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Corresponding author:
Nicholas Cutler.
n.cutler@unsw.edu.au

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Contents

About CEEM, WINDFORNEM and this report:

The UNSW Centre for Energy and Environmental Markets (CEEM) undertakes interdisciplinary research in the design and analysis of energy and environmental markets and their associated policy frameworks. Research areas include the design of electricity markets, market-based environmental regulation, sustainable energy technologies including wind energy and photovoltaics, and the broader policy context in which all these markets and emerging sustainable energy technologies operate. You can learn more of CEEM's work by visiting its website: http://www.ceem.unsw.edu.au.

This document is the first published release of the Wind Energy Forecasting Issues Paper as part of the AGO-CEEM Project - WINDFORNEM *Facilitating the Uptake of Stochastic Renewable Energy in the Australian National Electricity Market: Wind Energy*. The paper was originally drafted for the December 2005 wind workshop hosted at CEEM in Sydney. You can learn more about the workshop and the WINDFORNEM project at http://www.ceem.unsw.edu.au/windfornem/.

The corresponding author for this report is:
Nicholas Cutler
PhD Candidate
University of NSW, Sydney Australia
n.cutler@unsw.edu.au

1 Background

It is generally accepted that forecasting wind energy production is essential to facilitate high levels of wind energy penetration in an electricity grid. In December 2003, following a request from the National Electricity Market Management Company (NEMMCO), the Commonwealth Science and Industry Research Organisation (CSIRO) recommended that NEMMCO forecast Australia's wind power over 3 different time scales [1]. NEMMCO published an issues paper in February 2004 [2] adopting CSIRO's suggestions, as follows:

1. NEMMCO to predict the 0-6 hour in-house using statistical methods such as modified persistence (use not only the current observation, but previous ones with various weightings according to the age of the observation). Wind Generators to provide real-time operational data to NEMMCO.
2. Wind Farm Generators to provide 6-48 hour forecasts 4 times daily to NEMMCO.
3. Wind Farm Generators to provide daily mean forecasts, at least every week to NEMMCO.

The division of methods at the 6-hour outlook is due to overseas experience [3]. Statistical time-series prediction methods (combining multiple observations and perhaps numerical weather predictions with weightings) are the most accurate known method for a prediction horizon less than 6 hours. Common statistical methods include linear regression, kalman filtering, adaptive neural networks, support vector machines etc. For prediction horizons between 6 and 48 hours, predictions relying more heavily on numerical weather prediction (NWP) models are the most accurate known. It is also considered in [1] and [2] that the time taken to make a forecast based on NWP is at best 5 hours due to data gathering and computation. Hence, an expectation that this forecast predicts the 6-48 hour horizon is reasonable. NEMMCO made a proposal to the National Electricity Code Administrator (NECA) to move towards this approach in June 2004. However, a number of issues for Australia were not fully resolved in this process, including the following points below. These points have however been discussed world wide in some detail.

- Whether the prediction focus should be on expected behaviour only, or also consider a range of possible scenarios,
- How much emphasis should be given to predicting the timing and magnitude of large rapid changes in wind energy production,
- Whether the focus should be on predicting the behaviour of individual wind farms or on groups of wind farms, aggregated in appropriate ways, and
- How much emphasis should there be on forecasting variations in inter-connector power flow due to differences in wind power output, aggregated on a regional level.

Concurrently, in June 2004 the Australian Government released its Energy White Paper "*Securing Australia's Energy Future*", in which up to $14 million was allocated to the Wind Energy Forecasting Capability (WEFC) initiative to develop systems and software to forecast wind energy output. The project is managed by the Australian Greenhouse Office (AGO). The system being developed, known as the Australian Wind Energy Forecasting System (AWEFS), is initially intended for forecasting wind energy in the National Electricity Market (NEM), with the aim of expanding to other Australian Electricity Networks as needed.

Aware of the existing NEMMCO proposal, the Australian Government, through the WEFC initiative, made a submission to the National Electricity Code Administrator (NECA) as part of the formal Code change consultation. It was suggested that resolution of this matter should consider the new Australian Government initiative.

NECA's decision on the Code change was released in September 2004, inviting NEMMCO to further consider the appropriate Code changes in light of the Australian Government initiative. This decision was based on recognition of a broader policy approach within the AGO Wind Energy Forecasting Capability (WEFC) initiative, as well as wide spread concerns from other stakeholder submissions regarding the appropriateness of specifics in the model proposed by NEMMCO. However, it is important to note that both NECA and stakeholder submissions strongly supported wind forecasting in general and recognised NEMMCO's concerns.

In April 2005, the Electricity Supply Industry Planning Council of South Australia (ESIPC) published a report to the Essential Services Commission of South Australia (ESCOSA) recommending, amongst other things, the implementation of state-of-the-art wind forecasting if the amount of wind energy installed in South Australia was to rise above 500 MW.

In May, 2005 the Wind Energy Technical Advisory Group (WETAG) released a report on Integrating wind farms into the NEM for public comment [4]. The report acknowledged the AGO WEFC initiative and confirmed Australia's needs for a wind energy forecasting system with the following statement: "Forecasts of wind farm generation levels are important for the operation of the power system, for the management of supply reserves, and also for the market, to support the accuracy of forward spot market information."

In September 2005, NEMMCO published a registration of interest for an interim wind forecasting system to be provided by an external party. The system is intended to support the pre-dispatch process in the NEM and will provide forecasts for six wind farms in SA and one in Tasmania [5]. In early 2006, NEMMCO purchased the Multi-Scheme Ensemble Prediction System from a Danish company called WEProg. The system is now in operational use at NEMMCO and is intended to be superseded by the AWEFS when it is commissioned.

The AWEFS is intended to provide short and longer term wind energy forecasting for Australian conditions. It is intended that local research, including that supported by the WEFC initiative, at the Australian Bureau of Meteorology (BoM), the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the University of New South Wales (UNSW), would contribute to future improvements in the wind energy forecasting system's performance.

2 Current wind forecasting activity in Australia

As mentioned above, NEMMCO's currently operational interim wind forecasting system is the Multi-Scheme Ensemble Prediction System (MS-EPS). The system is planned to be expanded from forecasting the initial 6 or 7 wind farms to around 12 over its 1 to 1.5 year lifetime.

NEMMCO issued a Registration of Interest (ROI) for the AWEFS system in August 2006. The ROI is available online at http://www.nemmco.com.au/dispatchandpricing/awefs.htm. The expected date of contract settlement is intended to be at the end of March 2007.

The Centre for Energy and Environmental Markets (CEEM) at the UNSW is undertaking wind-related research in its WINDFORNEM project. The project is in two strands. The first will investigate issues specifically associated with wind energy, including the behaviour of the atmosphere, wind forecasting, the design of wind turbines and strategies for wind farm control. The second strand of research explores the design and performance of the Australian electricity industry to better facilitate high levels of wind generation [6].

The Bureau of Meteorology Research Centre (BMRC) is undertaking a project entitled "Review and improvement of the ability of the Bureau of Meteorology to support numerical weather assimilation and prediction public products to assist the Wind Energy Forecasting Capability initiative".

The BMRC has engaged two scientists for 12 months to conduct research appropriate to the project. The two positions are designed to focus on:

(a) Evaluation and enhancement of the parameterisation of the planetary boundary layer in the BMRC mesoscale prediction model; and
(b) Evaluation and enhancement of the BMRC assimilation system for the mesoscale model.

The work will in particular focus on assimilation and prediction at a horizontal resolution of 10 km in the Australian region. This work is an extension of existing capabilities within the Bureau where operational assimilation and prediction for the Australian region is performed at horizontal resolution of 37.5 km, with additional prediction at 12 km nationally and 5 km for several state-based domains.

As a part of the WEFC initiative, the CSIRO is undertaking research into the characteristics, predictability and impacts of wind energy production across key regions of Australia. To conduct this research, CSIRO has collected wind data from over 100 meteorological stations and wind farms around Australia. Results from this study are expected around the middle of 2006.

CSIRO will also facilitate a post doctorate study in relation to wind energy forecasting. The topic for this study is likely to be on surface data assimilation on a 0-6 hour time scale, or to contribute to how forecasting could be combined with CSIRO's research in ultra batteries to be used for storage and smoothing of energy output.

In South Australia (SA), the local penetration of wind has risen quickly and is rapidly becoming world ranked with 400 – 500 MW of grid-connected wind capacity. In December 2004, ESCOSA asked ESIPC to report on the potential impacts of continued wind energy growth in SA in relation to the NEM and system security. ESIPC collected some high-resolution data from wind farms in SA and discovered a high variability in the output. Their conclusions to date include that for a penetration higher than 500 MW in SA [7]:

- future wind farms should conform to a certain standard,
- state-of-the-art wind forecasting is required,
- NEMMCO should have control over optimising wind farm generator output, and
- Market changes should be made for wind farms to participate in ancillary service markets.

ESCOSA responded to this, incorporating submissions from WETAG and other market participants, with a proposed licensing principle of making some large wind farms scheduled generators with NEMMCO under an “Optimised Dispatch” status. This would involve occasional power control dispatch commands issued by NEMMCO to the wind farm to manage power system security. This version of this issues paper assumes that all in the NEM wind power is produced at maximum availability.

In addition ESIPC is analysing wind data collected from 10m masts. Their results are inconclusive at this stage due to the short period of data collection to date (5 months). In conjunction with ESIPC, John Boland at the University of South Australia made a statistical study on the variability of wind power output in South Australia using met tower wind data near prospective wind farm sites [8].

Other known related Australian projects are listed below. The list is not exhaustive but includes all known projects to the authors. The second project listed involves extensive research made at the University of Tasmania in collaboration with Hydro Tasmania. This project focussed on the forecast horizon in the range of minutes. This scale is of great importance to NEMMCO since dispatch commands are made every 5 minutes. This time scale is necessary for wind gust forecasting and for transmission purposes.

Institution	***Description***	***Contact***	***Status***
Hydro Tasmania	Installation of Zephyr to run initially on the Woolnorth wind farm to assist in Hydro Tasmania energy trading in the NEM	Kieran Jacka	Forecasts are in operation. Currently being installed for the market trading systems.
University of Tasmania	Research on very short-term wind forecasting model using adaptive fuzzy-neural networks	A/Prof Michael Negnevitsky [9-11]	Near completion

Table 1: Other known Australian projects related to wind forecasting

3 Overseas experience

Worldwide, the past decade has seen an explosion in wind energy forecasting systems. The process of installing them is not “plug-and-play” as their application is site-dependant. Making comparisons between them is very difficult due to the fact that different institutions with varying expertise install them in locations with different attributes (eg. flat, complex terrain, offshore) [3].

ANEMOS is a 4-year EU R&D project and is scheduled to finish in September 2006. The project “aims to develop accurate models that outperform considerably actual state-of-the-art” in wind forecasting. Many areas are currently being researched including:

1. Improving and combining statistical and physical downscaling of the NWP grid.
2. Characterising the uncertainty of forecasts.
3. Trialling many different mesoscale models to see which work better in different situations.
4. Upscaling wind forecasts for a small representative sample of wind data to the whole area of wind farms installed.
5. Other work specific to offshore wind energy forecasts, which is of not much relevance to Australia.

An ANEMOS workshop was held on 28 February 2006 at the recent European Wind Energy Conference in Athens, Greece. The workshop featured significant submissions on the various EU-project work packages associated with the ANEMOS. These are available at [12]. One of the reports [13] discusses various different physical modelling packages and combinations thereof, for wind energy forecasting. Another report, [14], discusses the statistical side of wind energy forecasting, with an emphasis on the Danish wind forecasting system, the Wind Power Prediction Tool, (WPPT).

Many other projects concerned with wind forecasting are taking place in Europe and the US. The known projects are listed below. More detail will be added as it is obtained.

Country	***Description***	***Name of system***	***Contact***	***Status***
Denmark	Short-term forecasting system based on meteorological wind predictions	Prediktor	Gregor Giebel, Risø	In operation. Ongoing development
Denmark	Short-term forecasting system based on advanced time series analysis	WPPT [15]	Torben Skov Nielsen, IMM, Technical University of Denmark	In operation. Ongoing development
Denmark	Short-term forecasting system using WPPT to combine power data and NWP predictions (which may come from Prediktor)	Zephyr [16]	As above	In operation. Ongoing development

EU	European collaboration research project, developing an advanced system shell	ANEMOS [12]	As above	Under research and development
France	Short-term forecasting system based on fuzzy adaptive neural networks	AWPPS (More-Care)	Armines/Ecole des Mines de Paris	In operation. Ongoing development
France	Research into bidding strategies for wind farms participating in energy markets	-	P. Pinson, École des Mines de Paris	Completed
Germany	Short-term forecasting system based on meteorological wind predictions	Previento [17]	Ulrich Focken, University of Oldenburg	In operation. Ongoing development
Germany	Combines power data and NWP from DWD using adaptive neural networks	WPMS [18]	K. Rohrig, University of Kassel, ISET	In operation. Ongoing development
Ireland and Denmark	Started as Honeymoon project. Now: short-term ensemble forecasting system based on a limited area NWP	MS-EPS [19, 20]	University College Cork, WEProg	In operation for Elsam in Denmark.
Spain	Wind energy forecasting system up to 72 hours using in-house mesoscale model	Casandra [21]	M Gaertner, MOMAC Group	Operational for some wind farms in Spain since 2004.
Spain	Short-term forecasting system based on meteorological wind predictions. RegioPred upscales from a few wind farms to a whole region.	LocalPred-RegioPred [22]	Ignacio Martí, CENER	In operation. Ongoing development
Spain	Short-term forecasting system based on statistical methods and combined forecasting	Sipreólico [23]	Ismael Sánchez, Uni Carlos III, Red Eléctrica de España	In operation. Ongoing development
UK	Short-term forecasting system based on statistical methods	RAL (More-Care)	RAL	Ongoing development
U.S.A.	Wind forecasting system for the California ISO	PIRP [24]	John W. Zack, AWS Truewind LLC	Operational since June 2004
U.S.A.	Combination of meteorological weather predictions and computational learning system (neural networks	No specific name, but custom made	Mark Ahlstrom, WindLogics	In operation. Ongoing development

	and support vector machines), rapid update cycle techniques.			
U.S.A.	Research using off-site up-wind measurements, neural networks and support vector machines to improve wind forecasting accuracy	3Tier Environ-mental forecast engine	Ken Westrick, 3 Tier Environmental Forecast Group	Project in early to mid-stage

Table 2: Known overseas projects concerning energy wind forecasting. IMM = Informatics and Mathematical Modelling department at the Technical University of Denmark.

4 Key Issues

The important key issues for wind energy forecasting in Australia are listed below, as discussed in the workshop held at UNSW in December 2005. This list is not exhaustive. Comments in regards to additional issues, or further discussions on those presented are always welcome. The most important issue – the forecasting objective, is discussed first and separately. This is followed by a discussion of the methodology issues relevant to achieving certain objectives, and finally other general wind forecasting system issues are described.

4.1 Forecasting objective

Defining the objective or purpose of a wind energy forecast is the first step in designing a wind energy forecasting system. The most obvious objectives are the prediction horizon from the present time (warning time), and the frequency of the predictions (eg. hourly). Even before that, power system planning could be required to ensure that the wind farm sites are suitably spread in different kinds of locations to assist in aggregated wind power output smoothing and improved aggregated wind power forecast accuracy. Wind energy forecasting for a power system may have multiple objectives, which may be met by different forecasting methods operating concurrently. Some different objectives are listed in Table 3, along with existing forecasting systems written to meet them, if known. The objectives are mostly based on power system operator concerns, but the last one is typically the concern of the wind farm developer and its financiers.

Following the workshop at UNSW on Dec 5 and 6, 2005, some indicative objectives can be deduced for Australia's wind forecasting system. These are based on existing NEM rules that NEMMCO is accountable for, including for example, the current market trading day and period being defined as 24 hours and 30 minutes respectively. See rule 3.4.2 in the National Electricity Rules [1]. Table 4 summarises these objectives, which primarily address the spot market applications of bidding and dispatch. The workshop did not address other applications, such as power system security assessment or derivative market requirements, in any detail.

Time ahead	***Frequency***	***Other Objectives***	***Common Solution Methods***	***Some Known Systems***
~2 Days	~Hourly	Mean energy output over the period	Meteorological wind speed predictions converted to wind energy using a wind farm power curve.	Zephyr Previento WPMS MS-EPS Casandra LocalPred
< 4 hours	< 30 minutes	Mean energy output over the period	Statistical methods such as modified persistence, adaptive fuzzy-neural networks, support vector machines using historical data and NWP forecasts	WPPT Zephyr More-Care WPMS Sipreólico 3Tier
< 30 mins	2.5 mins	Power gust control	Adaptive Neural Fuzzy Inference Systems	None known. Only research at Uni of Tasmania
All of the above	All of the above	Uncertainty	NWP Ensembles. Weather pattern recognition.	Previento MS-EPS Casandra
2-7 days	Irregular	Detect rapid changes for planning of maintenance	Meteorological predictions only	None known
6-48 hours	Irregular	Extreme events causing sudden changes in output	Meteorology. Up-wind off-site observations. Weather pattern recognition.	None known
Few hours	Hourly	Relative wind farm output for managing network flows	There is little written about the application of wind farm control based on current network flow constraints and wind farm locations	None known
Couple of years	Weekly	Mean seasonal behaviour (for major outage and reserve capacity planning)	On-site wind measurements, turbine siting and terrain flow modelling	Many, different systems to those listed above
Couple of years	Annual	Total annual output (during wind farm planning)	On-site wind measurements, turbine siting and terrain flow modelling	Many, different systems to those listed above

Table 3: Some forecasting objectives. The forecasting systems listed are previously listed in Table 2 with more detail.

Specific Outcomes	• Forecast the expected wind energy output at the individual wind farm connection points in the NEM. For the publicly released version for energy traders, the wind energy forecasts may only need to be for each state as a whole. • Detect and forecast large-swings in the power output. • Forecast the expected high-frequency variability around the expected value within the forecast time frame.
Time Frames	The current operation framework at NEMMCO involves energy traders submitting a bid to NEMMCO by 12:30pm EST. This bid is for the following trading day, which is for 24 hours, starting at 04:00 EST on the following day. Based on the received bids, NEMMCO releases spot price and demand forecasts for each state in the NEM just after 12:30pm, for the next trading day. These forecasts are then updated half-hourly. Hence, a wind forecasting system to suit these time frames could make sense, where NEMMCO would release wind energy forecasts at 12:30pm for the next trading day, i.e. from around 16 to 40 hours ahead, and then update it half-hourly. In addition to this, NEMMCO could also release the wind energy forecasts earlier than the 12:30pm trading submission deadline, since the wind energy forecasts are not based on trader behaviour. The forecasts could be released, say, 8 hours earlier and up to 48 hours ahead, and could be used by the traders to assist them with their energy bids. From then, the forecasts would still be updated half-hourly. However, NEMMCO's demand forecast, which is also independent of trader behaviour (largely based on temperature forecasts), for the next trading day are currently released with the spot price forecasts (after the 12:30pm deadline).
Other general objectives	• The wind energy forecasts are more valuable if there is a forecast uncertainty made with them. • Additional objectives are discussed in section 4.3 on page 16.

Table 4: Indicative objectives for Australia's wind forecasting system for spot market applications

4.2 Methodology Issues for Discussion

To achieve the objectives, various methodology issues require discussion. The issues directly related to wind forecasting are listed in the following.

1. **Characterising the Uncertainty of a prediction.** Power systems require knowledge of the forecasted wind energy uncertainty so they can prepare backup precautions if necessary. An extensive list of the contributors to the uncertainty of a wind energy forecast is as follows.
    a. Errors in initial conditions, including the measured wind farm energy outputs, other measured weather parameters at various locations and the mesoscale weather data obtained for the NWP simulation.
    b. The predictability of the atmospheric behaviour – some situations are more stable and predictable than others. Examples of less predictable situations include storms, fronts and localised effects such as solar insolation causing the air to heat and rise up a mountain slope.
    c. The more complex the terrain at the wind farm, the greater the localised wind turbulence, and this is harder to model.
    d. The accuracy and level of included detail in the NWP model, including the resolution and number of assumptions made for simplification.
    e. Accuracy of power/thrust curves for the wind turbines which essentially define the conversion of wind speed to wind power. The power/thrust curves also change over time influenced by material fatigue and natural incidents such as accumulation of dirt on the blades.
    f. Wind generator failure, caused by a number of design or maintenance based factors. Communication of planned maintenance for the wind turbines is important here.

    Characterising the uncertainty for a wind forecast is complicated. There is some work being done around the world on estimating the uncertainty using ensemble forecasts [25]. One example project is the ANEMOS project where they have also shown some results that indicate that the wind forecasts are less accurate with increasing terrain complexity. The BoM have done some work on characterising the uncertainty of the mesoscale model initial conditions, and filtering them. The forecast uncertainty is also shown to be related to the prevailing weather pattern, based on the assumption that the NWP forecast is more accurate with some weather situations than with others [26].

    Uncertainty could be defined in two ways as well. One is the confidence band for a wind energy forecast over a given period, and the other is the variability in which the wind energy could fluctuate within a given period. These two definitions of uncertainty are illustrated in Figure 1. The added value of estimating either of these uncertainties is open to discussion. Some known methods to characterise the forecast level uncertainty are given above. Variability could be characterised by the atmospheric conditions, and might be wind direction dependant for a given wind farm (eg. wind flowing up a cliff edge upwind of the wind farm is likely to be more unstable than the wind flowing from relatively flat terrain upwind of the wind farm).

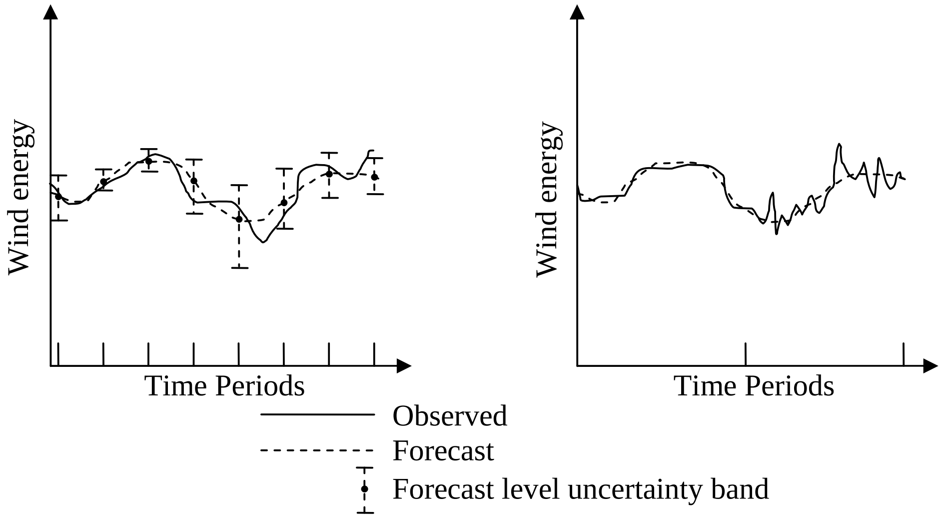

Figure 1: Two definitions of forecast uncertainty. The forecast level uncertainty over a given period as shown left, where the uncertainty represents a confidence interval within which the wind energy is expected to be[1]. Variability within a given period as shown right, where the actual forecast is very good in both shown time periods but the variability over each time period is quite different.

2. **Predicting extreme events.** Observations of wind farm behaviour have shown that large swings in the power output can occur, due to sudden changes in the wind resource or wind speeds exceeding the cut-off level causing wind farm shut down. Predicting the level and timing of these events is of most concern to all electricity market participants and power system operators. Predicting extreme events could be approached separately to the problem of predicting more common behaviour. It could be done by monitoring the conditions that cause these extreme events including extremely high wind speeds due to storms and tracking storm fronts.

   Another possible method to characterise extreme events is using weather pattern recognition. The Australian Bureau of Meteorology has been developing automated weather pattern recognition (synoptic analogues) techniques since 1980 and claim to be the only operational weather forecast bureau in the world with an operational "Synoptic Typer" incorporated into their NWP for weather forecasting [27-29]. Weather pattern recognition techniques are also known and have been shown to be a superior technique compared to NWP for predicting extreme events [30, 31].

   The extreme hurricane event in January 2004 in Denmark caused a loss of over 80% of total wind power over 4-6 hours. An event of this kind may be unlikely over the full extent of the NEM. It may be a more plausible scenario on a NEM region scale, such as for the South Australian region, which is where a significant proportion of the NEM wind farms have been installed to date.

   Another type of an extreme event is when the maximum wind power output occurs at the same time as an energy demand minimum, or visa versa. In Denmark, there have

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[1] Note that under current NEM rules, forecasts are made as point targets to reach by the end of a 5 minute period. Thus, these intervals are presented at the end of each time period, with the observed wind energy falling within the bounds in each case except the last one, as an example.

been only one or two occasions where all the wind farms were operating at maximum capacity, for a couple of hours. This would be expected to be even less likely in Australia since the extent of the grid covers a much larger area, and with significantly more complex terrain.

3. **Using off-site observations.** The National Electricity Market covers a power system of a length of more than 4000 kilometres from Port Douglas to Adelaide – the world's longest interconnected power system [32]. Storm fronts frequently traverse across this area, and could cause extreme wind changes as they pass wind farms. It might be possible to track these storm fronts (eg by weather radar) and predict corresponding wind energy changes. The timing accuracy of these events could be substantially improved after the first wind farm is affected, thereby giving a warning for subsequent wind farms. These warnings could be received from a W.A. wind farm for eastward weather events and from a Tasmanian wind farm for north-ward weather events. A few well placed met stations could also contribute to this. This could include off-shore measurements upwind from high-density coastal wind farm areas, such as South Australia (SA). For example, a Doppler radar (such as LIDAR) could be used on a buoy upwind from the SA coast. Research on using off-site observations to improve wind forecasts for downwind wind farms is underway at 3 Tier Environmental Forecast Group in the US [33]. They propose to use conditional neural networks and support vector machines to enhance their results.

4. **Rapid Update Cycle.** The use of "rapid update cycle" forecasting methods could be worth researching for the Australian context. The few-hours ahead forecasts are claimed to improve from a mean absolute error (MAE) of 10-15% to just 5% of rated wind capacity through the use of rapid update cycles [34]. Upwind off-site observations can improve the results achieved by rapid update cycle methods (see above).

5. **Using computational learning systems.** Some work is underway in the US to improve wind forecasts using a computational learning system – neural networks and support vector machines (an artificial intelligence algorithm using a kernel to map the data to a high dimensional space. The decision making on the forecast is made in this new feature space and the algorithm relies on selecting a suitable kernel [35]. Reference [33] shows that a conditional neural network algorithm improves wind forecasts, and that support vector machines produce similar results. It has been observed that it takes up to 4-6 months for these systems to learn such that no further improvement in forecast performance is discernable. At the December 2005 workshop, CSIRO introduced the concept of combining data from multiple wind farms to expand the knowledge space of the neural network. This technology may be a useful feature for the Australian wind energy forecasting system.

6. **Terrain.** There are complex terrains in Australia and hence perhaps predicting wind direction is more important than in other countries. Reference [36] mentions that a 10-15% change in wind power can occur over 15 minutes in Denmark but that sub-5-minute variations can occur in Tasmania due its more complicated terrain and varying wind resource. One way that may help with this is to use higher resolution terrain maps in the areas of the wind farms in the NWP.

7. **Real-time mesoscale modelling**. There is much yet to be explored regarding running mesoscale models in real-time. A recent ANEMOS paper introduces various mesoscale, and other model combinations with some preliminary results [13]. One potential beneficial technique is nudging. Nudging is used to adjust forecasts towards observations as real-time data becomes available. This could also be applied to the initial conditions of an NWP (mesoscale) model. Nudging may be a useful research topic to improve wind energy forecasts, but it can only help with a forecast time ahead of a few hours.

8. **Inter-connector flow.** Forecasting the aggregated wind power on a regional basis may be useful for management of inter-connector flows. For two consecutive relatively equal aggregate wind energy forecasts, the regional wind energy outputs may have changed (due to passing fronts, etc.). It may be useful to detect and forecast an extreme event where the regional wind power output changes unfavourably relative to the current inter-connector flow situation.

   Information on line-flows and other network constraints may be a useful input into wind energy forecasting for wind farm control.

9. **Use of 'local knowledge' from Bureau of Meteorology.** The BoM in Australia has developed a significant body of expertise in accurately forecasting wind changes (speed and direction) over the past decades. Clients such as airports require accurate predictions of say, wind direction changes to know when to switch from one run-way to another. This toolbox of expertise includes [37]:

   a. Upwind Automatic Weather Stations
   b. Radar images: Particles such as dust and insects often get caught in the wind change line and show up on the radar as a well defined line.
   c. Other fields such as moisture or pressure that have a discontinuity across the wind change line.
   d. Satellite images of cloud signatures associated with the wind change this is particularly useful over the water where there is no other information.
   e. Verbal or faxed reports from upstream sites such as fire towers or observers at airports.

   Most wind energy forecasting systems in operation around the world only use the NWP output provided directly from the model. This is at least true for application involving the Danish Meteorological Institute (DMI) [38]. The reason for this is that these extra services available from local weather bureaus are too expensive due to man hours and typically impractical to apply to wind energy forecasting.

10. **Verification.** Finally, a wind forecast needs verification. This, of course, depends on the objectives. Common verification criteria are level errors or phase errors by comparing the actual forecasts against the observed wind farm output. Also, certain verification methods are suitable for different time periods. Level errors are the most common way to assess any forecast and there are many standard methods such as root mean squared error (RMSE), mean absolute error (MAE) and the R-square statistic. Evaluating phase errors however, has been in discussion since the beginning of forecasting. In [39] it is shown how the RMSE can be decomposed into 3 separate values, the bias, the bias of the standard deviation and the dispersion. It is explained

how the dispersion component describes the contribution of phase errors to the overall RMSE. Another possibility is to evaluate the consistency of the uncertainty calculations compared with observations. For verifying an extreme event forecast, there are other methods such as the probability of detection (POD) and false alarm ratios (FAR) [27].

4.3 Other General Issues

Other general objectives concerned with the design of an Australian forecasting system include:

1. In-built funding and ability for **ongoing operational upgrades** beyond the immediate implementation period of the AWEFS. This raises questions into a production environment and testing environment for the system.

2. **Centralised or de-centralised wind forecasting.** It is likely that a combination of these will be used for Australia.

   It has been shown that forecasting errors are significantly reduced for predictions over multiple dispersed wind farms, compared with the errors for individual wind farms [19, 34], and hence the most accurate forecasts are made for the wind energy in the grid as a whole. Centralised wind forecasts are also advantageous for the power system operator (NEMMCO) to manage power system security. Non-dispatched wind energy can be regarded as negative demand. Assuming that is the case, in the dispatch process NEMMCO wishes to forecast net load seen by the dispatchable generators (load minus wind generation). Furthermore, if wind farms participate in the market it can be possible that it is economically beneficial for them to over- or under-bid their output compared to the actual wind energy forecast. This may now be beneficial for the transmission operator [40].

   It is planned that a centralised aggregated wind forecasting system be used to cover the entire NEM in Australia. However it is likely that in addition to this, NEMMCO will have great use for regional wind farm forecasts to manage inter-connector flows.

   De-centralised wind energy forecasts are also likely to be used, since individual energy market participants could require independent forecasts at the wind farm level. Energy market participants already make their own forecasts of load and spot market prices to assist in developing their NEM bidding strategy. The inclusion of a wind energy forecast to these would depend on the timing of the release of NEMMCO’s centralised wind energy forecast each day, as described in Table 4 on page 11.

   In South Australia, it has been proposed by ESCOSA that all wind farms install and maintain their own wind forecasting systems [41]. Under this arrangement, an economic incentive is important to ensure these forecasts remain state-of-the-art.

3. All wind farms above a certain size are likely to be required to provide **real-time wind farm output data** for input to the centralised wind forecasting system.

4. New governance arrangements could impose **location limitations** on future wind farm sites in the NEM, to ensure that wind farm sites are spread out without incurring

excessive connection costs. This would assist with forecast accuracy, and help to reduce the susceptibility to correlated large-swings in aggregated wind farm output.

5 Issues Summary

This paper discusses issues associated with what type of wind energy forecasting systems should be implemented in Australia. There are three potentially quite separate forecast objectives.

1. Forecasting expected wind energy output.
2. Detecting and predicting large rapid changes in wind power output. Potential methods include:
    a. Weather pattern recognition (synoptic typing).
    b. Being prepared for large rapid changes during the most uncertain ensemble forecasts of expected wind energy output.
    c. Using observations as a warning (eg. upwind wind farm output).
3. Detecting and predicting extreme events whereby the regional wind power output changes significantly relative to the current inter-connector flow situation (eg. for security or market reasons).

Issues concerned with the above forecast objectives include:

1. Characterising and estimating forecast uncertainty.
2. What models (including statistical models for the short-term and NWP models for the long-term) are best for forecasting wind energy in Australia.
3. Using observations as a warning (eg. upwind wind farm output).
4. Assess how valuable are the forecasting systems.

There are also other general issues such as:

1. Who are the clients of the AWEFS and what their needs are.
2. Incorporating the facility for ongoing upgrades into the wind energy forecasting system from research.
3. Whether both centralised and de-centralised wind energy forecasts will be made.
4. The SCADA wind measurement data provided to NEMMCO.
5. New governance arrangements could impose **location limitations** on future wind farm sites in the NEM, to ensure that wind farm sites are spread out without incurring excessive connection costs.
6. Control strategies for optimised dispatch of wind energy.

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