South Australian Wind Study — appraisal (2 pp.) and extracts from (7 pp.)

To try to get at the essence of the report as concisely as possible, the format used is to set 5 questions and then answer them, drawing data from the SA Wind Study. That uses 2 pages. Then 7 pages of annotated extracts follow. The original study is available at www.esipc.sa.gov.au, where there should be no trouble in locating it, but more specifically the 1994 kB file is at:

http://www.esipc.sa.gov.au/downloads/Planning_Council_Wind_Report_to_ESCOSA.pdf

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Q1. Does the report give any indication of the maximum penetration of wind into a grid system?

A1. The study is largely theoretical as far as SA is concerned, but it does include a survey of international experience, and this is useful to a degree. Wind infeed as a percentage of total electrical supply is given in Table 8.2, from which the following data are extracted:

	Wind infeed as percentage of total electrical supply
	%
Western Denmark	19.3
SA – 800 MW Case	***18.5***
SA – 400 MW Case	***9.3***
Spain	7.8
Germany all states	4.3
Eire	4.5
Scotland	2.4
Texas	1.5
Alberta	1.3
Australia (2006) all states	0.9
UK	0.7

Table 8-2 - System Energy and Wind Penetration – Summary (Overseas markets at end of 2004)

Note that the two SA cases are theoretical, and the study indicates with some confidence that few serious problems will emerge up to about 12% penetration. The figure for Western Denmark is misleading without knowing that Western Denmark was only able to make use domestically of 4% of its wind, the rest having to be exported. Oddly, the table does not include Denmark as a whole. The relevant figures there are that although wind provides 21% of total electrical supply, about 40% of that has to be exported. There are various reasons why every situation is idiosyncratic. In Denmark, a problem arises because co-generation (CHP) is widely used, which is essentially a non-flexible (sometimes termed "unscheduled") supply. Also the distance over which turbines are spread in Denmark is not great enough to lower the peak infeed factor significantly.

The 500 MW capacity at which SA are intending to call at least a temporary halt to wind would produce a penetration of 12% based on an interpolation of the above estimates. The study makes it clear that there would be difficulties, which might perhaps be overcome, when going higher than 12% penetration, but perhaps (I'm not sure the study makes this clear) that would involve spreading delivery of the wind output beyond SA which of course, as in the case of Western Denmark, completely changes the arithmetic of the penetration being achieved.

Overall therefore the study hardly bears on the maximum penetration of wind, though there are a few hints. Another is the mention that a study in New York indicated an upper limit of 13% *even* *with good interconnections to surrounding areas* Overall it certainly confirms that there are likely to be difficulties well before the maximum theoretical penetration of 20% is reached.

Q2. Can one apply the same analysis that can be used in northern Europe, where the wind has no correlation with demand?

A2. You mean, I expect, that with an erratic wind, as in northern Europe, wind is displacing baseload, and the DIB (dominant in-harness backup) has to supply what the wind fails to supply. Unfortunately that simple analysis cannot be applied in SA, because there is a good correlation between the diurnal demand and the diurnal wind (which is markedly stronger during the day). In other words, wind participates to some extent in demand-following, and thus may even diminish the amount of demand-following that has to be done by fossil fuel. However it would do so on an irregular basis, which is complex, and useful data will probably only come from an empirical study.

Q3. Does the study indicate whether more spinning reserve would be needed to cope with wind variability?

A3 I find the study to be opaque there. I think that it appears to indicate that there would be no need to duplicate the spinning reserve that has to be kept available to cover failure of a major power plant, but that implies, although it is not stated, that the chances of a combination of events occurring together, whereby much of the spinning reserve is being used to replace decreasing wind combining with the failure of the major power plant, are too remote to bother about.

What occurs to me is that an important question in addition to how much spinning reserve there needs to be is the question of how much electricity will have to be supplied by calling the spinning reserve into action, and how efficiently it will then supply that electricity. The study does not address that. Like other studies it appears to gloss over the energy costs of introducing wind.

Q4 Does the study indicate how efficiently the DIB (dominant in-harness backup) would operate?

A4 The DIB does not quite apply to SA because of the correlation between demand and wind on a diurnal and to some extent seasonal basis. Thus although there has to be an in harness backup, it may not be *dominant*. Wind may serve to decrease the amount of demand-following input needed. However the study does recognize that there is an unquantified problem when it says (p. 38): "Increasing wind generation shifts the investment decision away from the selection of what would normally be considered base load style of generation, to technologies that are more flexible." That is of course the type of problem which is most dramatic when baseload could be operated by CCGT plant and wind is chaotic and so makes no contribution to demand-following.

Q5 Then does the study have any bearing on the UK and northern Europe at all?

A5 Only a slight bearing. I would say that it confirms that there will be problems well before 20% penetration is achieved, perhaps with an upper limit close to 15%. For the UK the limit is likely to be lower. But using 15% for the UK, where about a third of fossil fuels are used to generate electricity, and about 75% of electricity is produced from fossil fuels, this gives an *upper* limit to saving of fossil fuels of (0.15 / 0.75) * 0.33 = 7%. However, for the UK as for all northern Europe, with erratic winds, the *lower* limit is zero or below, depending on how much highly efficient plant is displaced by plant operating the DIB.

Those are what I see as the key points of interest that can be extracted from the study. There are many other matters of some interest which provide somewhat vague pointers, even if not directly related to northern European problems. Anyhow I include extracts from the study that I chose as being somewhat relevant, or interesting, at Appendix A They are mainly extracts, although with some square bracket interpolations by me. There are 7 pages of them, but then the study ran to 88 pages!

Appendix A

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To assess the likely impacts of various levels of wind energy on security and reliability the Planning Council has modelled the national market with different levels of wind generation. The market generally absorbs the 400 [AF. 9.3% penetration] and 500 MW [AF. 12% penetration] of wind generation with only moderate impacts on the number of other generators online at any time. In most circumstances for these low cases there is, therefore, sufficient response to demand and wind variability and adequate inertia to maintain security.

However, in the higher cases the variability of wind generation increases and displaces more of the conventional generation that would otherwise be available to provide the necessary inertia and ramp rates that ensure security. In the 800 and 1,000 MW cases the variability of such a concentration of wind energy exceeds the variability of all other causes of uncertainty in the market today and would significantly increase the difficulty of forecasting future scheduled generation requirements. These factors would make it difficult to ensure that appropriate generators are available, committed and operating in advance.

Even where the wind variability is of a type that can be predicted, appropriate market incentives will be required to ensure that other generators are prepared to be available to provide system security measures.

The Planning Council concludes that the security and reliability of the power system with up to 500 MW [AF. providing 12% of total supply] *of wind generation in South Australia should be maintained provided there is attention given to particular and rare situations. With higher levels of wind generation, we need to introduce state of the art forecasting. The degradation in the accuracy of forward forecasts we would have* without *such forecasting would challenge the market's ability to provide:*

adequate ramp rate response in the short term; and

timely commitment of other generators and fuels to ensure that the security and reliability of the system is maintained.

This phase of the study concluded that the average generation pattern from wind in South Australia is very good by world standards and broadly supports the shape of demand. However, the variation around the average is very large and complex, and average outputs provide no guide to impacts.

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In any case, if the recommendations above are implemented, increasing penetration of wind generation in the market will require proponents to factor in the costs of decreasing dispatch volumes as constraints act more frequently and a corresponding reduction in the market value of wind generation. The costs of development will rise with the imposition of higher standards although the evidence, both internationally and from the detail contained in licence applications, is that this impact will be small. As the relative contribution of wind generation rises, the costs directed to wind generators as causers of ancillary services can also be expected to rise. Lower revenues and increasing costs will be met with innovation by wind developers and wind turbine manufacturers but at some point a balance will be achieved.

While this analysis is as complete as possible, it is important to note that real operational data is necessarily limited and there is only a short history of a small number of projects in South Australia and indeed across the national market. The Planning Council considers that care should be taken in applying its current projections and advice at very high wind penetration levels without updating this analysis with experience at levels expected later this year.

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While the actual capacity factor changes as a result of annual variations and the specific wind-farms used in the various cases, typical capacity factors for the State are consistently between 32% and 40%. [AF. i.e. 32% one year and 40% another]

CASE		AVERAGE OUTPUT (MW)	CAPACITY FACTOR
400	MW	148.8	37.6%
500	MW	181.8	37.0%
800	MW	297.5	34.6%
1000	MW	371.8	36.6%

Table 3-1: Typical Capacity Factors

The seven year dataset on which this analysis is based is a comparatively short period of time and European experience in wind analysis suggests that there can be up to a ±15% variation in the total wind resource annually. Therefore, while the average capacity factors listed above are very strong across all the cases, Figure 3-1 highlights the type of annual variations that, even over only seven years, have been observed: [AF. Figure shows variations in annual capacity factors between 32% and 40%.]

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Of most interest is the variation from one period to the next which will be met or exceeded on a given percentage of occasions. The results are summarised in the following *Table* and the 1% probability of exceedance variations are displayed in Figure 4-3.

OCCURRENCE	HALFHOURLY	HOURLY	2 HOURS	3 HOURS	4 HOURS	6 HOURS
10%	42.5	67.0	104.7	136.7	163.5	204.9
5%	55.0	86.4	134.5	173.1	204.2	248.4
2%	71.2	111.9	171.5	217.0	250.0	296.0
1%	83.5	130.0	197.4	245.3	280.8	325.7
Once per annum	162.5	242.2	329.2	381.6	402.1	439.7

Table 4-2- Case 2 - 500 MW of wind capacity in SA- Variation in MW

[AF. This idea is quite hard to grasp. By way of explanation, I will take one example: once per annum (with 500 MW of wind capacity installed); one can expect a 242.2 MW change of output during one hour, and a 439.7 MW change over 6 hours. The last figure seems to me particularly significant as follows:

Once a year, there would be a variation of 439.7 / 500 = 88% of wind capacity. Were one to install sufficient wind turbines to provide 15% of electricity, and supposing the wind turbines operate at 30% infeed factor, then turbine capacity would need to be 15 / 0.30 = 50% of total electrical supply. Thus once a year, there would be a variation, over 6 hours, of 50 x 0.88 = 44% of total electrical supply. To that may of course be added a variation in demand. That suggests to me the need for a lot of flexible, though rarely used, capacity.]

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The more general provision of data on each wind-farm's current output and provision for its remote control through market security systems will be imperative to maintaining system security with a larger proportion of wind energy on the system. [AF. The "larger" presumably refers to larger than 500 MW case, 12%, of total supply.]

The Planning Council considers that all future wind-farms should be required to meet tighter standards including the ability to:

ride through a prescriptive and more severe low voltage event;

generate and absorb reactive power and control voltage;

smooth short term fluctuations in output; and

be remotely controlled and to curtail output where necessary. The control of the wind-farms should provide the capability to manage their ramp rate of change. The requirements for the provision of communications and SCADA data currently imposed by NEMMCO should continue.

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In the two larger cases, [AF. Wind contributing 800 MW, 19%, and 1000 MW, 23%] the average variability in wind generation exceeds the average variability in [both] the demand and demand forecast accuracy. In these cases we could expect variability in wind generation to be the dominant cause of variability and uncertainty in market operations. The diversity of wind generation across the power system and the size of individual wind-farms clearly influences the levels which can be accommodated and this can be seen in these cases. The 400 and 500 MW cases are well dispersed across South Australia maximising the benefits of diversity whereas the 800 and 1,000 MW cases add large new wind-farms at only two sites.

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Figure 6-2 indicates that for 50% of the periods of minimum demand, the output from the wind-farms is above 22% of their installed capacity. Significantly, for 5% of the minimum demand periods the output from wind-farms is above 75% of their installed capacity and for 2% of the minimum demand periods the output from wind-farms is above 85% of their installed capacity.

[AF. The graph, even though it refers only to periods of low demand, shows that for all the wind 'cases' studied, peak demand is above 90%; so there is surprisingly little smoothing of the peak due to the wide spread of the wind farms — at least it is surprising in that E.ON Netz, with a spread of 800 km, managed to depress the peak infeed factor to 80%.

One thing that the "5% of the minimum demand time being above 75% of capacity" indicates is that 20% is a rough upper limit to wind penetration, even when wind correlates fairly well with demand, for this 75% is in low demand periods. For instance, if mean demand were to be 100 GW, and sufficient wind capacity installed to produce 20 MW (20% penetration), then at 30% infeed factor, the capacity to install would be 20 / 0.30 = 67 MW. For 5% of the time this would produce 67 x 0.75 = 50 MW. If low demand is about half of mean demand (a ball park approximation) then any more capacity than 20% would result in significant amounts of electricity going to waste. Note, too, that the assumption for that calculation is that there are no other inflexible inputs, such as CHP, for that would further reduce wind penetration.]

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The half-hourly variability in both the 800 [AF. 19% wind supply] and 1,000 MW [AF. 23% wind supply] cases exceeds the 260 MW contingency level. The variability over one to two hours exceeds two contingencies and the four to six hour variability is very high. Without adequate foreknowledge and planning it is likely that these cases could lead to insecurity.

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If the load factor of the pipelines is reduced as a result of the increased penetration of wind, as is indicated in the analysis, then this could increase pressure on the cost of gas transport. At this stage, the Planning Council has not attempted to calculate the potential cost impacts of this situation. [AF. This refers to problems of having gas available for backup.]

Market Participation Issues for Wind Generation

South Australia participates in the National Electricity Market and all the generators within the State are required to abide by the standards and rules that are contained in the *National Electricity Code* While wind generation was always envisaged as a part of the market, the rules were written at a time when the volumes of wind energy that are being proposed could not have been anticipated. As a result, the national market rules classify wind generators as non-scheduled. This classification has a number of implications for the operation of the market, some of which have the potential to lead to unacceptable market distortions as the quantum of wind energy increases:

Dispatch

Unlike other generators, wind generators do not participate in the normal market bidding process to determine which generators are allowed to operate to satisfy demand. Wind energy, therefore, never acts to set the wholesale pool price and is simply paid the going rate as determined by the bids of other generators. However, by lowering the overall volume of energy being bid for by those residual generators, wind will, in this circumstance, increase competition and create a downward pressure on pool price. [AF. It seems likely that this will only be the short term result. The longer term result will be that generators withdraw capacity until the bidding price is adequate to compensate for having to satisfy more erratic demands.]

Stability and Market Optimisation

Under the current rules, NEMMCO has no power to manage the stability and security of the market by incorporating wind into its normal market optimisation techniques. Normally, NEMMCO would set certain tolerance levels expressed as constraint equations that would ensure that the system remained in a secure operating state. As a non-scheduled generator, wind does not participate in this process and NEMMCO must either rely on powers of manual intervention or must constrain other non-wind sections of the market if it is to control security. A manual scheme cannot provide the immediate response that is likely to be necessary, particularly in light of the variable output associated with wind and, in any event, is potentially inefficient and undesirable in a market context. Constraining other plant to deliver security also risks inefficient outcomes and undesirable price impacts. [AF. This is effectively admitting that the capacity factors given are well above the infeed factors which would result if wind operators had to be scheduled, and hence waste some of the electricity they produce.]

Ancillary Services

A key consequence of wind being categorised as non-scheduled is that they do not participate in the markets for ancillary services. Ancillary services are an important part of the market design that allows NEMMCO to manage the market within secure limits. On the whole, the ancillary services operate on a causer-pays basis where the cost of providing the relevant service is paid for by the individual or group of market participants that create the requirement for the service. Conversely, those participants who can supply ancillary services are able to earn extra revenue in the market.

Under the current rules, wind energy will neither pay for the ancillary services that they cause nor be able to earn revenue from the provision of such services.

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Increasing wind generation shifts the investment decision away from the selection of what would normally be considered base load style of generation, to technologies that are more flexible. [AF. This is an interesting admission that even where there is a good correlation between wind output and demand, there is stilll an effect of displacing efficient fossil fuel generating plant and having to replace it with less efficient plant.]

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The cost of wind generation has fallen considerably since the early 1980's but is still higher than conventional fossil fuel generation. The countries with a significant penetration of wind generation all have support schemes which may include direct subsidies, tax benefits, obligations on other parties to purchase a percentage of green energy and arrangements to subsidise the cost of connection. [AF. Note that it is hardly useful to talk simply about "the cost" of wind generation. There is the price at which the wind generators are happy to sell, which is usually the cost which is cited, though probably with subsidies added, and the overall cost of integrating the wind turbines into the grid, divided by the amount of electricity they supply. This is the more important, though rarely discussed, cost, which involves many other factors, such as paying more for fossil fuel generators to operate more erratically and calling more spinning reserve into action more frequently.]

pp. 42–43 shows wind penetration in Table 8-2, which is shown graphically on page vi.

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Control and Curtailment of Wind Generation

The Eltra system in Western Denmark includes a relatively large amount of wind generation and unscheduled cogeneration (or combined heat and power generation). As almost all of this generation is not capable of central control or curtailment (sometimes referred to as run-back capability) Eltra has experienced difficulties on occasions in managing power flows on its 150kV and 400kV internal lines, sub-stations and interconnectors to Germany and Scandinavia. In other international examples, control or curtailment of wind generators has been routinely adopted to ensure secure network operation. For example, wind-farms on the Kintyre Peninsula connected to Scottish and Southern Energy are subject to routine curtailment to manage power flows on critical lines [AF. It would be interesting to find out what their infeed factor is.] Similarly, wind-farms in western Texas connected to ERCOT's system are subject to regular curtailment. [AF. These cases, and the following, are examples of how infeed factors are likely to be lower than capacity factors.]

Recent studies in the Republic of Ireland have determined that curtailment will be necessary at the higher penetrations of wind energy expected to be installed in the future. Spain has also undertaken work contemplating central control and curtailment of wind generation under certain circumstances. Garrad Hassan considers that, on the basis of international experience, South Australia will require control infrastructure for curtailment at some stage.

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Market Issues

Market issues raised by wind generation will vary with different market designs and, to date, there is only limited experience with high wind penetration in competitive markets other than Nordpool. The various market designs influence:

pricing outcomes with wind generation;

the need to participate in forward markets and hence for wind generation to forecast output; and

arrangements with regard to ancillary services. [AF. i.e need to pay for problems caused.]

Increasing levels of wind generation in deregulated markets also raise issues associated with grid connection costs and the incentives and penalties driving investment into efficient locations.
[AF. This is at least some acknowledgement of the complexity of the "cost" of wind generated electricity.]

Garrad Hassan concluded that there is no limit to the relative penetration of wind energy in a power system evident from international experience [AF. But Garrad Hassan seem to have overlooked that the penetration in Denmark would not be possible without interconnectors allowing offloading of excess to other areas Note also the calculation I do above, for page 23, relating to a 15% penetration and a 44% variation in 6 hours, so the fact that there is no evidence is partly because only Denmark has more than 15% penetration and its problems are concealed.] However, it is clear that with increasing levels of wind generation action needs to be taken to: ensure technical standards are appropriate;

introduce generation monitoring;

implement wind generation forecasting; and

manage congestion and potential security issues with schemes to curtail wind generation when necessary. Garrad Hassan considers that at some higher level of wind energy penetration, there will be an incremental cost will exclude further investment in wind energy. [AF. Higher than what!?]

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In parallel to the work of FERC, the operator of the New York Power Pool (NYISO) has been undertaking a detailed technical analysis of the expected impact of greater quantities of wind generation on its power system. The New York power system has a peak load of around 32,500 MW although typical loads are around 25,000 MW and loads can fall to 14,500 MW at low load conditions. The New York system is strongly interconnected to other power systems in the area including PJM to the south and the Northeast ISO to the north. It even has links to Canadian generators in Ontario and Quebec. They currently have almost no wind generation in operation but have applications to connect from almost 2,000 MW of wind generation. The NYISO used General Electric as their expert consultants and undertook detailed modelling of a theoretical case of 3,300 MW of wind generation connected around their grid. General Electric characterised the wind resource in the State, modelled the expected output and performance of some 37 notional wind-farms and examined potential impacts on the grid and the operation of the Power Pool. The recommendations were that the New York state power system could reliably accommodate at least 10% penetration of wind energy (based on peak load) subject to: [AF. 10% of peak load looks like being about (32,500 x 0.10) / 25,000 = 13% of mean load, and that is with good interconnections.]

employing state of the art technology in the wind-farms;

introducing state of the art forecasting;

undertaking a system reliability impact study on each individual wind-farm as part of its connection process, and implementing procedures to manage network constraints which may arise from wind generation in certain areas.

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As the wind resource is neither storable nor predictable, the Planning Council believes that, consistent with the previous assessment performed in 2003, the available capacity from a given wind-farm distribution across the State should be calculated based on that which is available for at least 95% of the time. This provides the wind-farms with a comparable level of unavailability based on their "fuel" resource as the conventional generators would have from forced outages. That is, the Planning Council has assumed that the planning capacity of a wind-farm is that percentage of its installed capacity that is statistically available for at least 95% of the time during weather conditions that would produce peak electricity demand.

The analysis performed to establish the level of planning capacity considered the combined output from the wind-farms for each of the different wind development cases for the top 10% of demand in each year. For comparison, the Planning Council also calculated the wind-farm output for the summer daylight hours when peak demand is usually experienced and the average contribution for all seasons for the same daylight hours in the year.

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As can be seen from *Figure A-1* - the planning capacity for the peak hours for the whole year is in the order of 8% and for the peak hours during the summer months the planning capacity is in the order of 23%. This outcome is consistent with results from the seasonal analysis where the average wind speed in the late afternoon in summer is higher than that of the other months. The planning capacity from the wind output during the top 10% of peak demand periods lies between these other values, indicating that the wind is less strong during periods when South Australia is experiencing its peak electricity demand. South Australia's peak electricity demand is highly dependent on the ambient temperature conditions in the State. Currently the 10% Probability of Exceedence (PoE) temperature conditions are based on an average of the daytime maximum and overnight minimum temperatures of 34.8℃. In the supply-demand balance the Planning Council requests that the generators provide their summer capacity estimates based on a 42℃ ambient temperature. The Planning Council understands that many of the wind-farms have maximum ratings of 40℃, however it is unclear how the output of the machines varies above this temperature.

During recent hot periods the Planning Council has monitored the output of wind-farms with respect to ambient temperature and it is apparent that some of the existing windfarms in the State are more sensitive to high ambient temperatures than others.

The Planning Council understands that this aspect of the performance of the wind-farms is highly dependent on the manufacturer and specification of the machines employed at each wind-farm and is in the process of gathering more information on the sensitivity of existing wind-farms, new farms under construction and the proposed new projects such that this *Figure* can be more rigorously determined. Without this additional information the Planning Council believes that it is prudent to leave the current *Figure* of between 7% and 8% for the calculation of the supply-demand balance to accommodate for this currently unquantifiable reduction at peak load until more detailed operational information is obtained.

[AF. This might be summed up as, the amount of wind power that can be relied upon when you need it is small, and still uncertain; for the present, 7–8% of the total wind turbine capacity is all that should be counted on as likely to be available.]

END