CHAPTER 5 - HISTORICAL GENERATION AND PERFORMANCE

5.1 Summary

This chapter provides information about historical levels of generation and performance of the supply sector in South Australia.

This year the approach to calculating figures for a “firm” contribution to wind generation has changed. Last year, a 95% confidence level was used to indicate an acceptable level of performance compared to conventional generation (meaning that the firm or reliable contribution was measured as the amount of generation that was likely to be available 95% of the time). Following research into alternate methods of calculating wind contributions to peak demand periods, this confidence level has been reassessed to 85%. Consequently the proportion of installed wind capacity considered to be firm in South Australia is calculated to be 5% in summer and 3.5% in winter.

The capacity of wind generation in South Australia continues to grow and wind energy has now reached 20% of energy production, There is now 1,150 MW of wind generating capacity in the state. According to the World Wind Energy Association’s data[49] this puts South Australia second behind Denmark in terms of penetration and the per capita figure of 0.702 kW per person is now higher than any major country in the world.

The Australian Energy Market Operator (AEMO) has analysed a number of parameters, such as variability and contribution to maximum and minimum demand, in the assessment of wind generation. The analysis found that the magnitude of fluctuations in wind generation increased when assessed over longer time intervals. The general trend shows variability falling as the number of wind farms increases, however, the reduction in variability is larger between 3 to 6 wind farms than between 6 to 9 wind farms. The reduction in variability between 6 to 9 wind farms and 9 to 14 wind farms is similar.

An analysis of energy demand and prices in South Australia indicated similar frequency demand levels over the past three years. However, South Australian wholesale electricity market prices for 2010/11 are lower than they have been since the start of the market and the relative gap between the volume weighted earnings price received by fossil fuelled generators (at 50.78 $/MWh) and the renewable generators (at 22.82 $/MWh) has widened.

5.2 Historical generation

Table 5-1 lists historical generation (energy) for South Australian power stations from 2005/06 to 2010/11. Figures for 2010/11 have been calculated on a pro-rata basis from data until 31 March 2011.

Table 5-1— Historical generation (energy) for South Australian power stations

	2005/06 (GWh)	2006/07 (GWh)	2007/08 (GWh)	2008/09 (GWh)	2009/10 (GWh)	2010/11 pro-rata (GWh)
Angaston	2	4	2	2	0	1
Dry Creek	1	16	10	6	9	3
Hallett	22	151	28	23	28	28

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[49] http://www.wwindea.org/home/index.php.

	2005/06 (GWh)	2006/07 (GWh)	2007/08 (GWh)	2008/09 (GWh)	2009/10 (GWh)	2010/11 pro-rata (GWh)
Ladbroke Grove	348	249	141	192	191	154
Mintaro	1	36	8	4	8	3
Northern	3,997	4,466	4,013	4,213	3,542	4,102
Osborne	1,176	1,251	1,230	1,244	1,189	998
Pelican Point	1,620	2,775	3,281	3,281	2,970	2,997
Playford	541	722	870	695	1,011	421
Port Lincoln	1	1	2	2	2	2
Quarantine	128	80	84	97	297	135
Snuggery	0	1	2	2	3	0
Torrens A	396	376	527	538	444	660
Torrens B	2,141	2,350	2,782	1,976	1,709	1,699
Clements Gap	0	0	0	3	165	173
Hallett 1	0	0	91	327	336	317
Hallett 2	0	0	0	16	250	242
Hallett 4	0	0	0	0	0	257
Lake Bonney S2	0	3	230	342	273	361
Lake Bonney S3	0	0	0	0	0	86
Snowtown	0	0	11	320	360	345
Waterloo	0	0	0	0	0	209
Non-scheduled wind	765	901	995	1,000	1,007	1,004
Total[a]	**11,140**	**13,382**	**14,305**	**14,282**	**13,792**	**14,198**

[a] Figures in this table are rounded to the nearest whole number and the table calculated prior to rounding.

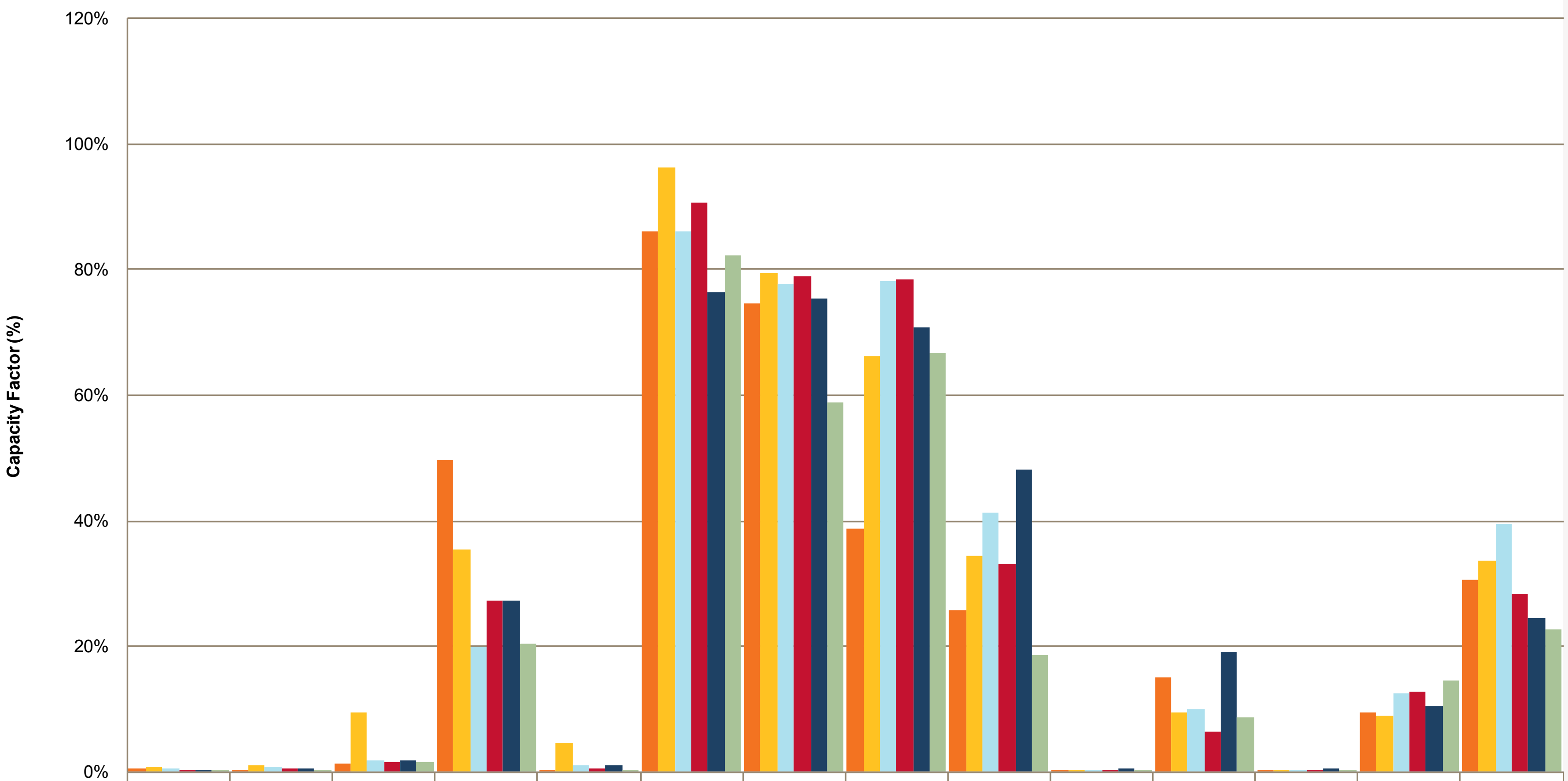
5.2.1 Capacity factors

Figure 5-1 and Figure 5-2 show the capacity factors for South Australia generation based on each power station's historical registered capacity. Plants that respond to peak demand generally have very low capacity factors, as they only operate for short periods and are idle for most of the year. Plants providing base load power have higher capacity factors, and tend to produce power continuously, unless shut down for maintenance.

Wind farm capacity factors primarily depend on wind speed and availability, although temperature and transmission network limitations can also affect the output. Some farms switch off or reduce their output during high temperatures to prevent temperature-related equipment damage.

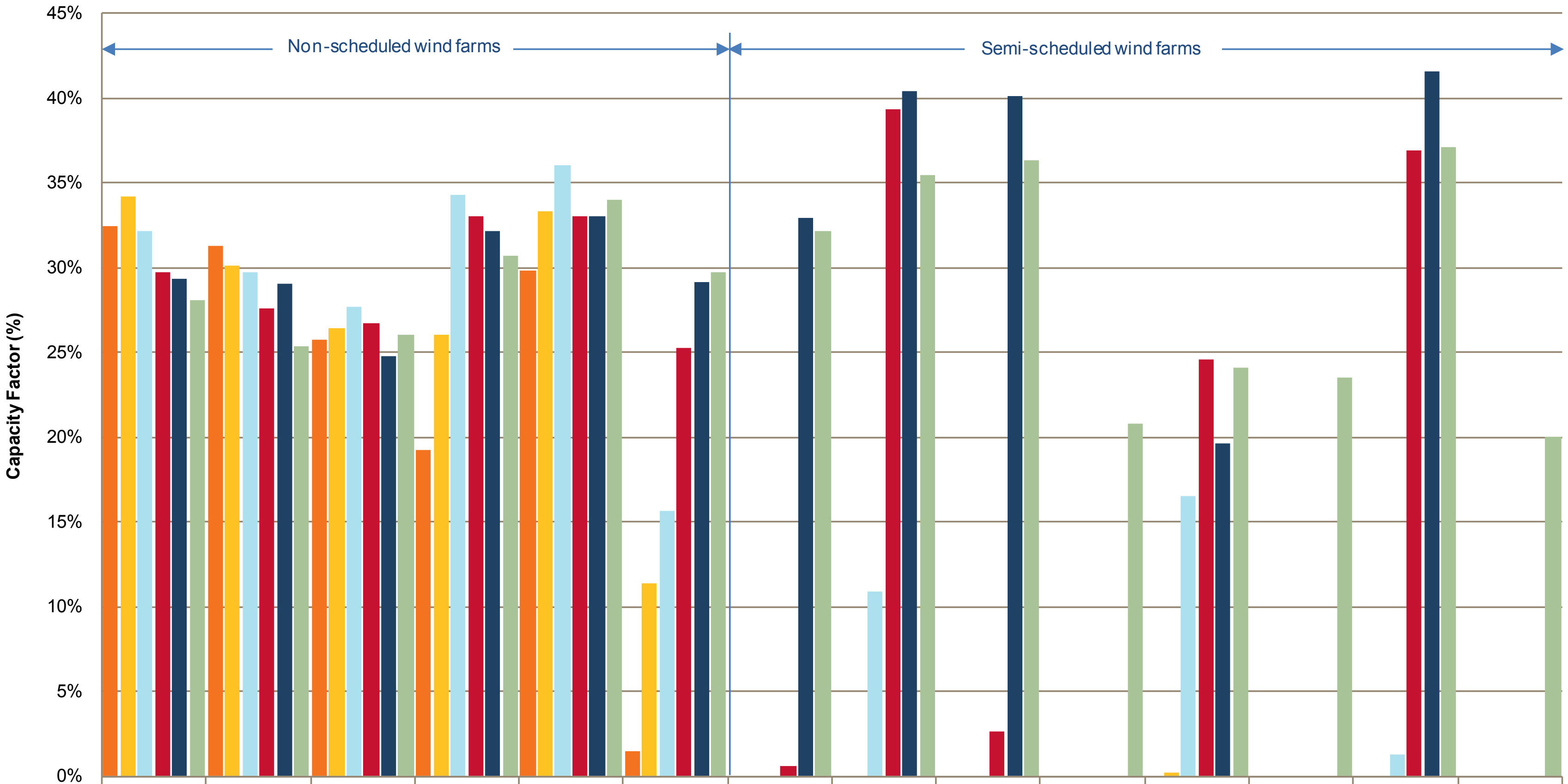
Hallett 1, Hallett 2, and Snowtown Wind Farms have the highest capacity factors, ranging from 35.5% to 41.5% over the past two years. Of the wind farms that have had at least a full year of operation, Lake Bonney 2 has the lowest capacity factor (24.1%). Lake Bonney 3, Waterloo, and Hallett 4 (North Brown Hill) have only been fully commissioned within the past year, and may have lower capacity factors due to being incomplete or not generating for part of the year.

Figure 5-1 — Financial year capacity factors for scheduled generators



	Angaston	Dry Creek	Hallett	Ladbroke Grove	Mintaro	Northern	Osborne	Pelican Point	Playford	Port Lincoln	Quarantine	Snuggery	Torrens A	Torrens B
■ 2005/06	0.6%	0.1%	1.4%	49.7%	0.2%	86.1%	74.6%	38.7%	25.7%	0.1%	15.2%	0.1%	9.4%	30.6%
■ 2006/07	0.8%	1.1%	9.6%	35.5%	4.5%	96.2%	79.4%	66.3%	34.4%	0.1%	9.5%	0.2%	8.9%	33.5%
■ 2007/08	0.5%	0.7%	1.8%	20.0%	1.0%	86.2%	77.8%	78.1%	41.2%	0.4%	10.0%	0.4%	12.5%	39.6%
■ 2008/09	0.4%	0.4%	1.5%	27.3%	0.5%	90.8%	78.9%	78.4%	33.1%	0.4%	6.4%	0.3%	12.8%	28.2%
■ 2008/10	0.1%	0.7%	1.8%	27.2%	1.0%	76.3%	75.4%	70.9%	48.1%	0.5%	19.1%	0.5%	10.6%	24.4%
■ 2010/11	0.2%	0.2%	1.7%	20.5%	0.4%	82.3%	59.0%	66.7%	18.6%	0.3%	8.8%	0.1%	14.6%	22.6%

Figure 5-2 — Financial year capacity factors for non-scheduled and semi-scheduled generators (wind farms)



	Canunda	Starfish Hill	Lake Bonney	Cathedral Rocks	Wattle Point	Mt Millar	Clements Gap	Hallett 1 (Brown Hill)	Hallett 2 (Hallett Hill)	Hallett 4 (Nth Brown Hill)	Lake Bonney 2	Lake Bonney 3	Snowtown	Waterloo
🟧 2005-06	32.4%	31.3%	25.8%	19.3%	29.8%	1.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
🟨 2006-07	34.2%	30.1%	26.4%	26.0%	33.3%	11.4%	0.0%	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%
🟦 2007-08	32.2%	29.7%	27.6%	34.3%	36.1%	15.6%	0.0%	10.9%	0.0%	0.0%	16.5%	0.0%	1.2%	0.0%
🟥 2008-09	29.7%	27.6%	26.7%	33.0%	33.0%	25.3%	0.6%	39.3%	2.6%	0.0%	24.5%	0.0%	36.9%	0.0%
■ 2009-10	29.3%	29.0%	24.7%	32.2%	33.0%	29.2%	33.0%	40.4%	40.1%	0.0%	19.6%	0.0%	41.5%	0.0%
🟩 2010-11	28.1%	25.3%	26.0%	30.7%	34.0%	29.7%	32.2%	35.5%	36.3%	20.7%	24.1%	23.5%	37.1%	20.0%

5.3 Inter-regional supply

South Australia is connected to the rest of the NEM via the Victoria-South Australia (Heywood and Murraylink) interconnectors.

5.3.1 Heywood

The Victoria-South Australia (Heywood) interconnector has a nominal dispatch limit of 460 MW, but the actual limit can vary in response to local network thermal ratings, voltage and reactive power limits, system demand and generation in the south east of South Australia.

5.3.2 Murraylink

The Murraylink interconnector connects Victoria and South Australia via the Riverland. While it is nominally rated at 220 MW the actual limit depends on the direction of flow and local conditions. For power flows from South Australia to Victoria, thermal limits on the 132 kV transmission system in the Riverland region area restrict power flows on Murraylink to less than 180 MW (with runback schemes in place). At times of low demand, power flows from Victoria to South Australia can be limited by transient stability limitations in Victoria or South Morang 500/330 kV transformer thermal limits, and at times of high demand, flows can be limited to less than 50 MW by voltage collapse constraint equations applied to Victoria.

5.3.3 Combined Heywood and Murraylink interconnector limits

As well as individual capabilities, there is a maximum combined transfer capability for the Murraylink and Heywood interconnectors. On 6 January 2011, the combined nominal maximum transfer capability for South Australia to Victoria was increased from 420 MW to 580 MW. This combined limit is affected by a number of physical and electrical limits, which are described by a series of specific constraint equations that include operational factors, such as demand, the output from certain power stations, and the status of specific items of transmission plant in both regions.

These constraint equations have been developed by the transmission entities in South Australia and Victoria for use by AEMO in determining dispatch patterns. There are many limitations that can reduce the maximum power transfer capability of the interconnectors under certain circumstances. Constraint equations also change over time to address specific transmission network alterations, including network augmentations, the connection of new loads, and the commissioning of new generation.

Power transfers between regions are managed by AEMO, within the limits defined by these constraint equations, in the National Electricity Market Dispatch Engine (NEMDE).

5.3.4 Historical interconnector flows

Table 5-2 and Table 5-3 show the total energy imported and exported, and the average power flow rates for both the Murraylink and Heywood interconnectors for each financial year.

Table 5-2 — Historical Heywood interconnector power flow

Financial year	Total imports (GWh)	Total exports (GWh)	Import average (MW)	Export average (MW)
1999/2000	3,574	1	408	63
2000/01	2,471	18	291	69
2001/02	1,439	123	198	83
2002/03	2,191	54	272	77
2003/04	2,554	31	305	74
2004/05	2,214	59	272	95
2005/06	2,374	35	285	83
2006/07	1,246	235	193	102
2007/08	657	526	140	129
2008/09	829	436	156	119
2009/10	1,109	304	182	114
2010/11 pro-rata	829	313	192	138

Table 5-3 — Historical Murraylink interconnector power flow

Financial year	Total imports (GWh)	Total exports (GWh)	Import average (MW)	Export average (MW)
2002/03	206	10	86	35
2003/04	217	60	46	28
2004/05	305	38	46	22
2005/06	270	31	41	20
2006/07	87	156	30	33
2007/08	40	176	20	29
2008/09	52	218	24	35
2009/10	80	267	31	43
2010/11 pro-rata	63	241	42	43

Figure 5-3 shows total imports and exports into South Australia from 1999/2000 to 2010/11. Energy imported into South Australia from Victoria during the year is plotted in orange column bars above the (zero) 0 GWh line (x-axis), and energy exported from South Australia to Victoria is shown below the line.

Historically, South Australia has imported electricity from Victoria, with net imports decreasing from 2006/07 to 2010/11. At the same time, the number of periods where South Australia exported energy to Victoria has increased. This corresponds with recent increases in wind generation in South Australia, and may have been influenced by drought conditions affecting supply in the eastern states.

Figure 5-3 — Total interconnector exports and imports

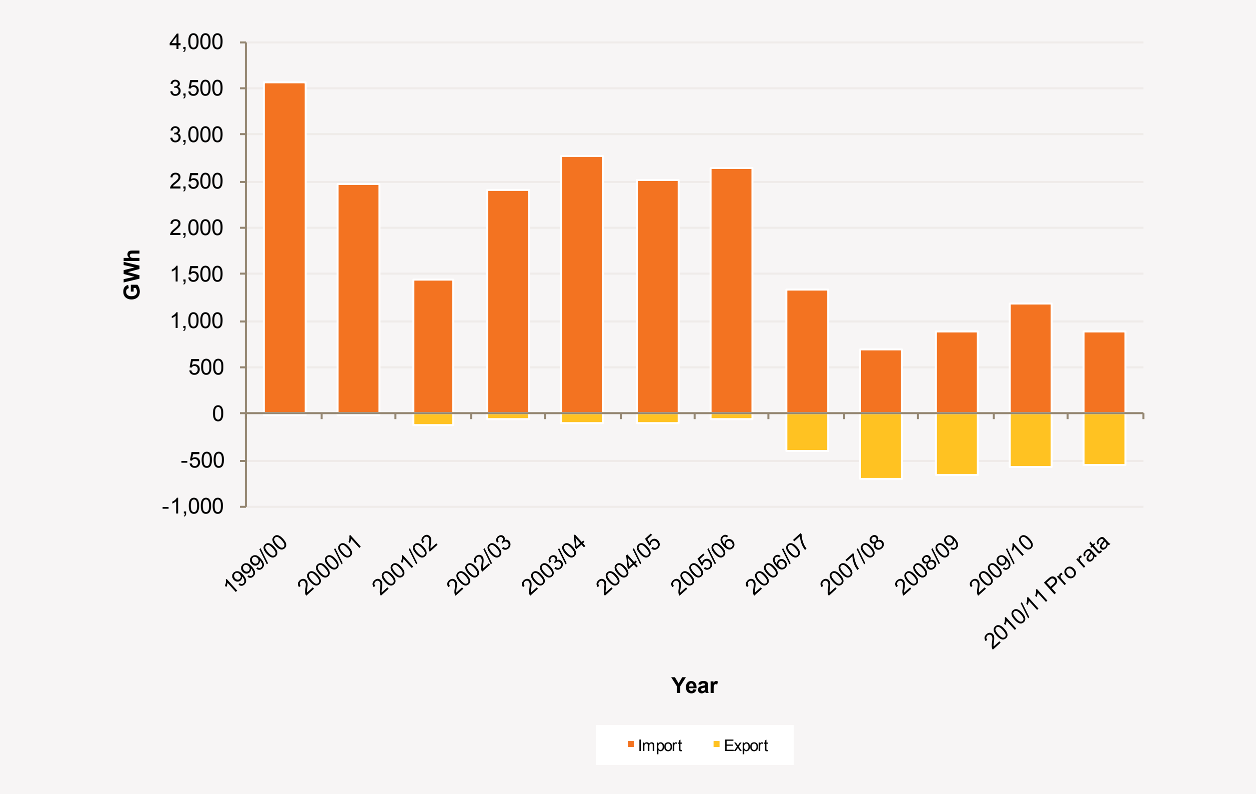
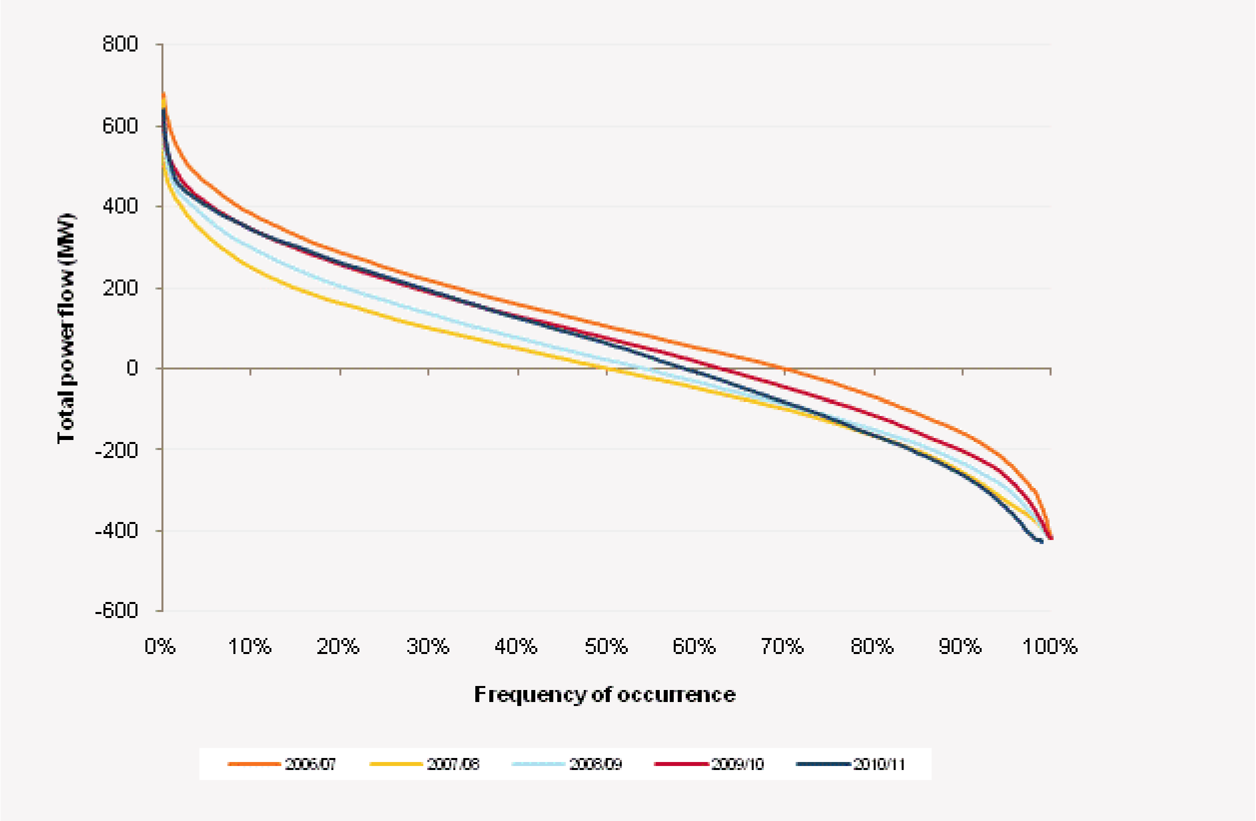


Figure 5-4 shows the combined flow duration curves for the Heywood and Murraylink interconnectors for the years from 2006/07 to 2010/11. Flow duration curves are a graphical representation of the frequency that the interconnectors were transferring specific amounts of power. The area between each curve and the x-axis represents the amount of energy transferred between South Australia and Victoria. If the area above the x-axis to the curve is greater than the area below the x-axis to the curve, it means that South Australia has imported energy from Victoria (net imports).

Figure 5-4 — Combined Heywood and Murraylink interconnector flow duration curve



Prior to 2006, South Australia was a large importer of power from Victoria when the interconnector contributed almost a fifth of state's energy needs. The flow duration curve for 2006/07 sits to the right of the other curves, demonstrating the tail end of this trend with high levels of imports (the area between the x-axis and the curve on the right-hand side of the figure for this year is significantly smaller than the area between the x-axis and the curve on the left-hand side of the figure, indicating net imports). This was followed by a drop to the left in 2007/08, when South Australia became a small net exporter of power to Victoria (5 GWh).

From 2007/08 to 2009/10, the interconnectors were used at progressively higher rates. The 2010/11 curve sits mostly to the left of the previous year, representing fewer periods of high imports and more frequent exports.

5.4 Wind analysis

Generally, across the day, the output from wind farms in South Australia is quite well correlated as all wind farms in the state experience relatively consistent atmospheric conditions. However, their output fluctuates over shorter time frames in response to local conditions. Infrequently these short time-frame fluctuations can be synchronised causing potential system security issues.

5.4.1 Wind Performance

South Australia has the highest penetration of wind generation in Australia, with wind farms contributing a considerable amount of energy, and able to deliver significant combined instantaneous output. Table 5-4 lists the combined maximum half-hourly output for all the wind farms operating in the state.

Table 5-4 — Maximum half-hourly wind farm output from 2004/05 to 2010/11

Financial year	Installed capacity (MW)	Maximum half-hourly output (MW)
2004/05	318	235
2005/06	334	286
2006/07	493	320
2007/08	685	540
2008/09	740	641
2009/10	868	765
2010/11[a]	1,150	978

[a] The end-date of the 2011 data used was 31 March 2011.

The significant growth of wind generation over recent years, and the variability of wind over a short period of time, means that transmission network and power system management is becoming more challenging.

Figure 5-5 shows changes in wind generation (variability) as a percentage of total wind farm installed capacity over different time intervals. The chart shows the number and magnitude of fluctuations over the period 2003 to 2011.[50] This is based on a frequency analysis of the number and magnitude of the fluctuations in wind generation over different time intervals. For example, the half-hourly variability represents the difference between each 30-minute reading. Similarly, the six hourly variability is the difference between wind farm output readings six hours apart. The analysis uses raw generation data and does not take into account any changes in generation caused by bidding behaviour of scheduled or semi-scheduled wind farms or variations caused by the imposition of constraints applied either by AEMO or the network service provider on the output of the generator.

The results show that variability is greater over a longer period of time. The six-hourly variability shows that for approximately 1.2% of the time the fluctuation is 50% of total installed capacity or more, while the half-hourly variability shows that for the same percentage of time the fluctuation is 15% of total installed capacity or less. On a half-hourly basis there were only 16 occurrences where the fluctuation was greater than 50%.

[50]

Figure 5-5 — Variability as a proportion of installed capacity

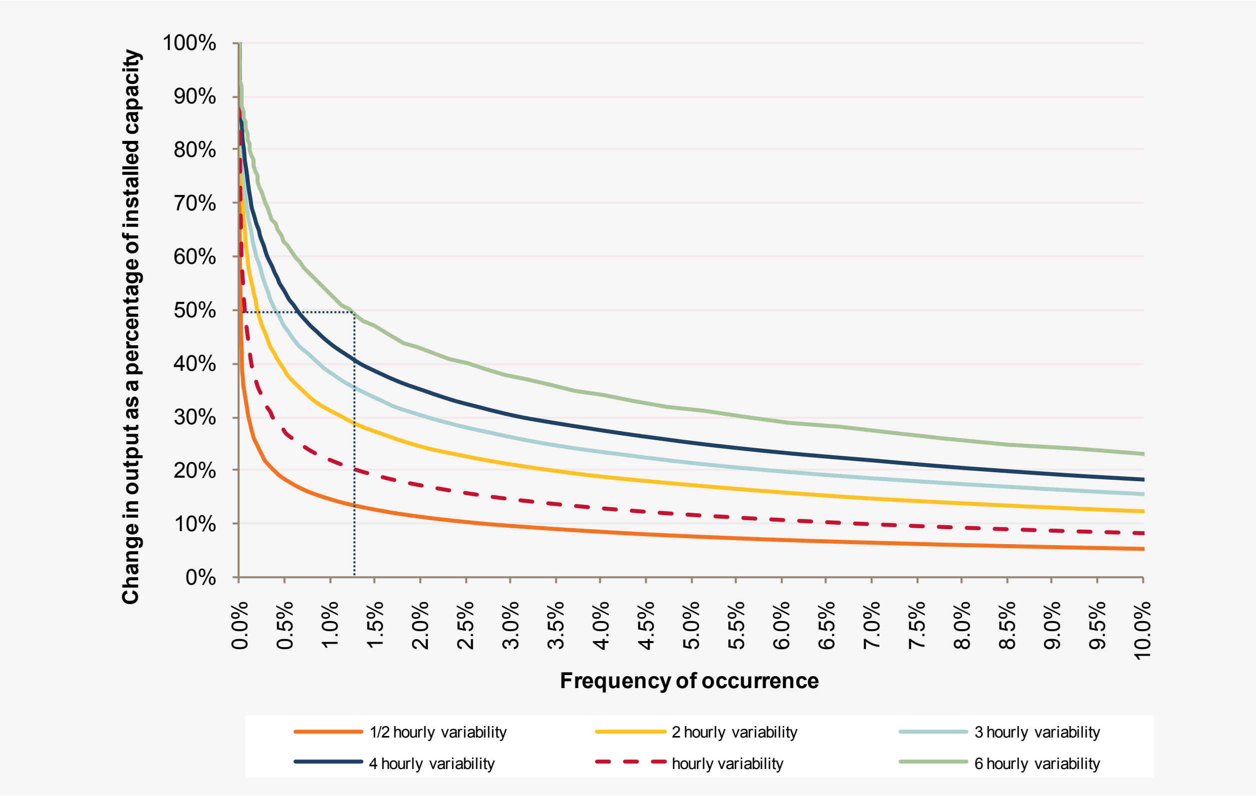


Figure 5-6 shows the variability with increasing numbers of wind farms over different time intervals. Charting intervals ranging from half-hourly to four-hourly, it presents a similar analysis to wind variability as a proportion of installed capacity (Figure 5-5). Examining four different increments of development, the data is divided into subsets based on the number of operating wind farms (three, six, nine, and fourteen), and is designed to highlight the change in variability as more wind farms are connected.

The first and longest data set includes the half-hourly generation readings from the state's first three wind farms, covering the period from when the third wind farm commenced operation to 31 March 2011. The second data set covers the first six wind farms from the time when the sixth wind farm in the state commenced operation to 31 March 2011. The third covers nine wind farms. The fourth data set covers the last eight months when 14 wind farms were operating. The data set for the 14 wind farms may be less reliable as a result.

The general trend shows variability falling as the number of wind farms increases. The most notable and largest reduction occurs between three and six wind farms, reflecting the benefit of diversity. The reduction in variability between six and nine wind farms is significantly less pronounced, and is barely evident with 14 wind farms. The reasons for this are still being investigated.

Variability is higher over the longer time intervals (two and four-hourly), and the reduction in variability on a percentage of installed capacity basis masks the increase in the actual variation that is occurring.

Figure 5-6 — Wind variability charts

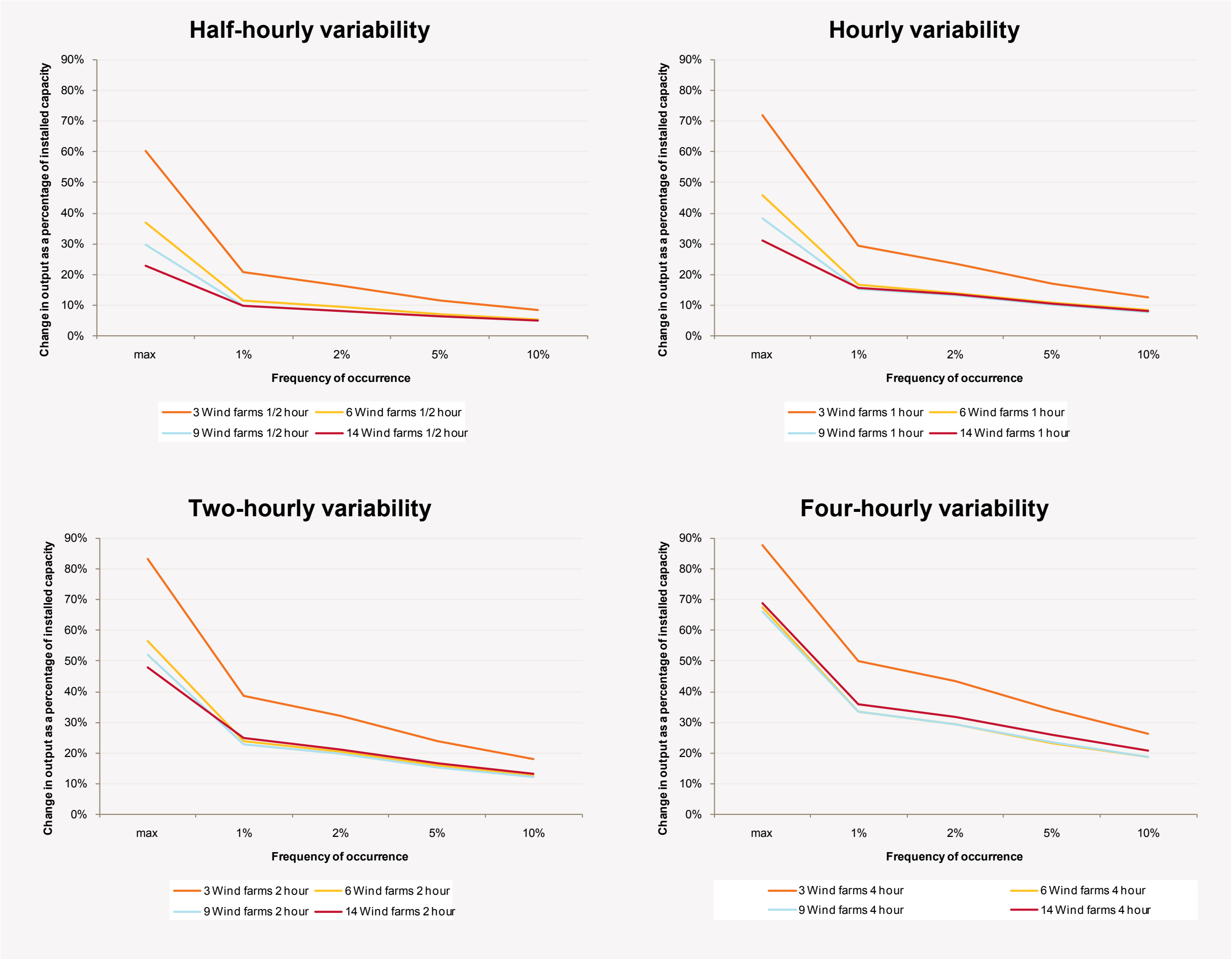


Table 5-5 compares total wind farm installed capacities with variability. For example, with an installed capacity of 1,150 MW across fourteen wind farms, the largest half-hourly change was 253 MW, which is similar in size to the region's largest fossil-fuelled generating unit. The largest four-hourly change, however, was 757 MW, which is approximately the same size as the region's normal daily load variation. The loss of 253 MW over 30 minutes is not as challenging for the market operation as it would be if it was instantaneous. However, managing changes of this magnitude increases the importance of accurate forecasting, particularly with respect to the timing of significant changes.

These results highlight that while variability is relatively small as a percentage of total installed capacity, as installed capacity increases, the magnitude of that variability becomes more challenging to manage.

Table 5-5 — Total installed capacity and maximum half-hourly and four-hourly variability

Wind farms	Installed capacity (MW)	Maximum half-hourly variability (MW)	Maximum 4-hourly variability (MW)
3 wind farms	161	97	141
6 wind farms	388	143	258
9 wind farms	740	220	490
14 wind farms	1,100	253	757

Table 5-6 shows key statistical information about variability over five and ten-minute intervals, contrasting the change in variability as more wind farms have been developed.

The variation as a percentage of installed capacity for the 10% and 5% frequency of occurrence calculations is relatively consistent for six and nine wind farms, but higher for 14. The 1% frequency of occurrence and maximum data set values are showing that over time-frames less than four hours there is a diversity benefit.

Australian and international research into wind variability confirms that the correlation between the behaviour of wind farms reduces significantly with distance and with shorter time periods to the point where some are increasing their output while others are decreasing. That is, as the time frames considered decrease, the correlation between the output of wind farms decreases.

Research is ongoing, with the University of South Australia, School of Mathematics and Statistics, to better understand this outcome. Short-term wind variability and the variation in customer demand are both supplied via the ancillary services market.

Table 5-6 — Five and ten-minute variability[a]

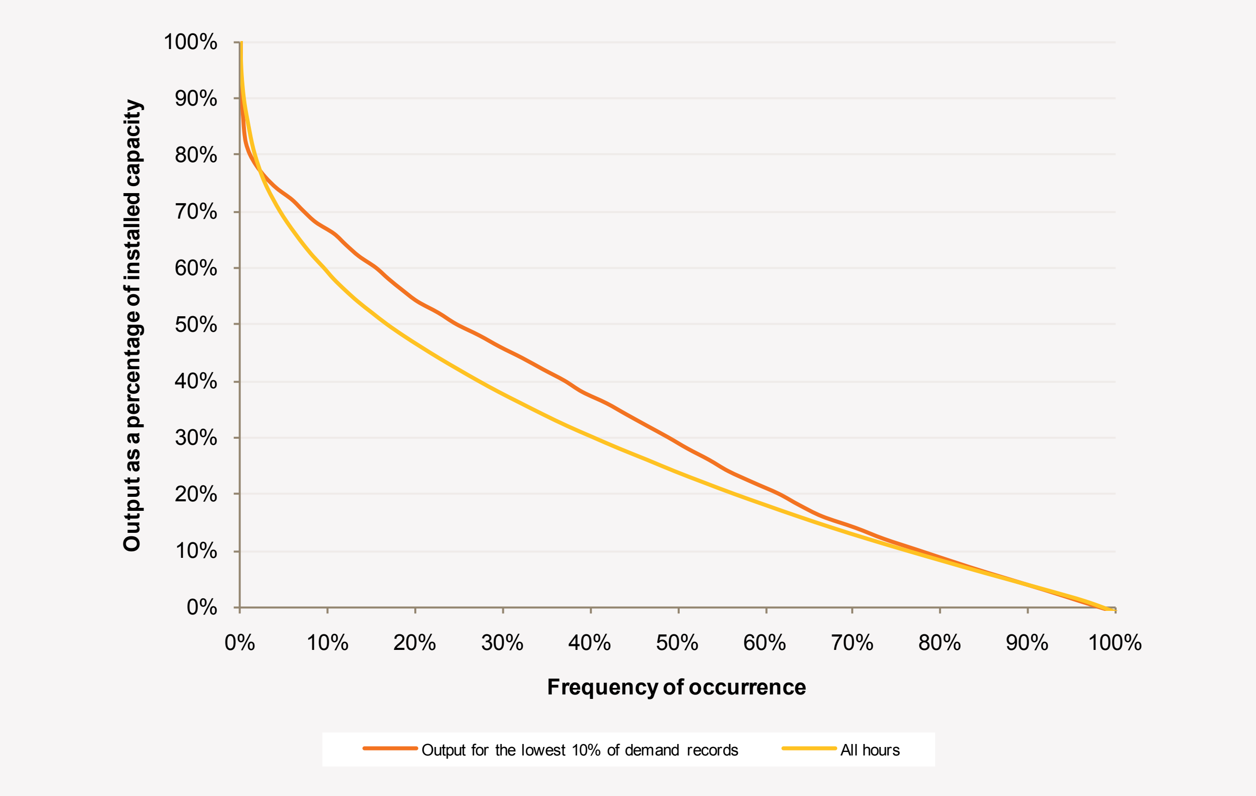
	6 Wind farms		9 Wind farms		14 Wind farms	
	Five-minute	**Ten-minute**	**Five-minute**	**Ten-minute**	**Five-minute**	**Ten-minute**
Mean	0.72%	1.09%	0.77%	1.18%	0.85%	1.32%
Median	0.43%	0.65%	0.51%	0.79%	0.60%	0.93%
Standard deviation	0.92%	1.38%	0.88%	1.32%	0.90%	1.36%
Variation as a percentage of installed capacity						
10% frequency of occurrence	1.7%	2.6%	1.7%	2.7%	1.9%	2.9%
5% frequency of occurrence	2.4%	3.6%	2.3%	3.6%	2.5%	3.8%
1% frequency of occurrence	4.4%	6.6%	4.0%	6.2%	4.2%	6.5%
Maximum	28.8%	29.8%	22.6%	26.2%	20.4%	22.1%

a. The analysis datasets were created on the same basis as the longer time intervals. While the size of the fourteen wind farm dataset is limited to the last eight months, the means and medians increase with the number of wind farms, implying more variability as numbers increase.

5.4.2 Wind contribution during low demand periods

Of particular interest for South Australia, where the load factor is quite low, is the output of wind farms during low demand periods where the minimum output of the fossil fuelled generators, interconnector capacity and potential wind generation can result in both network and generation constraints.

Figure 5-7 — Generation duration curve for wind generation during periods of low demand



AEMO has considered the contribution of wind generation at periods of low South Australian demand. Figure 5-7 is a graphical representation of those times when demand was within 10% of the minimum South Australian demand. These periods of low demand tend to be overnight, and the results indicate that wind at these times is more variable than average. However for over 50% of these times, wind generation is above the average. This analysis is based on the actual production from the wind farms and does not account for wind operators reducing their output in response to negative market prices or being constrained off to maintain network security. The results suggest that there may be opportunities for network development to exploit these periods of high wind generation and low demand. This is being further investigated in the 2011 National Transmission Network Development Plan (NTNDP).

5.4.3 Wind contribution during peak demand

Within a planning framework, such as that used to assess where there is sufficient generation to meet demand, it is necessary to calculate a peak demand contribution figure. Wind generation contribution was previously calculated using wind farm outputs during summer peak periods for a given confidence level. The confidence level was set as a percentage that represented the typical reliability of a fossil-fuelled generator. In the past, this level was set at 95%, meaning that the full output of the generator would be available during peak periods at least 95% of the time.

Recently this approach has been more intensively scrutinised and alternate methods have been examined. For the purposes of this analysis, AEMO has used a confidence interval to 85% because a 95% availability is potentially overly conservative. Establishing the contribution from wind on this basis involves mathematically sampling the normalised historical wind generation dataset, and statistically analysing the frequency that different levels of output occur for two subsets.

Another potential approach for the future could be to use a simulation technique where, within the 0.002% Reliability Standard, the contribution at peak demand is determined by calculating the equivalent capacity of a non-stochastic generator, such as an open-cycle gas turbine. This methodology would be highly computationally intensive, likely to be quite specific with respect to the configuration of the wind farms and difficult to generate a statistically significant sample.

Subset 1 involves the wind contribution for periods when demand is within 10% of each financial year's maximum demand.

Subset 2 involves the wind contribution during the top 10% of demand records.

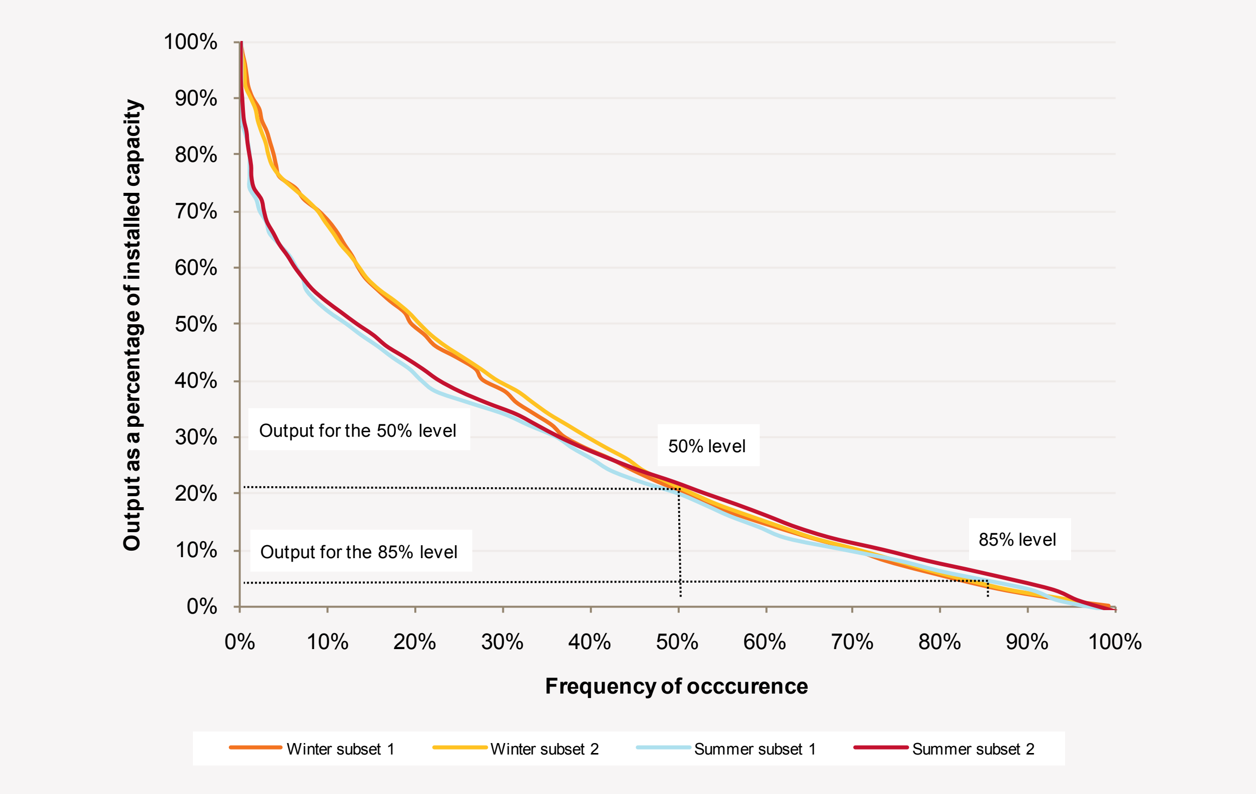
Figure 5-8 shows the contribution of wind generation from the two subsets during summer and winter as a proportion of peak demand. Two points have been marked on the figure (50% and 85%) showing the range of likely outputs during periods of high demand.

Based on the recorded performance of wind generation during the top 10% of summer demand records, wind generation in South Australia contributes at least 5% of its installed capacity for 85% of the time, and at least 20% of its installed capacity for 50% of the time. The results for the 85% level for summer and winter are listed in Table 5-7.

Table 5-7 — Wind contributions

	Summer	Winter
Contribution	5%	3.5%

Figure 5-8 — Peak demand period wind generation duration curves



5.4.4 Period of high temperature January/February 2011

South Australia experienced a short period of high temperatures in late January and early February 2011. Table 5-8 lists the recorded temperatures for the period.

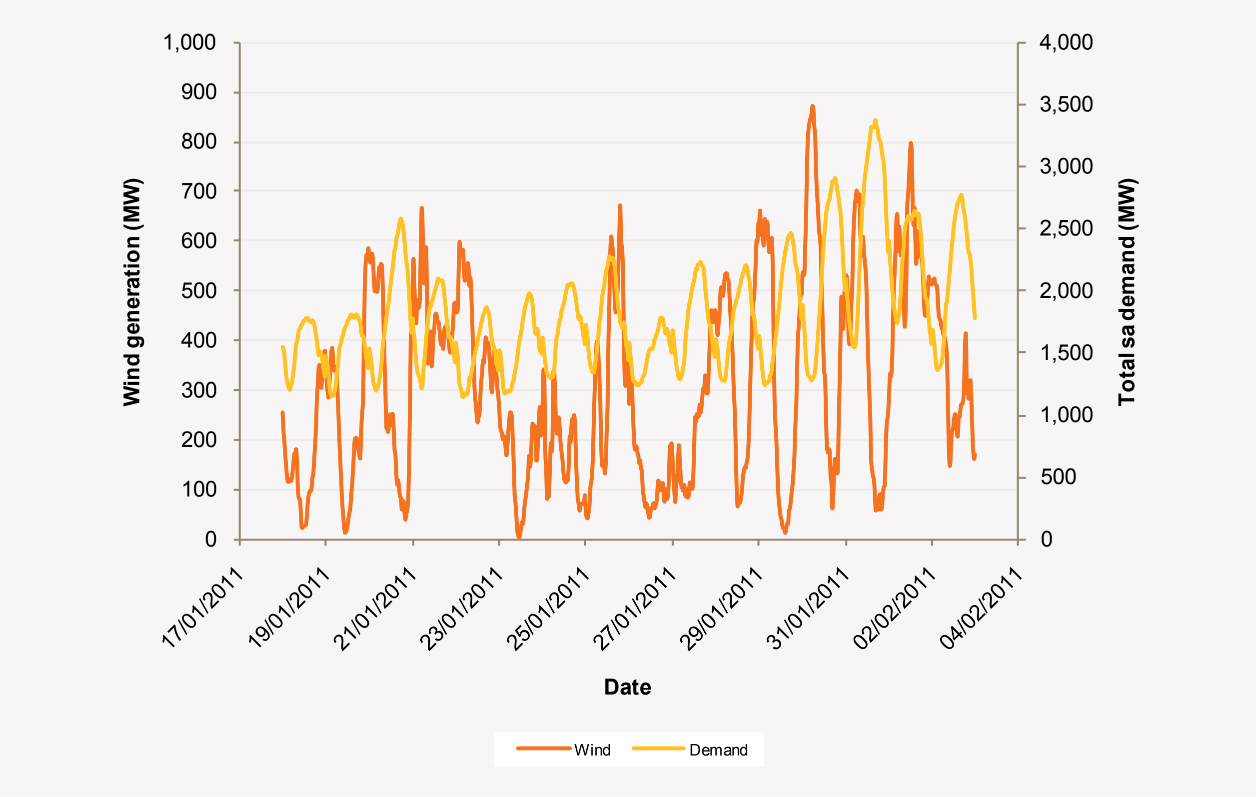
Table 5-8 —January/February 2011 heat wave

Date Day	20th Th	21st Fr	22nd Sa	23rd Su	24th Mo	25th Tu	26th We	27th Th	28th Fr	29th Sa	30th Su	31st Mo	1st Tu	2nd We
Max temp (°C)	37.0	29.2	32.1	32.0	27.3	32.5	29.6	32.0	31.8	37.7	42.5	42.9	33.2	36.0

Figure 5-9 shows wind generation and total South Australian demand for the same period. The maximum contribution from wind during this period was 873 MW at 5:30 AM on 30 January 2011, and peak demand (the demand supplied by scheduled, semi-scheduled, and significant non-scheduled generating units) was 3,433 MW at 4:30 PM on 31 January 2011.

The figure, which demonstrates the correlation between demand and wind generation, shows that as demand increased, the contribution from wind generation fell. While the output of some wind turbines is limited during periods of high temperature, the output of the wind farms increases due to local winds created by heating and cooling of the land mass at sunrise and sunset.

Figure 5-9 — Wind generation and total South Australian demand from 20 January 2011 to 2 February 2011



5.4.5 Seasonal variations in wind generation

Figure 5-10 shows the monthly energy production figures from wind farms operating in South Australia since September 2003. The highest output generally occurs during the winter months, and prominent heatwaves cause a significant decline in monthly output.

Figure 5-10 — South Australian total wind generation September 2003 to March 2011