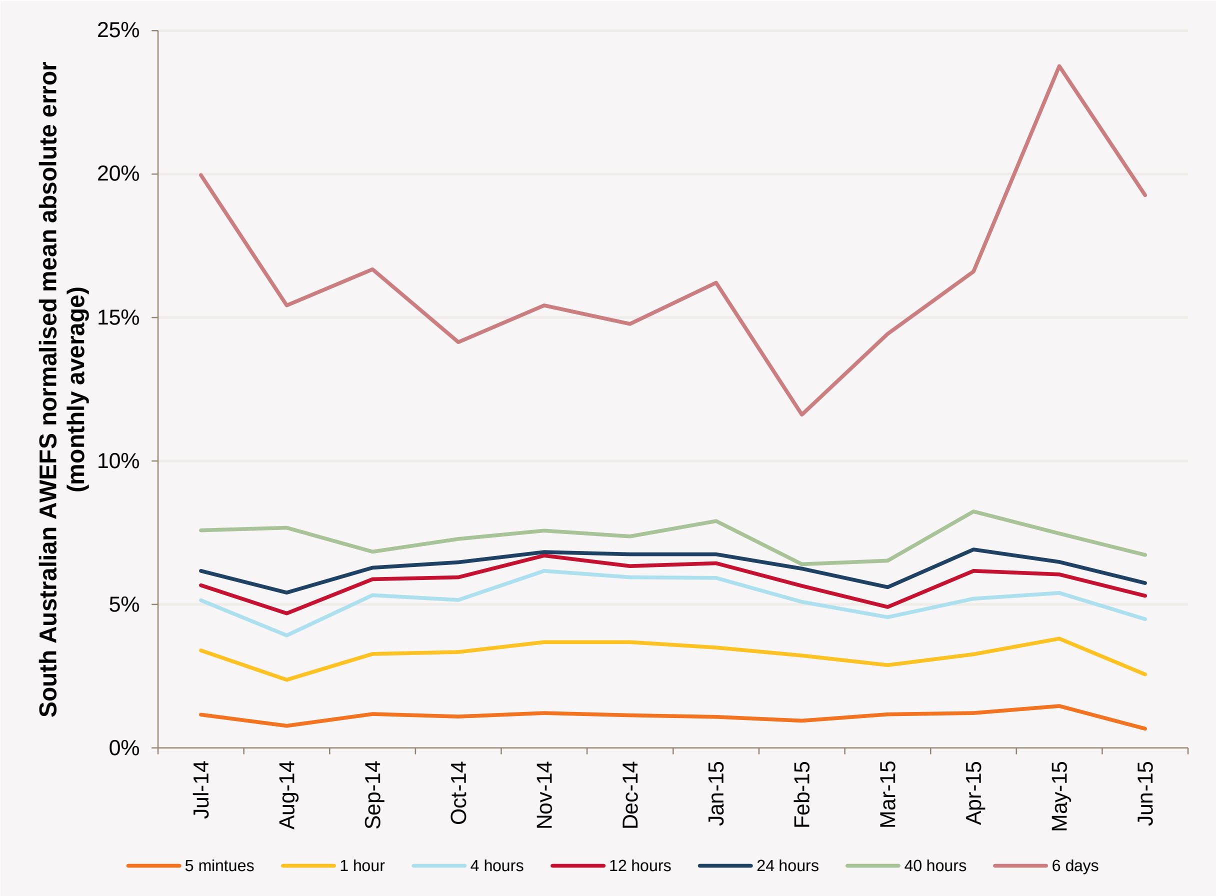
AWEFS accuracy is most commonly measured as the normalised mean absolute error (NMAE) of the forecast. The NMAE is calculated as the absolute difference between forecast and actual output, divided by the nominal capacity.

AWEFS accuracy is monitored for compliance with performance standards at the NEM level. Performance standards are also monitored at regional level, although this is not mandated.

Figure 23 shows monthly average NMAE figures of the AWEFS forecasts for South Australian wind farms. Forecast accuracy decreases as the forecast horizon extends, in line with the decreasing accuracy of the input weather models.

[24] Further information available at: http://www.aemo.com.au/Electricity/Market-Operations/Dispatch/AWEFS.

Figure 23 Normalised mean absolute error of AWEFS forecasts for South Australia 2014-15



APPENDIX A. WIND FARM STATISTICS

A.1 Wind farm capacities

Table 12 Registered capacities of South Australian wind farms

Wind farm	Dispatchable unit identifier (DUID)	Registered capacity (MW)*	Classification	Area for SAWSR 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
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	Not included in areas analysed
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, 7 October 2015. Available: http://www.aemo.com.au/About-the-Industry/Registration/Current-Registration-and-Exemption-lists. Viewed: 16 October 2015.

A.2 Wind farm capacity factors

Table 13 Capacity factors of South Australian wind farms[25]

Wind farm	DUID	2010–11	2011–12	2012–13	2013–14	2014–15
Canunda Wind Farm	CNUNDAWF	27.4%	30.5%	28.0%	30.7%	28.9%
Cathedral Rocks Wind Farm	CATHROCK	30.6%	31.8%	30.2%	34.0%	29.4%
Clements Gap Wind Farm	CLEMGPWF	33.8%	35.1%	33.6%	35.3%	33.7%
Hallett 1 (Brown Hill)	HALLWF1	38.8%	40.0%	40.1%	42.3%	37.3%
Hallett 2 (Hallett Hill)	HALLWF2	39.2%	40.8%	41.1%	41.1%	37.4%
Hallett 4 (North Brown Hill Wind Farm)	NBHWF1	27.6%	39.5%	36.8%	40.9%	36.3%
Hallett 5 (The Bluff) Wind Farm	BLUFF1	-	28.9%	33.7%	36.4%	29.5%
Lake Bonney 2	LKBONNY2	26.0%	27.6%	27.5%	30.2%	28.7%
Lake Bonney 3	LKBONNY3	24.9%	25.4%	28.0%	29.9%	27.6%
Lake Bonney Wind Farm	LKBONNY1	26.0%	28.5%	27.0%	29.2%	27.1%
Mount Millar Wind Farm	MTMILLAR	29.7%	30.6%	30.2%	33.2%	30.5%
Snowtown Stage 2 Wind Farm (North and South total)	SNOWNTH1 and SNOWSTH1	-	-	-	-*	34.8%
Snowtown Wind Farm	SNOWTWN1	40.0%	43.3%	43.3%	45.1%	38.6%
Starfish Hill Wind Farm	STARHLWF	24.4%	28.1%	22.4%	31.1%	28.2%
Waterloo Wind Farm	WATERLWF	27.3%	32.0%	32.2%	34.9%	30.2%
Wattle Point Wind Farm	WPWF	32.8%	34.0%	31.1%	37.0%	33.2%

* A capacity factor is not shown for Snowtown Stage 2 Wind Farm for 2013–14 since it did not meet the analysis criteria of first generating 90% of registered capacity until mid-June 2014; analysis over such a short part of the 2013–14 financial year would not be sufficiently representative of an annual factor.

[25] Data taken from the 2015 South Australian Historical Market Information Report (SAHMIR). Available: http://www.aemo.com.au/Electricity/Planning/South-Australian-Advisory-Functions/South-Australian-Historical-Market-Information-Report. Viewed: 6 October 2015.

A.3 Wind generation variation

Table 14 Key statistical characteristics and five- and 10-minute wind generation variation for 2014–15

FY 2014–15	Mid-north area		South-east area		Coastal peninsula area		South Australian wind farms	
	5-minute	10-minute	5-minute	10-minute	5-minute	10-minute	5-minute	10-minute
Key statistical characteristics of absolute variation (% of registered capacity)								
Mean	0.9%	1.4%	1.4%	2.3%	1.6%	2.3%	0.7%	1.2%
Median	0.6%	0.9%	0.7%	1.2%	1.0%	1.5%	0.5%	0.8%
Standard deviation	1.0%	1.6%	2.2%	3.5%	1.9%	2.8%	0.8%	1.2%
Key statistical characteristics of absolute variation (megawatt equivalent)								
Mean	7.8	12.6	4.7	7.5	3.0	4.4	10.7	17.1
Median	5.1	8.4	2.4	3.8	1.9	2.8	7.3	11.8
Standard deviation	9.2	14.3	7.0	11.2	3.6	5.3	11.5	18.0
Absolute variation								
90th percentile	0.1%	0.1%	0.0%	0.1%	0.1%	0.2%	0.1%	0.1%
10th percentile	2.0%	3.3%	3.6%	5.7%	3.7%	5.4%	1.6%	2.6%
5th percentile	2.7%	4.3%	5.2%	8.4%	5.0%	7.4%	2.2%	3.5%
1st percentile	4.7%	7.3%	10.1%	16.9%	8.6%	13.2%	3.7%	5.7%
Maximum	32.5%	36.4%	42.3%	64.0%	38.2%	43.8%	16.3%	21.5%

Table 15 Key statistical characteristics and five- and 10-minute wind generation variation for 2013–14*

FY 2013–14	Mid-north area		South-east area		Coastal peninsula area		South Australian wind farms	
	5-minute	10-minute	5-minute	10-minute	5-minute	10-minute	5-minute	10-minute
Key statistical characteristics of absolute variation (% of registered capacity)								
Mean	1.1%	1.7%	1.5%	2.4%	1.7%	2.5%	0.8%	1.3%
Median	0.7%	1.2%	0.8%	1.3%	1.1%	1.6%	0.6%	0.9%
Standard deviation	1.2%	1.9%	2.2%	3.5%	2.0%	3.0%	0.9%	1.4%
Key statistical characteristics of absolute variation (megawatt equivalent)								
Mean	6.8	10.9	4.9	7.9	3.3	4.8	10.1	16.2
Median	4.6	7.3	2.6	4.2	2.1	3.1	7.0	11.4
Standard deviation	7.7	12.2	7.0	11.4	3.9	5.7	10.6	16.7
Absolute variation								
90th percentile	0.1%	0.1%	0.1%	0.1%	0.1%	0.2%	0.1%	0.2%
10th percentile	2.5%	4.0%	3.6%	5.8%	3.9%	5.8%	1.8%	3.0%
5th percentile	3.3%	5.3%	5.3%	8.7%	5.4%	8.0%	2.4%	3.9%
1st percentile	5.7%	8.9%	10.4%	17.2%	9.3%	14.3%	4.1%	6.5%
Maximum	25.0%	37.7%	55.5%	62.2%	45.0%	50.4%	16.1%	23.1%

* Values for some cells are different to those published in the 2014 SAWSR due to improved time-alignment between non-scheduled and semi-scheduled wind farm data.

MEASURES AND ABBREVIATIONS

Units of measure

Abbreviation	Unit of measure
$	Australian dollar
GWh	Gigawatt hour
hr	Hour
min	Minute
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
MD	Maximum demand
MT PASA	Medium-term Projected Assessment of System Adequacy
NEM	National Electricity Market
NER	National Electricity Rules
NMAE	Normalised Mean Absolute Error
PV	Photovoltaic
SA	South Australia
SAER	South Australian Electricity Report
SAEMETR	South Australian Electricity Market Economic Trends Report
SCADA	Supervisory Control and Data Acquisition
ST PASA	Short-term Projected Assessment of System Adequacy

GLOSSARY

The 2015 SAWSR 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 2015 SAWSR 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.
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.

Term	Definition
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.