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Assessing the Validity of Wind Farm Noise Monitoring Data for Periods of Partial Wind Farm Operation

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ABSTRACT

Wind farm noise compliance assessments require measurement of the wind farm noise under full operating conditions. Normal wind farm operation typically includes periods where one or more wind turbines may be unable to operate, due to maintenance requirements, grid restrictions, or other factors. For a large wind farm with many wind turbines, or in situations where cumulative noise impacts from other wind farms need to be considered, there may be very few periods where all wind turbines at the wind farm, and any neighbouring wind farm, operate simultaneously. In such scenarios it is rarely practicable to simply take noise monitoring data from only the periods where all wind turbines were operating, as this may involve excluding a significant proportion of the noise monitoring data set, which would result in a considerable increase in the duration of noise monitoring that is necessary to obtain the required size of data set.

To reduce the proportion of data that needs to be excluded, noise modelling can be used to determine whether the combination of wind turbines operating at any particular time would have resulted in a materially lower noise level than would have occurred with all wind turbines operating. Based on such modelling, non-representative noise measurement data can be excluded from the assessment. This paper discusses a data exclusion methodology that has previously been used for wind farm noise assessments in Australia, and investigates the effect that various modelling simplifications and exclusion criteria could have on the noise assessment outcome, based on a case study of noise monitoring data from 18 locations at two large Australian wind farms.

For the case studies investigated it was found that the effect of excluding periods of noise data where there were non-operational wind turbines was minor, and the exclusion of such data could possibly be an unnecessary step in practical noise assessments for large wind farms, when using the assessment methodologies in use in Australia.

Keywords: Wind, Turbine, Noise I-INCE Classification of Subjects Number(s): 14.5.4

1. INTRODUCTION

The majority of wind farm developments approved in Australia are subject to operational noise conditions which include a requirement to demonstrate compliance with specified noise criteria using a prescribed assessment procedure.

In an ideal scenario, all wind turbines at the wind farm would be operational during the noise compliance monitoring. However, normal wind farm operation typically includes periods where one or more wind turbines may be unable to operate, due to maintenance requirements, grid restrictions, or other factors. To avoid biasing the noise assessment, noise data measured during periods when there are non-operational wind turbines at the wind farm may need to be excluded from the analysis.

A simple approach would be to exclude all noise data measured during periods when any of the wind turbines were non-operational. However, for a large wind farm with many wind turbines, or in situations where cumulative noise impacts from other wind farms need to be considered, there may be very few periods where all wind turbines at the wind farm, and any neighbouring wind farm, operate simultaneously. As such the simplistic approach of only analysing the noise data for the periods when all wind turbines were operating may add weeks to the overall monitoring period required to capture

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sufficient data for the assessment.

By determining the periods when the presence of non-operational wind turbines would and would not have had a material effect on the measured noise levels at the assessment location, the amount of data that is required to be excluded can be significantly reduced. For example, if a non-operational wind turbine is located much further away from the assessment location than other operational wind turbines, the effect of the non-operational wind turbine on the overall wind farm noise level may be insignificant. The benefit of not excluding this data unnecessarily is a reduced noise monitoring period and associated cost saving.

This paper presents a methodology that has been used to determine whether or not to exclude wind farm noise measurement data during periods when some of the wind turbines at the wind farm were non-operational. The paper then investigates the effects that various exclusion and simplifications to the methodology could have on the noise assessment outcome.

2. OVERVIEW OF WIND FARM NOISE ASSESSMENT PROCEDURES

There are a number of wind farm noise assessment procedures in use in Australia, including for example, various versions of the South Australian Wind Farms Environmental Noise Guidelines (1,2,3) and New Zealand Standard 6808 (4,5). The procedures all utilise a broadly similar assessment approach, based on wind speed-dependent noise criteria.

In general terms, assessment of the wind farm noise is undertaken by measuring the L_{A90} or L_{A95} Sound Pressure Levels at the assessment location in a continuous series of 10-minute intervals for a minimum period of 10 to 14 days, equating to between 1440 and 2000 10-minute data points. However, due to the need to exclude some data due to extraneous noise influences and non-operational wind turbines, a longer period of noise monitoring is often required.

Following the monitoring, the measured Sound Pressure Levels are screened to exclude any measurement intervals that were influenced by extraneous noise or rainfall, and any periods where the noise due to the wind farm would not have been representative of normal operation. It is this last element of the screening process that is the focus of this paper.

After the data screening process is completed, each remaining 10-minute Sound Pressure Level measurement is then graphed against the corresponding 10-minute average wind speed that occurred during the measurement interval. The result is a scatter plot comprising a series of 10-minute Sound Pressure Level versus wind speed data points. A regression curve is fitted to this data set (see Figure 1) and the value of the regression curve at each wind speed is taken as wind farm noise level for the purpose of the assessment, after adjusting for background noise contribution, if appropriate.

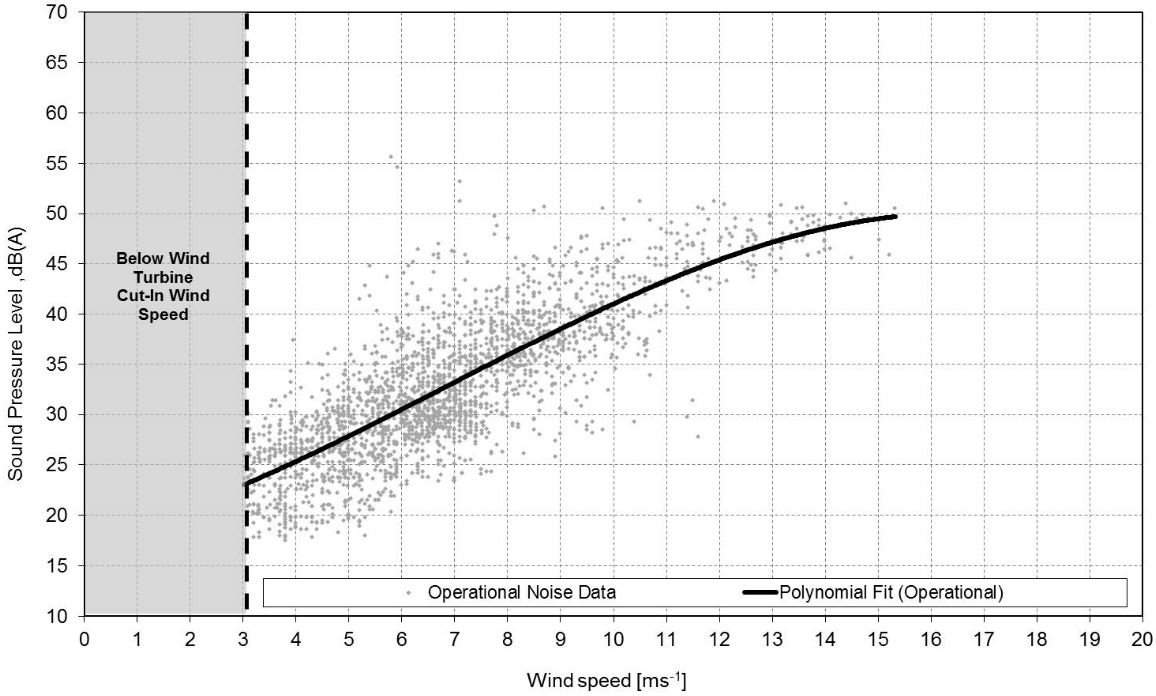

Figure 1 – Example regression curve

3. GENERAL DESCRIPTION OF DATA EXCLUSION METHODOLOGY

Methods to determine whether to exclude periods of noise measurement data due to non-operational wind turbines are not specifically documented in any of the assessment methodologies outlined above. The following paragraphs describe one method of doing this, which has been accepted by regulatory bodies for previous wind farm noise assessments undertaken in Australia. The method is as follows:

1. A computer noise model of the wind farm is used to predict the total wind farm noise level at the assessment location with the full wind farm operating. The Sound Power Level of each wind turbine in the noise model is assigned according to the actual conditions recorded at each wind turbine during the 10 minute period under consideration (e.g. the Sound Power Level is determined from the wind turbine specifications based on actual power output or wind speed at each wind turbine). For wind turbines which were not operational during the 10-minute period under consideration, the Sound Power Levels are assigned based on the conditions recorded at the nearest operational wind turbine or using another reasonable assumption (an alternative conservative assumption would be to assign the maximum Sound Power Level of the wind turbines to any non-operational wind turbines). The average wind speed and direction recorded at the site during the 10-minute period are included in the propagation calculation.

2. The wind turbines which were not operational during the 10-minute period under consideration are then turned off in the noise model, and the model is used to predict the total wind farm noise level without any noise contribution from the non-operational wind turbines i.e. the actual operating scenario during the 10-minute period under consideration.

3. The difference between the wind farm noise level predicted in step 1 (i.e. the noise level that would be predicted to occur if the full wind farm had been operating) and the level predicted in step 2 (i.e. the noise level that would be predicted to occur with all wind turbines operating) is calculated.

4. If the difference is greater than a given value (for example 0.5 dB(A)), then the noise measurement for the period under consideration is excluded. This value is termed herein the ‘exclusion criterion’. The value of the exclusion criterion represents the magnitude of difference which is considered material in terms of the overall wind farm noise level at the assessment location.

4. PARAMETERS TO BE INVESTIGATED

4.1 Value of Exclusion Criterion

To apply the above exclusion methodology, it is necessary to define a value for the exclusion criterion. At face value it would seem reasonable to apply an exclusion criterion with a small value, such as 0.5 dB(A), since a small difference such as this would generally be regarded as insignificant in practical terms.

However, in practice the value of the exclusion criterion selected does not translate directly to that same difference in the final regression curve when the full data set is analysed. This is due to a number of factors including that:

1. The regression curve is generally based on a large number of data points (10-minute periods), some of which may be affected by non-operational wind turbines, but many of which are not. The averaging effect of the regression analysis reduces the impact of any individual data points that are affected by non-operational wind turbines.

2. The difference due to the presence of non-operational turbines may be much less than the selected exclusion criterion value for many of the individual periods which remain included in the final data set.

The first aspect of the investigation presented in this paper therefore investigates how the value of the exclusion criterion selected affects the final regression in practice, what values of exclusion criterion may be appropriate, and whether the distance of the assessment location from the nearest wind turbines has any influence.

4.2 Modelling Simplifications

The second aspect of the investigation presented in this paper investigates possible simplifications that could be applied to the exclusion methodology presented in Section 3.

It is noted that to apply the exclusion methodology as it is described in Section 3 requires the wind farm noise levels to be predicted separately for each 10-minute period, due to the different operating conditions of each individual wind turbine during each different 10-minute period. As the full data set for each assessment location may include hundreds or thousands of 10-minute periods where there was non-operational wind turbines, performing these predictions is a complex and computationally intensive process.

Given the above, it would be desirable if simplifications could be made to the modelling to reduce the complexity and computation time required to complete the data exclusion analysis. In particular, the effects of the following potential modelling simplifications have been investigated:

1. Determining the periods to exclude with all wind turbines modelled as operating at their maximum Sound Power Level, rather than based on the actual operating conditions of each wind turbine during each 10-minute period.

2. Determining the periods to exclude with modelling of the noise propagation for the worst case wind direction only, rather than actual wind direction that occurred during any 10-minute period.

Analysis has been undertaken to determine if the above simplifications significantly alter the periods of noise data that would be excluded from the analysis when compared with the more complex modelling methodology outlined in Section 3.

5. INVESTIGATIVE APPROACH

The investigation has been undertaken using a case study approach to determine the practical implications of the choice of exclusion criterion and modelling simplifications for typical wind farm operating scenarios.

Noise monitoring data from two large Australia wind farms has been analysed for the purpose of the study. The data analysed includes 18 noise monitoring locations in total, ranging from 220 metres to 2.7 kilometres from the nearest wind turbine.

Between four and six weeks of continuous noise monitoring was conducted at each location, during which time various combinations of wind turbines at each wind farm were operational and non-operational, due to factors such as maintenance requirements and faults. The operation and non-operation of wind turbines during the monitoring periods used in the analysis represent typical normal operation for large wind farms.

Periods of the noise monitoring which were influenced by extraneous noise were excluded from the analysis as far as practical.

Modelling was conducted using a commercially available environmental noise modelling software package to establish the predicted noise levels and individual wind turbine noise contributions at each noise monitoring location. The process of predicting the noise levels for each 10-minute period was automated using an algorithm developed by AECOM.

To investigate the effect of using various values of exclusion criteria and the proposed modelling simplifications, the regression curves derived using the parameter under investigation were compared to a ‘Reference Regression Curve’ for the assessment location.

The ‘Reference Regression Curve’ is the curve representing the measured wind farm noise levels with all wind turbines operating. In practice, due to the large number of wind turbines at the wind farms used in the study, there were no periods during the noise monitoring where all wind turbines at either wind farm operated simultaneously. Therefore, the ‘Reference Regression Curve’ has been determined in accordance with the exclusion methodology presented in Section 3, using an exclusion criterion of 0.05 dB(A), which essentially replicates the result that would be obtained if all noise data measured during periods with non-operational turbines is excluded.

6. INVESTIGATION OF EXCLUSION CRITERION

Three values of exclusion criterion were investigated and compared with the Reference Regression Curve for each location. The following exclusion criteria values were investigated:

1. No exclusion of data due to non-operational wind turbines (i.e. including all periods of noise monitoring regardless of non-operational wind turbines)
2. 0.5 dB(A) exclusion criterion
3. 0.1 dB(A) exclusion criterion

For the periods of monitoring at the two wind farms included in this case study, it was found that the use of a 0.5 dB(A) exclusion criterion typically resulted in approximately 10 to 15% of the overall noise measurement data being excluded due to non-operational wind turbines. Using a 0.1 dB(A) exclusion criterion, this increased to approximately 35 to 45%, and in the case of the Reference Regression Curves, which used an exclusion criterion of 0.05 dB(A), approximately 45 to 55% of the overall noise measurement data was typically excluded.

The following tables present the average differences of the regression curves derived using each value of exclusion criterion, when compared with the Reference Regression Curves. Although the numbers presented are the averages for the locations in the sample, it is noted that the values for individual locations generally did not differ from the averages presented by more than ± 0.3 dB(A). (Note, a positive number in the tables below means the Reference Regression curve was greater than resulting regression curve by the difference shown).

Table 1 – No Exclusion of data due to non-operational wind turbines

Average difference in dB(A) from Reference Regression Curve at given wind speed											
Distance from nearest wind turbine	Locations in sample	Wind speed, m/s									
		3	4	5	6	7	8	9	10	11	12
Up to 1000m	6	0.9	0.9	0.7	0.7	0.7	0.6	0.4	0.3	0.5	0.5
1000m to 2000m	6	0.8	0.8	0.7	0.6	0.3	0.3	0.3	0.3	0.4	0.4
Over 2000m	6	0.6	0.5	0.3	0.2	0.1	0.0	0.1	0.2	0.3	0.4
Overall	18	0.8	0.7	0.6	0.5	0.4	0.3	0.3	0.3	0.4	0.4

Table 2 – 0.5 dB(A) exclusion criterion

Average difference in dB(A) from Reference Regression Curve at given wind speed											
Distance from nearest wind turbine	Locations in sample	Wind speed, m/s									
		3	4	5	6	7	8	9	10	11	12
Up to 1000m	6	0.5	0.4	0.4	0.5	0.3	0.1	0.2	0.3	0.3	0.3
1000m to 2000m	6	0.4	0.3	0.3	0.2	0.1	0.0	0.1	0.2	0.2	0.2
Over 2000m	6	0.3	0.3	0.3	0.1	0.1	0.0	0.1	0.1	0.1	0.2
Overall	18	0.4	0.3	0.3	0.3	0.2	0.0	0.1	0.2	0.2	0.2

Table 3 – 0.1 dB(A) exclusion criterion

Average difference in dB(A) from Reference Regression Curve at given wind speed											
Distance from nearest wind turbine	Locations in Sample	Wind speed, m/s 3	4	5	6	7	8	9	10	11	12
Up to 1000m	6	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
1000m to 2000m	6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Over 2000m	6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Overall	18	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1

Several conclusions cans be drawn from analysis of the above tables. Firstly, by not excluding any data due to non-operational wind turbines the values of the resulting regression curves were changed by less than 1 dB(A) compared with the Reference Regression Curves. This suggests that in many cases where there are short periods with a relatively small number of wind turbines not operational (i.e. typical of large wind farm operation) the additional step of excluding those periods of noise data from the analysis may be unnecessary, as the resulting effect on the final regression curve is minor in practical terms. It is however noted that the difference is greatest for the monitoring locations closest to the wind turbines, and decreases with distance from the wind farm.

This is most likely due to the fact that for locations close to the wind farm, a smaller number of wind turbines provide the dominant contribution to overall noise level than when further away. The result is that the non-operation of a nearby wind turbine has a much larger effect on the overall noise level when closer to the wind farm. The contribution of noise sources other than the wind farm is also greater at further distances, even though it has been attempted to minimise the influence of extraneous and background noise as far as possible in the analysis.

Secondly, the difference between the Reference Regression Curve and the curve derived using an exclusion criterion of 0.5 dB(A) is generally less than 0.5 dB(A), as expected.

Thirdly, the difference between the Reference Regression Curve and the curve derived using an exclusion criterion of 0.1 dB(A) is negligible. Further, the resulting noise level difference between using an exclusion criterion of 0.1 dB(A) and an exclusion criterion of 0.5 dB(A) is insignificant for a practical noise assessment.

Whilst the differences in the resulting regression between using a 0.1 and 0.5 dB(A) exclusion criterion are insignificant, the amount of extra noise data required to be excluded using a 0.1 dB(A) exclusion criterion is considerable, with up to 35% more data excluded. For a nominal four week monitoring campaign, this represents approximately 10 days of additional noise monitoring.

If data exclusion is to be undertaken due to non-operational wind turbines, the use of a 0.5 dB(A) exclusion criterion appears to be reasonable, based on the case studies investigated here.

7. INVESTIGATION OF MODELLING SIMPLIFICATIONS

As discussed in Section 4.2, the exclusion methodology could potentially be simplified by determining the periods to exclude using modelling based on all wind turbines operating at their maximum Sound Power Level, rather than based on the actual operating conditions during each 10-minute period.

For the case studies above, this simplification was applied and was found to have negligible effect on the amount of data excluded due to non-operational wind turbines. Consequently, it also had negligible effect on the resulting regression curves. This result suggests that this simplification is reasonable.

It is thought that this outcome would be due to it being the relative noise contribution of each wind turbine that matters when considering which periods to exclude in the exclusion methodology that has been applied. The wind turbines closest to the monitoring location generally dominate the noise contributions at the monitoring location, and due to being in the same proximity, would generally all experience similar wind conditions. As such, each of the nearby wind turbines in the case study typically generated similar Sound Power Levels, and the relative noise contribution of each of the nearby turbines therefore remained approximately the same as if they were all operating at maximum

Sound Power Level.

The second simplification discussed in Section 4.2, is simplifying the modelling of the wind direction in the exclusion analysis to only model the propagation of noise from each wind turbine based on the worst case wind direction, rather than the actual wind direction during each 10-minute period.

This simplification was found to have a larger effect on the exclusion analysis than the first simplification above. Specifically, when the exclusion analysis was undertaken using the modelling simplification of worst case wind direction only, up to 20% more data points were excluded from the analysis when compared with the case modelling the actual wind direction during each 10-minute period. The resulting effect was that the wind farm noise levels determined from the regression curve were typically between 0.1 and 0.3 dB(A) higher than the case using modelling based on the actual wind direction for each 10-minute period, which is relatively insignificant. Using the worst case wind direction in the modelling for the exclusion analysis therefore represents a conservative simplification.

Given the findings above, it would appear reasonable to simplify modelling of the wind farm noise emissions for the purpose of the exclusions analysis, to calculate the contributions based on maximum Sound Power Level and worst case wind direction only. The authors experience has found has found that such an approach greatly reduces the complexity of the modelling process, reducing set-up and computation time by several days in the case of large data sets.

8. CONCLUSIONS

This paper has presented an analysis of a data exclusion methodology which has previously been used for wind farm noise assessments in Australia, for determining whether periods of noise monitoring data should be excluded from a wind farm noise assessment due to the presence of non-operational wind turbines at the wind farm. An investigation has been performed into the effect that various modelling simplifications and exclusion criteria could have on the noise assessment outcome.

The degree of influence that the exclusion criterion and modelling simplifications have on the outcomes will depend on the locations of wind turbines relative to the assessment locations, and on the proportion of the monitoring period for which non-operational wind turbines were present.

For the two wind farms used for the case studies presented in this paper, it was found that the resulting effect of excluding periods of noise data where there were non-operational wind turbines was minor, and could possibly be an unnecessary step in practical noise assessments for large wind farms, when using the assessment methodologies in use in Australia.

It is recommended to conduct a sensitivity check when performing a wind farm noise assessment analysis to determine if the periods of non-operational wind turbine have any material influence. Based on the findings of this paper, such a check can be performed using wind turbine noise contributions modelled based on a simplified case of worst case wind conditions and maximum Sound Power Levels, rather than on the actual wind turbine sound power levels and wind direction for each individual 10-minute period.

In the event that sensitivity analysis for a particular set of wind farm noise monitoring data shows it is necessary to exclude periods of noise data where there were non-operational wind turbines, it appears that an exclusion criterion of 0.5 dB(A) may be appropriate, when using the exclusion methodology presented in this paper.

9. REFERENCES

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