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Research into a continuous wind farm noise monitoring system

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Summary

A wind farm operator's obligations to carry out noise compliance monitoring at newly constructed wind farms is an increasingly significant aspect of a wind farm's acceptance by a community, particularly in Australasia, where wind farm noise commissioning measurements are common place.

The significance of wind farm commissioning works can be demonstrated, for example, by the submission to the Australian Federal parliament of the Renewable Energy (Electricity) Amendment (Excessive Noise from Wind Farms) Bill 2012. Whilst the proposed amendment was ultimately not passed by the parliament, wind farm noise monitoring remains an area of active interest to members of the community and politicians in Australia. Further, the content of the proposed bill represented an intriguing challenge for wind farm operators, to continuously monitoring noise from a wind farm, with the potential requirement that the collected information be displayed in real time. Such an approach to monitoring draws obvious comparisons with some continuous noise monitoring circumstances, for example the monitoring that occurs around major airports to assess noise impacts from aircraft.

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However, noise from wind farms at neighbouring residential properties can often occur at levels close to or lower than the ambient noise generated by sources such as traffic, birds, rain, wind in vegetation and farming activities. Conversely, during part of the night-time period, background noise levels can often be much lower than the level of the wind farm.

As a result, extensive assessment can often be required to determine the contribution of wind farm noise at a residential property located at moderate to large distances away from a wind farm and, in some cases, the assessment may ultimately be inconclusive.

This paper reports on recent field research of a proposed continuous wind farm noise monitoring system, discussing the obstacles encountered in presenting real time wind farm noise information, along with the innovations by which they may be overcome. In particular, the proposed system relies on intermediate monitoring locations between the wind farm and neighbouring residences. The technical challenges associated with full implementation of such a system are discussed, as well as the implications the system may have on a wind farm's social licence to operate and its general perception by the community and, in turn regulators and law-makers.

Forward by Pacific Hydro

The Cape Bridgewater (CBW) wind farm is located on the south west coast of Victoria, Australia and has been operating since 2008. Across the broader community the wind farm has been well received and the company enjoys a positive reputation. Additionally, the CBW wind farm continues to operate within all current government noise guidelines and regulations.

However, during this time Pacific Hydro had become aware of some resident dissatisfaction with the wind farm and of a number of claims they have made about negative impacts of living near it. In most cases, these residents had objected to the wind farm before construction and in some cases had been part of a protest that saw the original planning approval by Energy Equity overturned by the Victorian Civil and Administrative Tribunal in 1998.

External to the CBW environment, the anti-wind movement had begun to gain traction including in some cases via well-funded, professionally organised groups from Victoria and New South Wales. More recently anti-wind issues have been picked up by a number of prominent radio shock jocks, some federal conservative politicians and a number of independent Senators.

A number of affected CBW residents have become deeply involved in these anti-wind groups as an outlet for their frustrations and to seek support, emotional and otherwise.

It is also clear that the issues faced by Pacific Hydro are not unique to CBW as other wind farm developers seem to be facing a similar situation. This would indicate to Pacific Hydro that as the wind industry matures in Australia, community expectations of social performance will increase. If the industry does not respond to this increase in expectations, we face the risk of an ever expanding regime of regulation and potentially a moratorium such that is currently affecting the coal seam gas industry in New South Wales and Victoria.

While we can lay blame on others for “whipping up” concerns about wind farms and health and for having political or ideological motivations for their attacks on wind energy the company came to the realisation some 12 months ago that a revised approach to community engagement was required that has both meaningful interaction with the community and greater transparency of our operations at its core.

It is this revised approach that guided the company’s decision to engage Marshall Day Acoustics to conduct the research outlined in this paper.

While there appears no immediate plans to reintroduce the Excessive Noise Bill into the federal parliament, that does not signal the end to community desire for greater transparency and accountability from the wind industry.

Pacific Hydro feel that this research has greatly assisted our, and hopefully the broader industries understanding of what is possible and improved our readiness should the bill be reintroduced.

An argument could also be mounted for voluntarily adopting such an approach as there appears to be several wind farm management applications that could prove useful. Such a move would also send a very strong signal to all stakeholders that the wind industry takes its responsibilities seriously and has nothing to hide.

1. Introduction

1.1 The Excessive Noise Bill

Australia’s wind farm noise laws and reporting requirements are managed by state governments and usually administered by each state’s environment agency. During 2013, Australia’s national parliament was presented with proposed legislation [1] to require the collection and reporting of wind farm noise data in addition to existing state requirements. . This bill serves to emphasise the potential of a continually expanding regulatory structure impacting on the Australian wind industry. It included penalties for breaches of conditions and outlined an approach to data capture and reporting which was potentially untested. The bill included the following provisions:

> *For the purposes of this Act, a wind farm creates excessive noise if the level of noise that is attributable to the wind farm exceeds background noise by 10 dB(A) or more when measured within 30 metres of any premises:*
> *(a) that is used for residential purposes; or*
> *(b) that is a person’s primary place of work; or*
> *(c) where persons habitually congregate.*
>
> *[...]*

The nominated person for an accredited power station that is a wind farm must ensure that information prescribed by the regulations relating to the following is published on the internet:
(a) noise attributable to the wind farm;
(b) wind speed and direction at the wind farm;
(c) weather conditions at the wind farm;
(d) power output of individual turbines at the wind farm.

The bill was criticised by many groups on various grounds and eventually was not passed into law by Australia's parliament. In part, its inception appears to have been motivated by a lack of publicly available information about wind farm noise data collection and reporting. It is a requirement of planning permit conditions for most Australian wind farms to undertake post-construction compliance noise monitoring and submit a report to the relevant authority [2] [3] [4]. Rightly, or not, a number of Senators and members of the Australian community felt that access to noise data and operational information from wind farms was insufficient, inaccessible and/or deliberately hidden from the public.

1.2 Research project

During the public submission phase of the bill's reading, a number of wind farm operators commented on the proposed monitoring requirements. In their submission to the committee [5], Pacific Hydro opposed the adoption of the bill stating the following reasons:

The bill seeks to add a layer of regulatory burden to the Renewable Energy Electricity Act for an issue (noise) which is most appropriately addressed by state planning and environmental regulations; not the federal Renewable Electricity Act.
The bill seeks to apply an arbitrary and unscientifically based noise limit to wind farms in particular despite existing guidelines being in place for industrial noise sources and wind farms.
The proposed noise limit cannot be measured on a real-time basis and hence would impose an unworkable requirement on generators.
If adopted, this bill would set a precedent for all forms of infrastructure which will have significant impacts for ongoing investment in Australia, potentially for any noise generating source – be it a quarry, road, mine, processing plant, factory, or other electricity infrastructure.

While Pacific Hydro had concerns about the practical implementation of the requirements of the bill, it acknowledged the potential need for additional information that is publicly accessible, but equally that the provision of such information should be technically robust, efficient (in terms of cost and time), administratively manageable and meet community needs. At the point in time when the bill was tabled, no workable, tried, tested, agreed approach was known of.

To examine the feasibility of a practical system designed to achieve outcomes consistent with the intent of the bill, Pacific Hydro began a collaborative research project with Marshall Day Acoustics. The aim of this project was to test a proposed approach to continuous wind farm noise monitoring, data capture and reporting that could be used to provide information to regulators and to the public about wind farm noise. Importantly, the project needed to consider and respond to the presentation of data to a general audience in a timely and cost effective manner.

1.3 Noise monitoring concept

A core aspect of the Excessive Noise Bill was that wind farm noise levels be provided publically in real-time. In Australia, wind farm noise assessment typically requires medium to long term unattended background noise ($L_{A90,10min}$, $L_{A95,10min}$) monitoring at residential locations, with a subsequent regression analysis of noise levels and wind speeds to estimate a trend of wind farm noise. This process can additionally require corrections to account for pre-construction background noise levels, periods of rain and periods of high local wind speeds (at the microphone).

While real-time monitoring of noise levels is used for some types of noise sources, such as airports, its application to wind farm noise may not give an accurate representation of wind farm noise levels:

- Noise from wind farms at neighbouring residential properties can often occur at levels close to or lower than the ambient noise generated by sources such as traffic, birds, wind in vegetation and farming activities [6]. Therefore, while collecting real-time data with conventional noise monitoring equipment could be informative as a measure of total noise levels at the monitoring location at a given time, it would be challenging to determine the contribution of wind farm noise to the total noise level.
- Real-time estimates of wind farm noise are likely to be less accurate than the regression based analysis of longer-term unattended monitoring data and are unlikely to be suitable for regulatory review or compliance assessment

In light of these factors, it seemed that the emphasis of a real-time monitoring system would be better suited to the general provision of information to the public rather than formal assessment with regulatory requirements and evaluation of compliance with noise limits. With this in mind the concept of a continuous noise monitoring process with periodic presentation of data was seen as the most likely outcome.

Concurrently, the method of acquiring noise level data required consideration. Several noise monitoring methods are available including:

1. Conventional (omnidirectional) outdoor noise monitoring systems
2. Directional monitoring equipment
3. Conventional systems (see 1) with a complex filtering regime[2]

It was considered that the task of continuous monitoring, including general system maintenance issues and the presentation and explanation of the system to end users (regulators and the general public), would be well suited to a simpler style of measurement system such as System 1 above.

On the balance of this range of factors, particularly the emphasis on informing communities rather than formally assessing regulatory compliance, it was conjectured that reliable results could be achieved by an unattended noise monitoring system at a location intermediate between wind turbines and residential locations, where the signal to noise ratio is comparatively greater.

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[2] For example, with filtering based on multiple one-third octave band thresholds, narrow band analysis or fine resolution time history analysis

This type of approach to measurement is commonly used for other types of environmental noise assessments [7] and has been proposed as an alternative way of assessing compliance in some recent wind farm documents [8] [9] [10].

Therefore intermediate locations were proposed as the basis of a field study of a continuous noise monitoring system. The following selection criteria were proposed to identify suitable intermediate measurement locations:

- A predicted wind farm noise level higher than 45 dB L_{Aeq}, to provide an improved signal to noise ratio
- A separation distance of at least 300 m to 400 m from the nearest turbine(s), to avoid measured noise levels being overly influenced by the noise contribution of a single wind turbine.

Monitoring at intermediate locations was anticipated to provide a more reliable quantification of wind farm noise, which could potentially prove useful as an on-going source of up-to-date information to help inform wind farm neighbours about a farms operation and for wind farm data tracking for correlation with any complaints. It would also reduce the burden on wind farm neighbours from having monitoring equipment installed near the dwellings for extended periods of time.

Concurrently, as noise limits for Australian wind farms typically apply at residential dwellings, the results of monitoring at intermediate locations could not be directly compared with any existing residential limits. Some degree of interpolation would be required for data collected at intermediate locations to be compared with limits. For example, by correcting measured levels for the predicted wind farm sound level difference between the intermediate location and a residential location or, conversely, by determining a derived noise limit for the intermediate location.

To validate the reliability of the intermediate locations, additional measurements were proposed at locations representative of neighbouring residential dwellings.

It should also be noted that in the context of longer term environmental monitoring 'real-time' may refer to immediate display of acquired data or, alternatively, display of data within a short time from its acquisition, for example one to two hours or one to two days depending on the context. For the purposes of a feasibility study it was determined that acquiring noise data every twenty-four hours would be sufficient to demonstrate the ability for a continuous noise monitoring system to operate successfully. If this target was achieved, subsequent works could investigate the practicality of a more regular supply of information.

1.4 Overview

The key contextual aspects of the research project are summarised in Table 1.

Table 1: Overview of relevant aspects of the research project

Aspect	Description
Context	An increased level of anxiety from some near neighbours to some wind farms resulted in the federal government considering new regulations for ongoing monitoring of wind farm noise. However there is no determined standard or methodology
Stakeholders	State & federal governments State regulators, such as Planning departments and Environmental Agencies Some local community members, particularly those who live in close proximity of a wind farm Industry and those interested in renewable energy
Objectives	To demonstrate to stakeholders a higher degree of transparency and accountability To investigate a new methodology with the aim of informing any new regulatory regime
Scope	Set up a research project with a field study of continuous noise monitoring at locations near turbines and near dwellings to understand the relationship between audible wind turbine noise and existing background noise (Methodology informed by the recent work [6] to test the collection and interpretation of noise data and prepare regular reports) Conduct monitoring at a number of locations
Output	An assessment of the suitability of real-time noise monitoring systems for wind farms Presentation of research outcome to the local community living near the surveyed wind farm and other stakeholders

2. Study site and measurements

2.1 Monitoring locations

Pacific Hydro nominated one of their wind farms, the Cape Bridgewater Wind Farm (Stage 2 of the Portland Wind Energy Project), as a site for the research.

Five monitoring locations were selected:

- Two intermediate locations within the 45 dB L_{Aeq} predicted noise contour and within 300-400m from the wind farm (IL1 and IL2)
- Three locations selected to be representative of residential dwellings nearby the intermediate monitoring positions (HL1, HL2 and HL3)

The five (5) monitoring locations are presented in Figure 1 together with the 45 dB L_{Aeq} predicted noise contour and dwellings in the vicinity of the Cape Bridgewater Wind Farm.

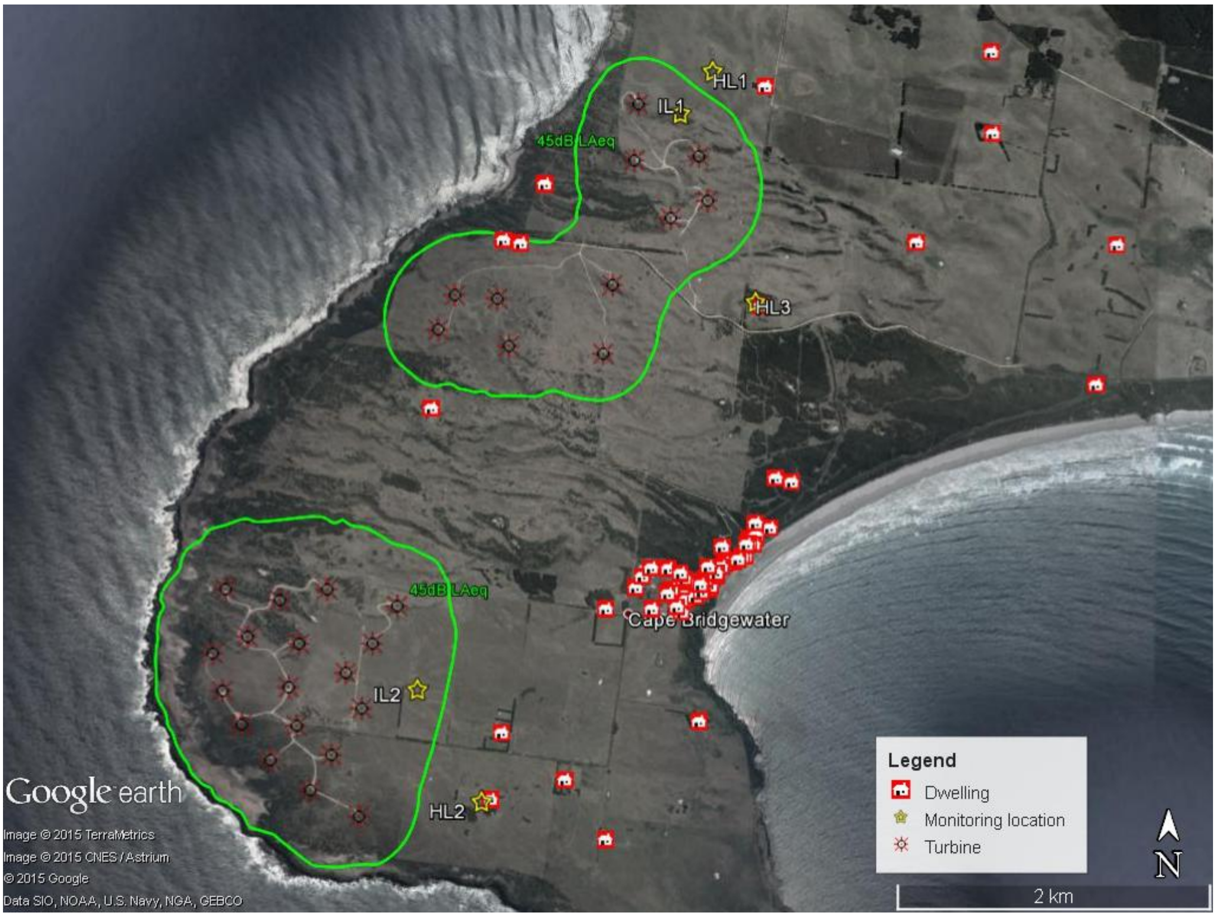

Figure 1: Noise monitoring locations

2.2 Equipment

As the focus of the field study was to conduct an outdoor assessment of audible A-weighted wind farm noise, a conventional outdoor noise monitoring system was used for measurements at all five (5) selected locations.

For each location the noise monitoring system comprised of one 01dB DUO Smart Noise Monitor, one NetComm outdoor 3G router (to provide a boosted 3G mobile reception) and a solar panel and associated battery pack. Additionally, a Vaisala WXT520 weather station was installed at each of the intermediate monitoring locations, IL1 and IL2. A typical noise monitoring system is presented in Figure 2.

Figure 2: Typical noise monitoring system

Microphones were installed approximately 1.5m above ground level (AGL). Associated weather stations, where installed, were also positioned approximately 1.2-1.5m AGL, and approximately 2-3m away from the sound level meter. Where required, an electric fence was installed around equipment to prevent disturbance from livestock and wild life.

2.3 Sound level measurements

Sound level meters were configured to measure broadband and one third octave band L_{Aeq} noise levels in 1 second intervals ($L_{Aeq,1s}$), including one-third octave band frequencies in the range 6.3Hz and 20kHz.

2.4 Local weather data

Weather data local to the sound level meters was collected at the two intermediate locations (IL1, IL2). Six parameters are recorded simultaneously in 1 second intervals: wind speed; wind direction; rain intensity; air temperature; relative humidity, and; atmospheric pressure.

2.5 Wind farm data

Weather measurements from the wind farm site, including wind speeds and directions referenced at 10m AGL and hub height were provided from Pacific Hydro’s SCADA system along with selected turbine performance data including generated power and generator rotational speed.

2.6 Data transfer

Noise and local weather data was transferred from the sound level meter to a central database via the 3G network.

Wind farm data was generally collated on a weekly basis with email transfer.

2.7 Monitoring period

Monitoring spanned two consecutive periods:

- An initial monitoring period of 3 months from December 2013 until March 2014.
- A review of results indicated that while the proposed noise monitoring concept was working suitably, at some locations there was insufficient data for some weather conditions. Monitoring was therefore extended for a further 3-4 month period, until approximately mid July 2014.

2.8 Web interface

During the field study phase of the project, a web interface was developed which could:

- Manage data transfer from noise monitoring equipment to a central database
- Display monitoring results use pre-determined assessment and display method
- Present information to relevant stakeholders in an efficient and timely manner.

The website is currently in the final-prototype phase of development.

3. Data analysis and filtering

In common with the measurement parameters detailed in the relevant noise assessment guideline for the project [11], $L_{A95,10min}$ sound levels were calculated from the measured $L_{Aeq,1s}$ sound levels at each monitoring location. These calculated noise levels were then correlated with the averaged hub height wind speeds collected at the nacelle of the three (3) nearest wind turbines over the same time period. Each pairing of 10 minute L_{A95} noise level and average hub height wind speed is referred to as a *data point* in the following sections.
Selected turbine performance data, together with local weather data, was used for basic filtering of correlated data points to remove periods where wind farm noise was less likely to be a dominant noise source. Data points were filtered using the following criteria:

- Average 10 minute power output from the three (3) nearest wind turbines of at least 150 kW, to remove data collected at or below cut-in wind speed
- Average 10 minute wind speeds less than 5 m/s measured at the nearest intermediate monitoring location, to remove noise data potentially influenced by excessive wind induced noise on the microphone [12] [13]
- Average 10 minute rain intensity equal to 0 mm/hr, to remove noise data potentially influenced by rain fall
- Wind direction sectors representative of downwind conditions, to reduce the potential influence form extraneous noise sources.

The number of data points captured during the field study, including the amount of data points included in analysis after filtering, is presented in Table 2.

Table 2: Number of analysed data points

Monitoring location	Number of collected data points	Number of filtered data points	Number of analysed data points
IL1	30,255	26,943	3,312
HL1	30,044	28,803	1,241
IL2*	25,185	20,986	4,199
HL2	21,243	20,184	1,059
HL3	30,573	29,003	1,570

* It should be noted that noise data was not collected at IL2 for six weeks due to power supply failure.

Table 3 details the percentage of data points identified for filtering for each of the filtering variables detailed above together with the cumulative percentage of data points removed through the filtering process. Data points were removed from the analysis when at least one of the filtering thresholds was exceeded.

Table 3: Percentage of data points outside the filtering thresholds

Monitoring location	Power output	Local wind speed	No local weather data	Rainfall	Wind direction	Cumulative
IL1	28%	26%	9%	4%	68%	89%
HL1	28%	26%	10%	4%	88%	96%
IL2	31%	10%	20%	3%	57%	83%
HL2	28%	7%	48%	2%	83%	95%
HL3	31%	26%	10%	4%	81%	95%

4. Outputs

4.1 Binned analysis

Correlated data points have been analysed for each integer wind speed bin to examine the relationship between measured noise levels and wind speeds. As an example, the 8 m/s bin includes all data captured at hub height wind speeds between 7.5 m/s and 8.5 m/s. The measured $L_{A95,10min}$ noise levels in each bin are then averaged arithmetically and the standard deviation is calculated.

For each noise monitoring location a chart is presented below with the following information:

- Measured data points removed by filtering for power output, local wind speed and rainfall (light grey points)
- Measured data points removed by filtering for wind direction sectors not representative of downwind conditions (black points)
- Analysed data points (green points)
- Binned average noise levels (red bars) with error bars indicated ± one standard deviation

Binned average noise levels are only been displayed for wind speed bins containing a minimum of 20 data points.

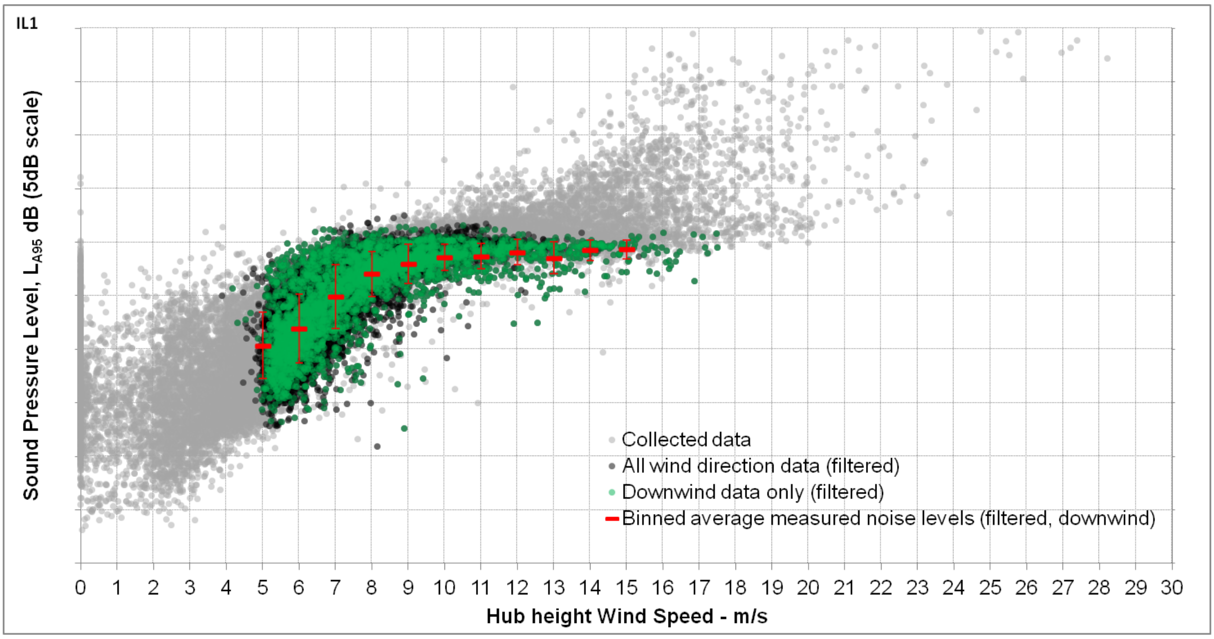

Figure 3: Measured L_{A95} noise levels at IL1 vs. hub height wind speed

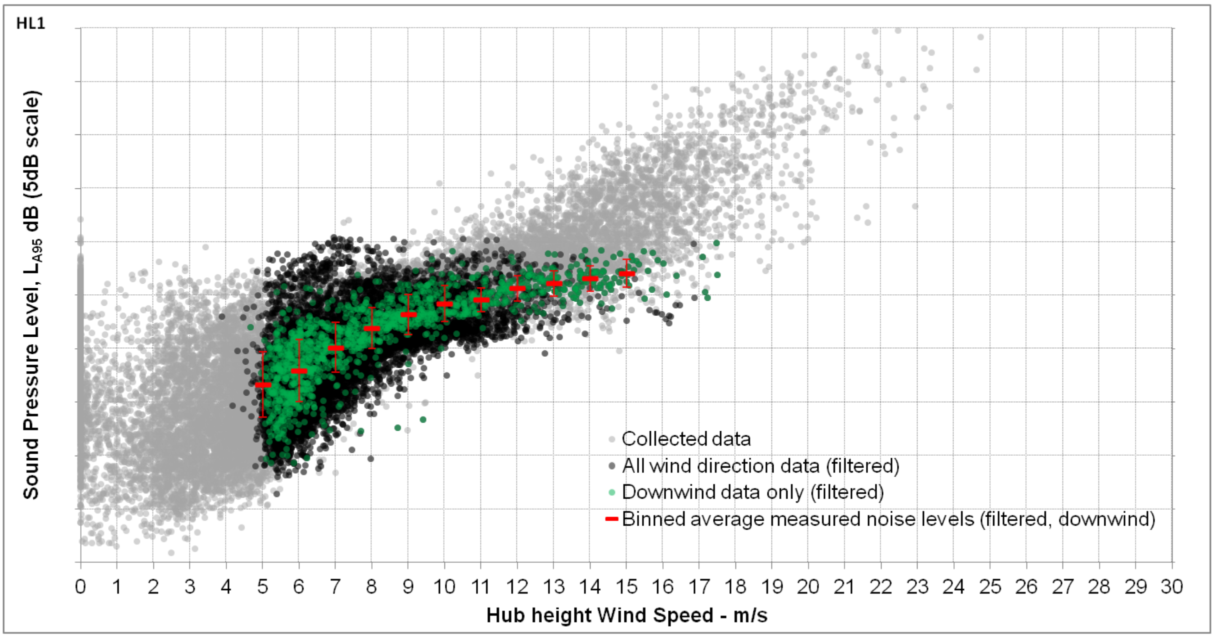

Figure 4: Measured L_{A95} noise levels at HL1 vs. hub height wind speed

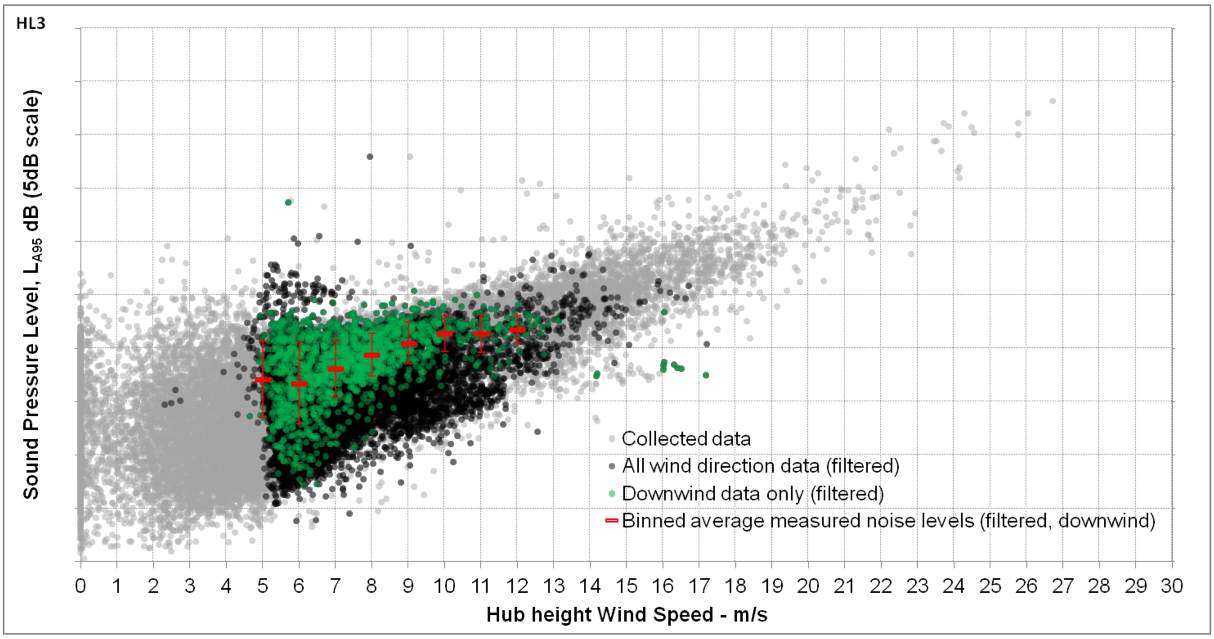

Figure 5: Measured L_{A95} noise levels at HL3 vs. hub height wind speed

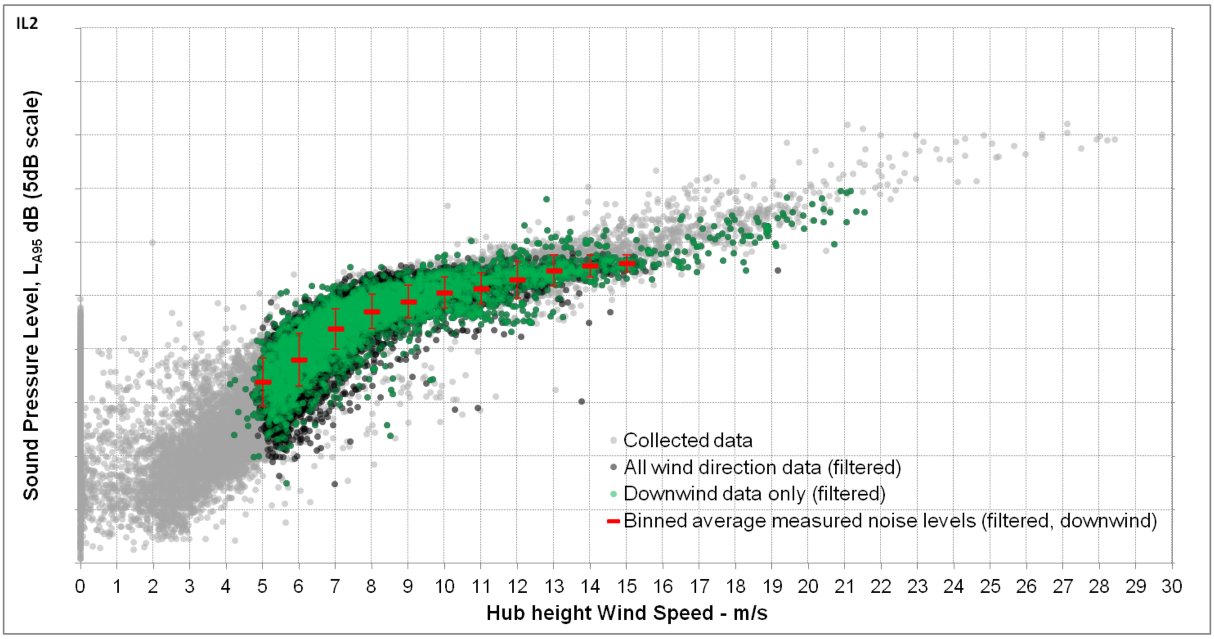

Figure 6: Measured L_{A95} noise levels at IL2 vs. hub height wind speed

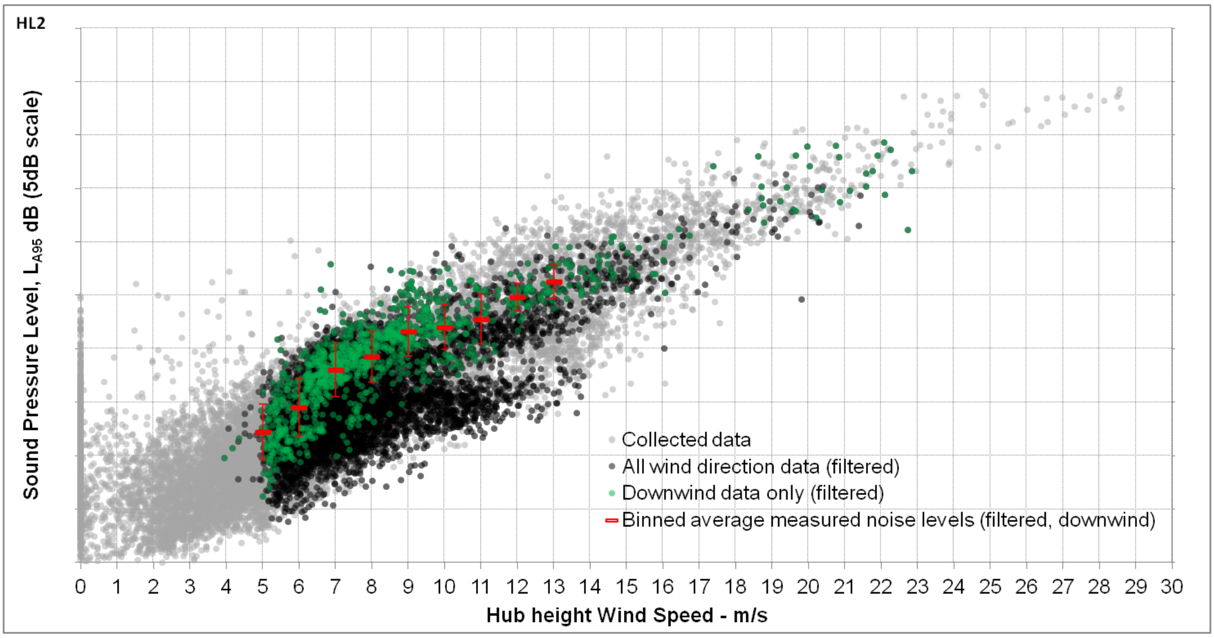

Figure 7: Measured L_{A95} noise levels at HL2 vs. hub height wind speed

These figures demonstrate that the nominated measurement locations and basic filtering methods generally identify a collection of data points that are consistent with an expected trend of wind speeds and noise levels in the area around a wind farm. In particular, Figure 3 and Figure 6 present the data collected at IL1 and IL2 respectively and show that:

- for wind speeds between approximately 5 m/s and 9 m/s, noise levels steadily increase, by 5 to 10 decibels
- for wind speeds between approximately 10 m/s and 14 m/s, noise levels are comparatively constant, increasing by less than 5 decibels.

Each of these trends is consistent with the typical sound level output from the pitch-controlled variable speed turbines installed at the wind farm. This suggests that wind farm sound is a dominant component of the noise environment at both intermediate locations.

Figure 4, Figure 5 and Figure 7 demonstrate a greater degree of scatter of data points and the comparatively constant sound level region identified at the intermediate locations is not as apparent. These trends are consistent with the noise environment at these locations including a greater contribution from noise sources other than wind turbines.

4.2 Daily time history

An aim for this project was to present data in a form that is suitable for providing information to regulators and to the public about wind farm noise. While the noise level vs wind speed plots presented in the preceding section are helpful to acousticians their somewhat abstract form is not ideal for presentation to a more general audience.

To facilitate a more understandable presentation of collected information, time history plots were developed displaying measured sound levels from an intermediate location, an associated location representative of a neighbouring dwelling and the evaluated average wind speed. Such plots have, historically, not been a common part of a wind farm noise assessment, likely due to the complicating influence of extraneous noise on short term measurements and the need for measurement data to generally represent a range of weather conditions rather than those that occur over a period of hours or a few days.

However, in this instance the intention of the plots is indeed to convey information about wind farm noise over a short period, such as a single day. Selected examples of time history plots are shown below with the following information:

- Data points removed through the filtering process (grey points)
- Measured $L_{A95,10min}$ noise levels at the Intermediate Location IL1 (blue points)
- Measured $L_{A95,10min}$ noise levels at House Location HL1 (green points)
- Measured $L_{A95,10min}$ noise levels at House Location HL3 (orange points)
- Measured hub height wind speeds (red points)

Figure 8 shows an example of 24hr time history plot from 0600hrs to 0600hrs the following day.

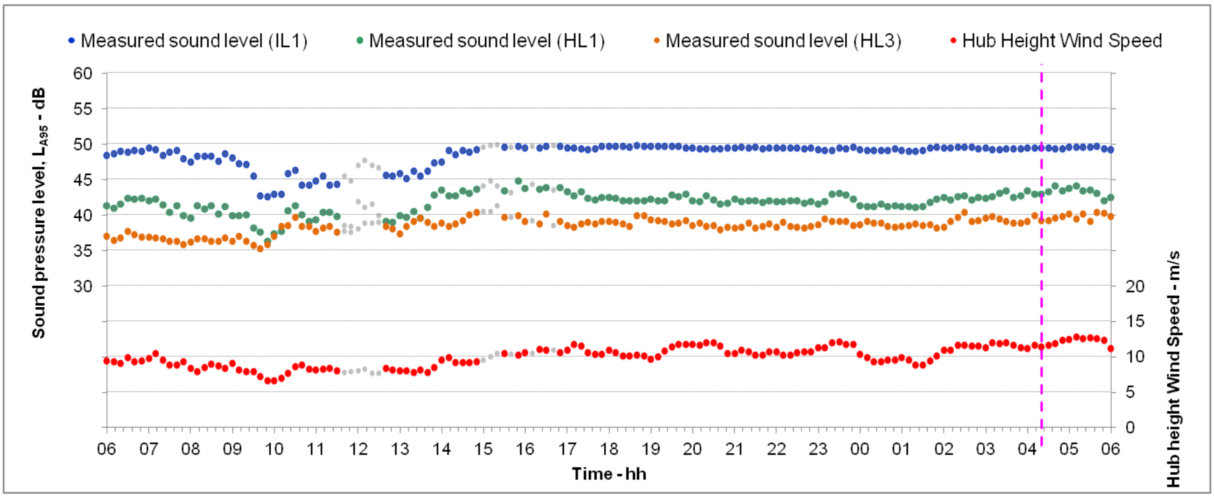

Figure 8: Example time history output #1

This style of time history chart clearly and simply illustrates the trend of wind speed and measured noise levels over time. Of particular note is the relative level of noise across the three monitoring locations, with the levels at IL1 being 5 to 10 dB higher than levels measured at HL1 and HL3 over the same time period. Additionally, variations in wind speed can be matched, in many cases, to variations in the measured noise levels. In particular from Figure 8 the following can be noted:

- After 1500hrs, the nearby turbines around the wind speed of rated power and noise levels at IL1 reach a plateau and do not vary significantly with subsequent variations in hub height wind speed
- Between 2300 hrs and midnight, the hub height wind speed increases by approximately 2 m/s which is paired with a 1 to 3 dB increase in the noise level at HL1 but no significant variation at HL3. This variation may be due to a higher level of extraneous ambient noise sources at HL3.

Figure 9 shows another example of a 24hr time history plot.

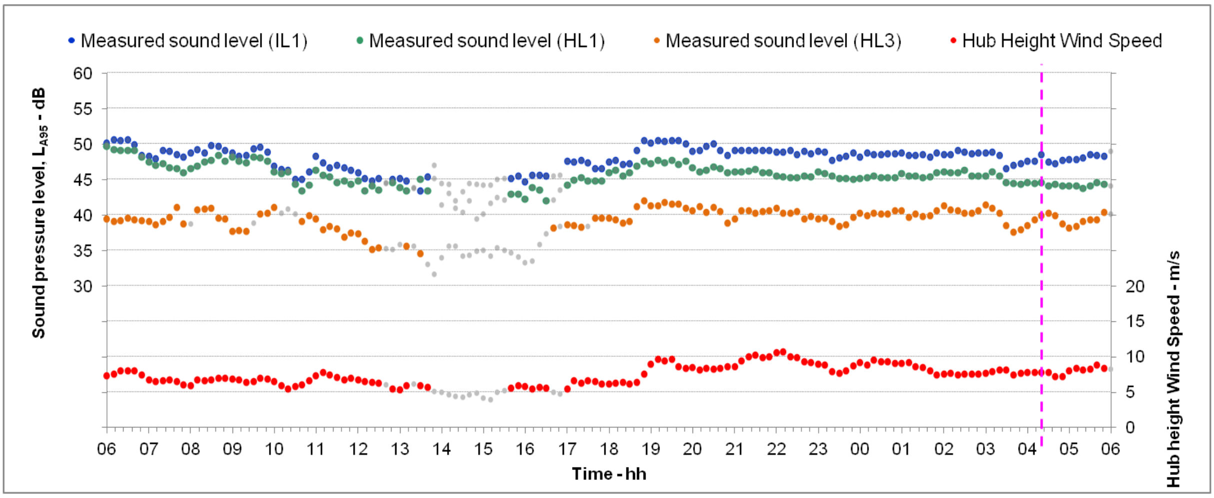

Figure 9: Example time history output #2

The following observations can be made from Figure 9:

- Between 0600 hrs and 1300 hrs measured noise levels at HL1 are approximately equivalent to IL1. As HL1 is approximately twice as far from the nearest turbine as IL1, this strongly indicate an elevated level of extraneous ambient noise at HL1
- As well as providing clearer information to the general public, this type of plot could also be useful to wind farm operators. Noise level data collected at intermediate locations could assist with identifying any unusual trends in wind farm noise or turbine operation. The data may also allow a more pro-active approach in responding to complaints.

5. Concept validation

On the basis of the available results, the research project was considered successful. For the wind farm used for the field study, the use of intermediate locations has generally provided a robust and informative appraisal of wind farm noise. This issue is discussed further below along with a review of aspects of the proposed method that could be improved.

5.1 Noise monitoring at intermediate locations

Measured noise levels at intermediate locations have demonstrated trends that are consistent with the expected noise output from the surrounding turbines which, in turn, suggests that the influence from extraneous noise at the intermediate locations is reduced, particularly for hub height wind speeds between about 5 m/s and 14 m/s.

To investigate this point further, the noise data at IL1 have been used to estimate noise levels at associated house locations (HL1 and HL3). Specifically, the binned average noise levels at IL1 have been adjusted by the difference in predicted noise levels (using ISO9613-2:1996 [14]) between this intermediate location and HL1 and HL3 respectively. Figure 10 presents the measured noise levels at IL1 (red points), HL1 (blue points) and HL3 (green points) together with the estimated noise levels at HL1 (blue line) and HL3 (green line) based on the binned average noise levels from IL1.

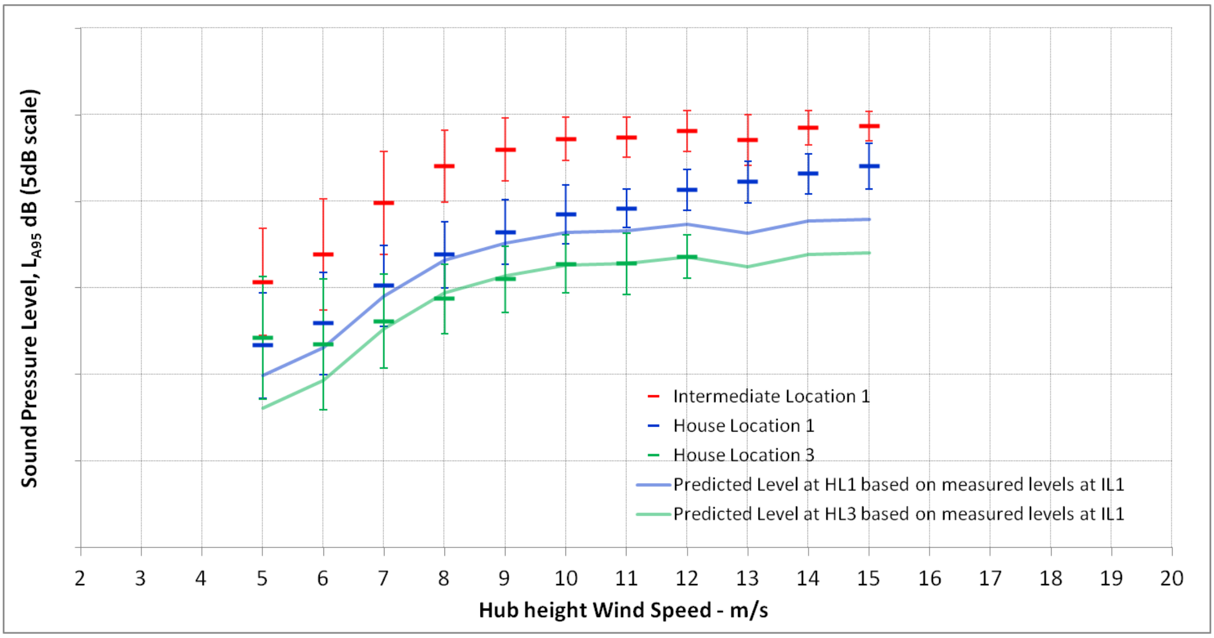

Figure 10: Average noise levels at IL1, HL1 and HL3 vs. hub height wind speed

The figure shows that estimated wind farm sound levels at HL3 are in close agreement with measured sound levels at that location. Conversely, at HL1 the estimated wind farm sound levels are generally lower than the measured values, with the difference increasing with increasing wind speed. This suggests that other sources of ambient noise at HL1 influence the measured sound levels at higher wind speeds. It is worth noting, for example, that HL1 is closer to the ocean than HL3 and the noise environment around HL1 may therefore be more affected by ocean noise.

5.2 Noise monitoring at locations representative of neighbouring dwellings

Monitoring results suggest that the noise data collected at locations representative of nearby dwellings was likely influenced by ambient noise sources, as shown by comparison of measured and estimated noise levels at HL1 in Figure 10 above. This is further demonstrated in Figure 11, which shows the binned average noise levels from IL2 (red points) and HL2 (blue points) together with the estimated noise levels at HL2 (blue line) based on measured noise levels at IL2.

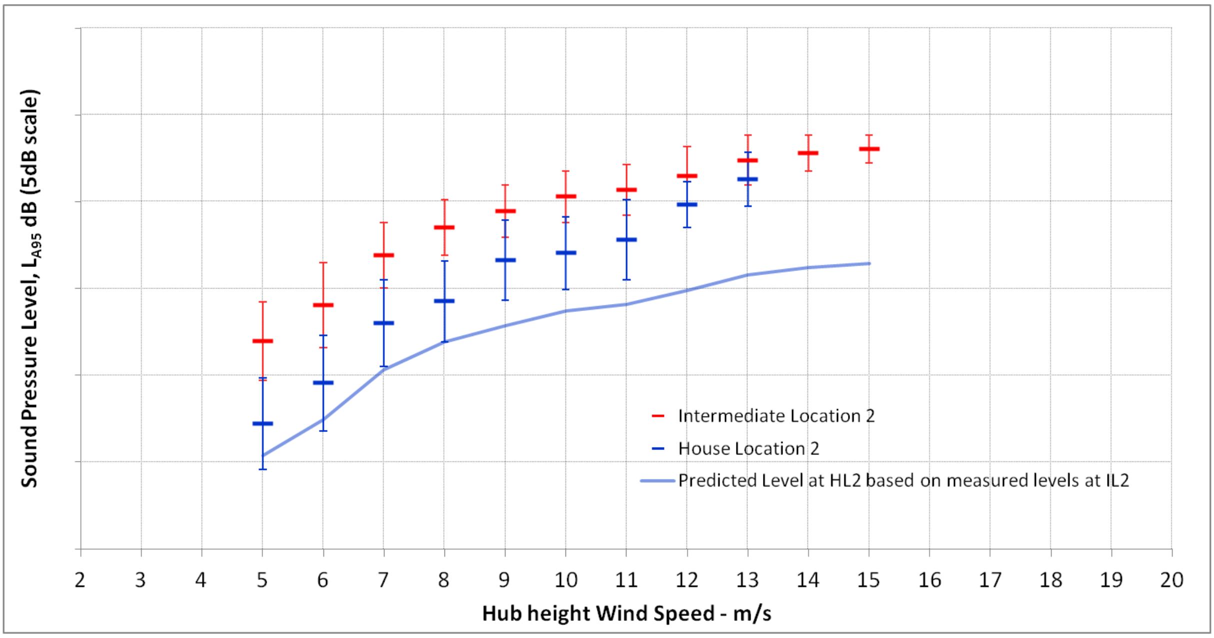

Figure 11: Average noise levels at IL2 and HL2 vs. hub height wind speed

This figure shows that measured noise levels at HL2 are significantly higher than the estimated noise levels at HL2. This suggests that other sources of ambient noise at HL2 influence the measured sound levels across the measured range of wind speeds.

The intention of noise monitoring at locations representative of nearby dwellings was to evaluate, as part of the field study, whether the intermediate noise monitoring locations were suitably representative of the wind farm noise that may propagate to the more distant locations.

At this stage, it is not envisaged that locations representative of nearby dwellings would be a long term component of any continuous noise monitoring system, however monitoring at such locations for an initial ‘start-up’ period or at semi-regular intervals may be helpful in some cases to confirm the appropriateness of data collected at intermediate locations nearer the wind farm.

5.3 Improvement opportunities

5.3.1 Wind farm acoustic performance indicators

As noted, the focus of this research was to evaluate a methodology for providing real time acoustic information to a general audience rather than formally assessing compliance with regulatory controls. Nonetheless, it would be possible to use data collected at intermediate locations as an *indicator* of wind farm performance, including a coarse assessment of wind farm compliance. For example, the following indicators could be considered for comparison with the noise levels measured at intermediate locations:

- Derived noise limits determined by adjusting the noise limits applicable a the nearest affected residential property based on predicted noise level difference
- Predicted noise level from the wind farm at the intermediate location

5.3.2 Automated data acquisition

Throughout the field study, wind farm met and turbine data was manually supplied by weekly emails. While automated weekly emails were able to be generated by the end of the filed study, it was not possible to assess the reliability of this data or, more ideally, to obtain a real-time stream of wind farm data. While it is recognised that the access to wind farm data will vary from site to site it is stressed that any long term continuous wind farm noise monitoring system would depend critically on an automated supply of wind farm data.

5.3.3 Effect of wind induced noise

As detailed in Section 3, data points were removed from the analysis when local wind speeds at the microphone exceeded 5 m/s in order to reduce the potential effect of wind induced noise on measured noise levels. While this method is commonly used in some jurisdictions, the filtering can results in limiting the analysed hub height wind speed range, particularly at very windy sites. As discussed in other works [15] [16] and as recommended in the UK Institute of Acoustics [13], use of secondary wind shields has been shown to reduce the effect of wind induced noise on the microphone.

For a portion of the field study a second 01dB DUO noise monitor fitted with a secondary wind shield was installed at IL1. The second unit was installed for approximately six weeks between May and July 2014 (referred to as ‘reduced data set’ below). Data collected at the second noise monitoring was analysed as per the details above to investigate the influence of monitoring with a secondary wind shield.

Noise levels from the IL1 noise monitor with the secondary wind shield exhibited a systematic level difference of approximately 1.2 dB at low wind speeds when compared with the original IL1 monitor. For ease of comparison, the noise levels in Figure 12 for the noise monitor with the secondary wind shield have been arithmetically adjusted by 1.2 dB to account for this observed offset. It is noted that this adjustment does not affect the conclusions drawn in this section as the observed difference in noise levels between the two noise monitors at hub height wind speeds above 11 m/s are up to 5 dB.

Figure 12 below shows noise levels measured at the intermediate location IL1 for the noise monitor with the secondary wind shield (green data points and red bin averages) and for the noise monitor with standard proprietary wind shield (orange data points and purple bin averages). The figure shows data points from the reduced data set, *without* filtering for local wind speed at the microphone.

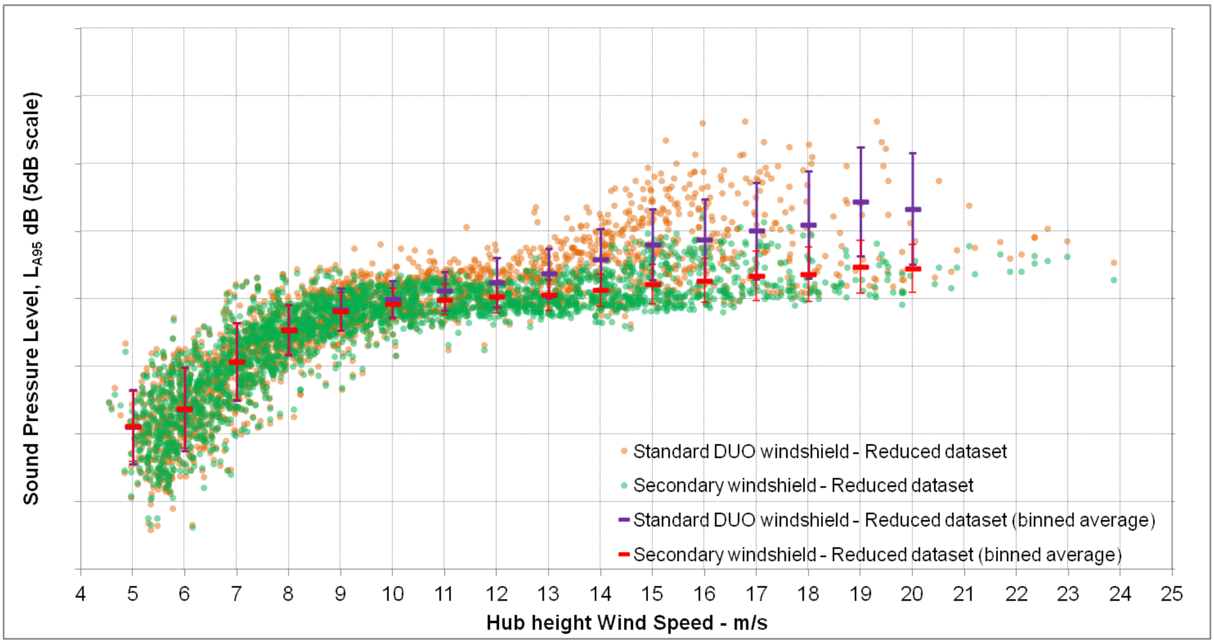

Figure 12: Measured noise levels using standard wind shield vs. secondary wind shield

It can be seen from Figure 12 that measured noise levels at IL1 from the monitor with the secondary wind shield are typically lower than the noise levels from the monitor with the standard wind shield at higher wind speeds, by up to approximately 5 dB at 19m/s.

In Figure 13 below, the same measured noise levels at IL1 from the monitor with the secondary wind shield are compared with noise levels at IL1 from the monitor with the standard wind shield *including* filtering for wind speeds at the microphone above 5m/s (orange data points and purple bin averages). The data points are again from the reduced data set.

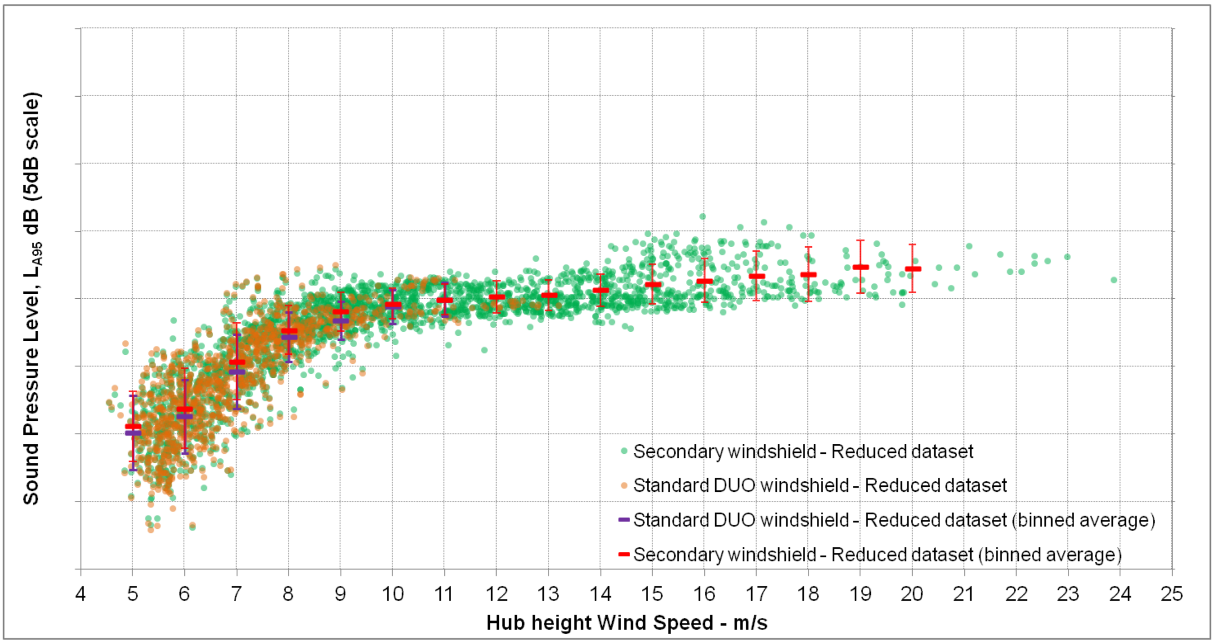

Figure 13: Measured noise levels using standard wind shield vs. secondary wind shield

It can be seen from Figure 13 that, for this particular survey, using a secondary wind shield extends the potential range of assessable hub height wind speeds beyond that determined using a standard wind shield.

6. Discussion

The research project has investigated an alternative approach to wind farm noise measurement and presentation of results that goes beyond conventional compliance requirements. The approach promotes the use of intermediate monitoring locations where wind farm noise is more likely to be a significant contributor to the ambient noise environment. Through the use of secondary monitoring positions at locations representative of residential dwellings, the intermediate location method has been shown to be suitable for a realistic evaluation of wind turbine noise at a known separation distance. The observed sound level differences between intermediate locations and more distant locations representative of residential dwellings is generally consistent with predicted wind farm sound level difference, once account for local ambient noise conditions is made. The basic approach of comparison measurement was also easy to explain to non-technical audiences who (generally) quickly grasped the reason for two (or more) measurement points.

The capacity to set up, and use a web-based interface to monitor the equipment and data has also proved useful and leveraged the increasing capability of smart and wireless technology in general and improved communications capacity at the research site. Given general directions in web-interfacing, cloud computing and data processing capabilities, as well as the intellectual property gained through this research project, there is potential for future projects to be managed or monitored in this way.

There are potential avenues for this type of measurement to assist in operational monitoring and maintenance schedules given the potential to track and identify times of higher noise that may relate to particular operations (unwinding or searching for wind in low wind/low background noise conditions) and/or to investigate concerns form wind farm landholders or operators. This could include the possibility of automated objective assessment of special audible characteristics.

The project results indicate that specific geographic and location features (in this case being near to a coastline, waves and where strong winds are a feature of the existing natural environment) will have an impact on the results that are measured, with this influence increasing with increasing distance away from turbines. Regulatory authorities, or other researchers, may wish to conduct further studies at different wind farms and in different terrain to further evaluate the robustness of the approach and improve on the equipment set-ups used in this study.

The research project's connection to public presentation and non-technical understanding also led to a more informative way to present data points than is used in current practice in compliance-based approaches. It also shows higher wind and low background times of day much more clearly to a lay-audience. From the community's perspective, an ability to request data which is presented in a way that is (reasonably likely to be) understandable and uses familiar terms is likely to be seen as an improvement on the current settings. Moreover, from the government's perspective, an improvement to community access to information is likely to be seen as an improvement on the present status.

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