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Analysis of Noise Immission levels measured from Wind Turbines

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Abstract

Different analysis techniques are explored for noise immission levels captured in accordance with a newly proposed Ontario protocol for quantifying the noise immission from wind turbines for the purposes of comparison to local regulatory limits and establishment of compliance with those limits. The three methods include a polynomial regression analysis, a binning process and a statistical analysis on binned data. The results of the different analysis methodologies are compared and the limitations of each are explored.

1. Introduction

In Ontario, Canada, wind turbine facilities have been rapidly growing due to new opportunities to develop renewable energy. With this growth, the Ontario Ministry Of Environment (MOE) has developed specific guidelines for noise pollution limits from Wind Turbine facilities. In cases where the turbine facilities are built and operating, there is currently no standardized method for conducting measurements from wind turbines in order to determine whether a facility is in compliance with the applicable noise limit. This has led to inconsistencies in the way consultants measure, quantify and assess the noise immissions from wind turbine facilities in noise audit scenarios.

Aercoustics Engineering Limited has been contracted by the Ontario Ministry to assist them in developing a standardized method to be used in quantifying the noise contribution from wind turbines at the point of immission (typically residential dwellings). The study has included a literature review, and practitioner consultation before developing a proposed measurement method. This paper discusses various data analysis methods in order to quantify the noise contribution from the turbines as measured using the proposed measurement protocol.

2. Noise Immission measurements

The final stage of the contract is the field validation of the protocol. During this stage various locations are used as test cases to determine if the methodology yields reliable results. At the time of this paper, field tests at two such locations were carried out. The measurement campaign included measuring sound from a wind turbine facility at setbacks of 538 and 650 metres from the closest turbine. Unattended measurements

were carried out for approximately three weeks. During the measurement campaign the following was measured simultaneously:

2.1. Sound data

Unattended sound measurements were conducted with the microphone at 4.5 metre height (point of reception height for two storey dwelling in Ontario), and measurements were logged in 1 minute intervals. For each interval, the 1/3rd Octave Band equivalent continuous sound level (Leq) was logged, as well as spectral statistics (L5, 10, 50, 95, 99). Additionally, the time signal was recorded at an 8000Hz sampling rate. The microphone was fitted with a double windscreen –similar in specification to the one suggested in IEC-61400-11.

2.2. Meteorological and other non-acoustic data

Meteorological data was captured simultaneously at the same measurement location at a 10 metre height. The Ontario Ministry Sound Level Limits are prescribed with reference to the wind speed at 10 metres height. At that height, the following parameters are logged in 1 minute intervals:

1. Temperature
2. Humidity
3. Average wind speed
4. Min/Max wind speed
5. Wind direction
6. Precipitation (Rain capable only)

During the measurement campaign, the wind speed at the hub height was also obtained from the turbine SCADA system, along with the power output of the turbines. This information was available in 10 minute intervals.

Figure 1: Noise Immission measurement test site

3. Analysis methods

Given the large amount of data, the protocol proposes applying filters to isolate times when the maximum signal to noise can be expected. With this, only data taken at night is considered (10pm – 5am). Additionally, data taken during rainy periods and gusty periods is removed. The spectrum is also visually inspected to identify any insect or animal noise that effect the measurements – in the cases of insects (such as cicadas or crickets) the 1/3rd octave bands affected are discounted. The data is also filtered for times when the turbines are generating power (>10%) capacity.

During the measurement campaign one night is selected for obtaining the ambient noise. This is done by parking the turbines in the vicinity of the measurement location such that the predicted level falls at least 10dB.

The remaining data is then used in the analysis. Three analysis techniques were considered:

3.1. Polynomial best fit

In this method, a polynomial (Up to 3rd order) is fit to the LAeq vs. 10m wind speed data. This is done for both the turbine operational, and ambient data set. From the polynomial fits, the level at integer wind speeds is obtained, and the ambient LAeq level is logarithmically subtracted from that of the turbine operational level. The result is the expected contribution from the turbines. This can be compared to the MOE noise limit at those integer wind speeds.

3.2. Binning by Wind speed

This method groups the filtered data by integer wind speed. Within each wind speed, there will be a number of 1-minute LAeq measurements. For each bin, the mean (arithmetic) LAeq is tabulated, along with the Standard deviation. The same is carried out for the ambient noise. As in the case with the Polynomial fit, the ambient level is logarithmically subtracted from the turbine operational level. The obtained contribution from the turbines only is then compared with the allowable level.

3.3. Statistical spread within each wind speed

Where the first method has a very broad look at the variability of the data, the second method gives some idea of the spread with the standard deviation. This method considers the variability within each bin in more detail. For each integer wind speed bin, the probability distribution of the A-weighted level is computed. This can be carried out with both the turbine operational, and the ambient case. This data can then be presented in a surface chart where contours of different probability density give an understanding on what range of noise levels were measured within each wind speed. With this information, one could compute the percentage of time the noise level at the immission point falls within the Sound Level Limits. It should kept in mind, however, that this includes the ambient contribution. This method gets more complicated if the ambient level is to be subtracted from the noise levels with the turbines operational.

4. Preliminary Results

With the first two locations, three weeks of data was captured which covered 10m high wind speeds up to a speed of 9m/s. Given a requirement of at least 60 individual measurements within each usable wind speed interval, enough data was captured for the range of 0 – 8m/s with the turbines operational. However, for the night where the turbines were parked – the forecast proved wrong and insufficient data was obtained for the ambient case for wind speeds above 3m/s. Nonetheless, the analysis methods are carried out for this data, and provide interesting insight.

4.1. Polynomial best fit

Figure 2 shows the data spread for the filtered data set including both turbine noise and background noise. The dark line shows a 3rd order polynomial fit. From the curve fit, the points at each integer wind speed would be tabulated and, with available ambient measurements, be used to calculate the contribution from the turbines alone.

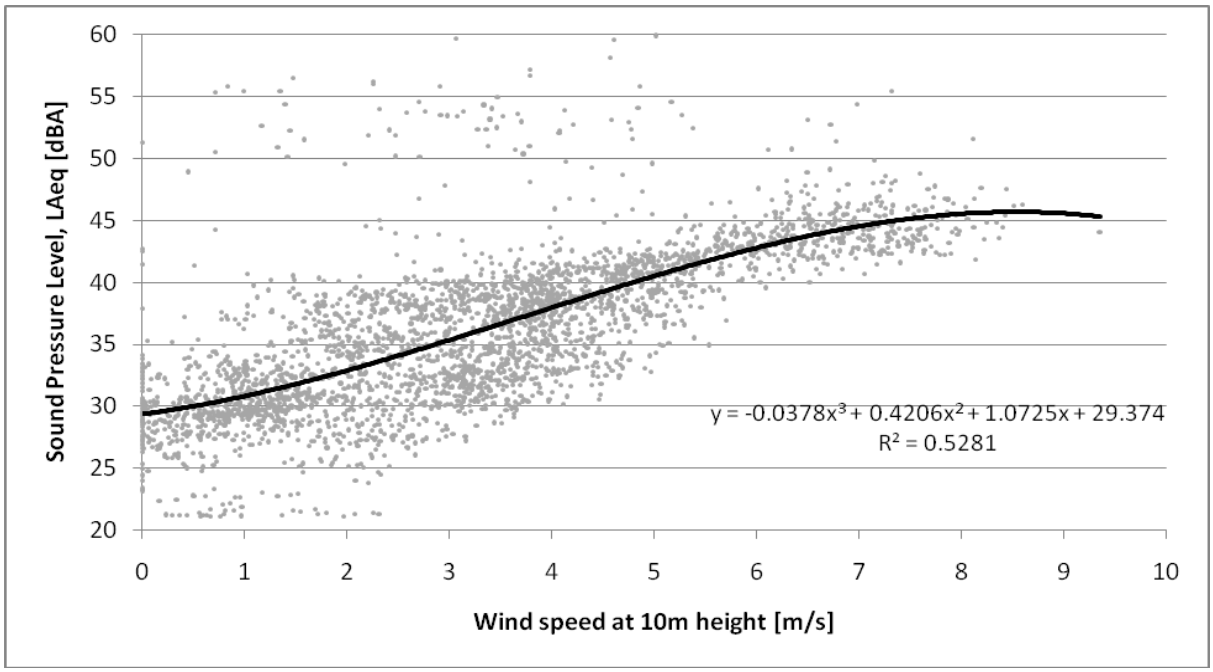

Figure 2: Sound Level measured ~550m away from closest turbine. The data includes the ambient noise.

The benefit of this method is in its simplicity. The drawback is that the accuracy is skewed at the periphery of the polynomial curve. There is also a requirement that there be at least 60 points in the integer wind speed measured. This ensures that there are sufficient samples in the data set at the wind speeds of interest. Extrapolating the polynomial is not permitted. A second drawback is that little information is obtained about the variability of the data. The coefficient of determination, R^2, gives an idea about the overall fit of the polynomial, but does so in a simplified manner.

4.2. Binning by Wind speed

Table 1 below shows the mean noise level in each wind speed along with the number of samples within each bin, and the standard deviation. The information is graphically presented in Figure 3.

Table 1: Mean LAeq for binned wind speeds

Wind speed [m/s]	LAeq [dBA]	No of points	St dev
1	30.9	459	4.9
2	33.1	456	5.1
3	35.4	556	5.1
4	37.4	593	4.0
5	40.5	324	3.9
6	43.3	195	2.0
7	44.5	188	2.2
8	44.8	60	1.8
9	46.3	2	0.1

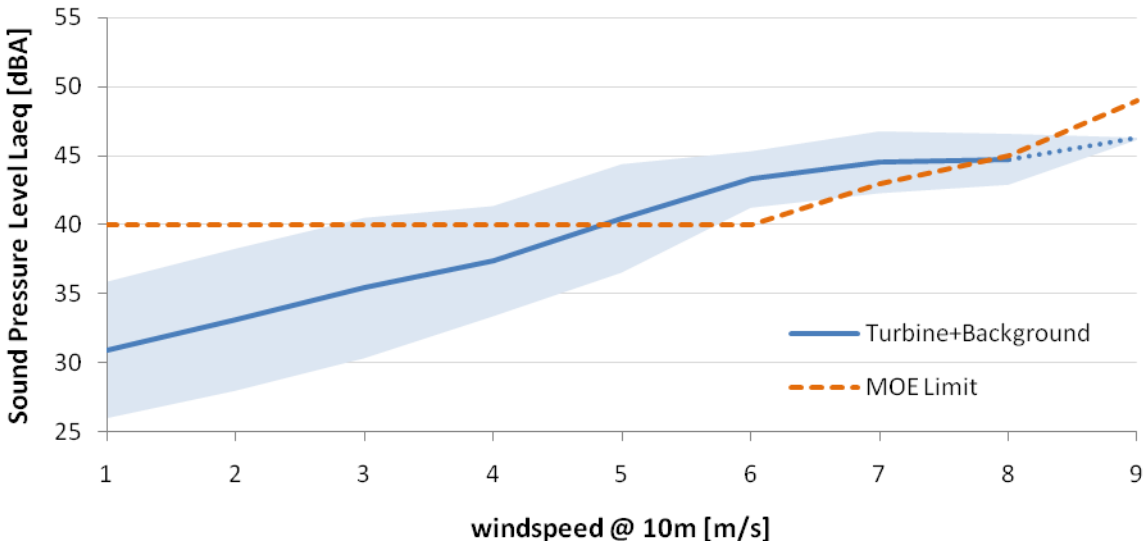

Figure 3: Sound level measured ~550m away from the closest turbine analyzed by binned wind speeds. The dark line represents the mean LAeq within each bin. The shaded zone represents one standard deviation

This method is quite similar to the polynomial best fit. The differences are that it does not explicitly assume a polynomial behaviour of the data set, and that it provides information on the variability of the data at each wind speed. The figure shows the solid line as dotted after 8m/s due to the number of data points being below 60.

4.3. Statistical spread within each wind speed

The probability distribution of the overall A-weighted sound pressure level was computed in 1dB increments from the binned data set. The distribution for each wind bin is presented in Figure 4 below as a function of overall A-weighted sound pressure level. The contour chart is also presented showing the distribution of data within each bin (Figure 5).

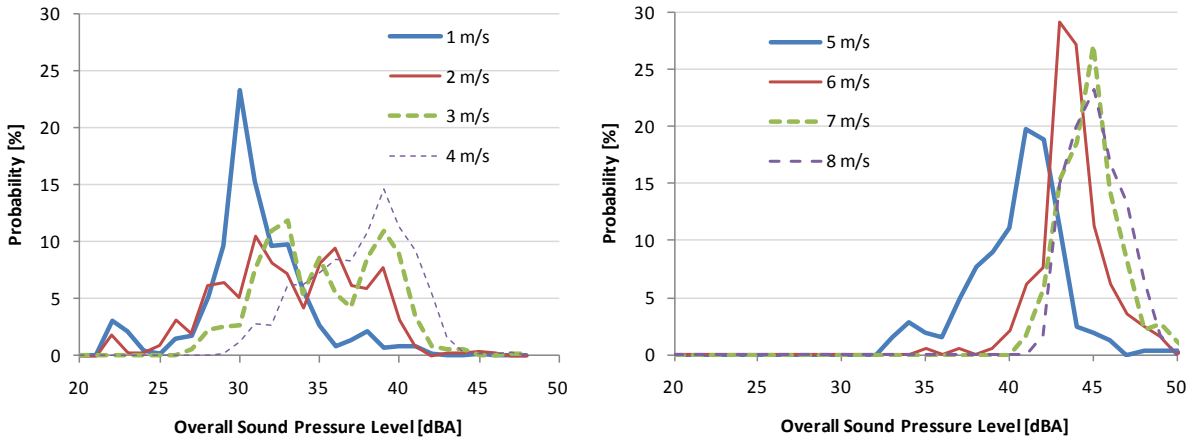

Figure 4: Probability density of the LAeq at varying wind speeds.

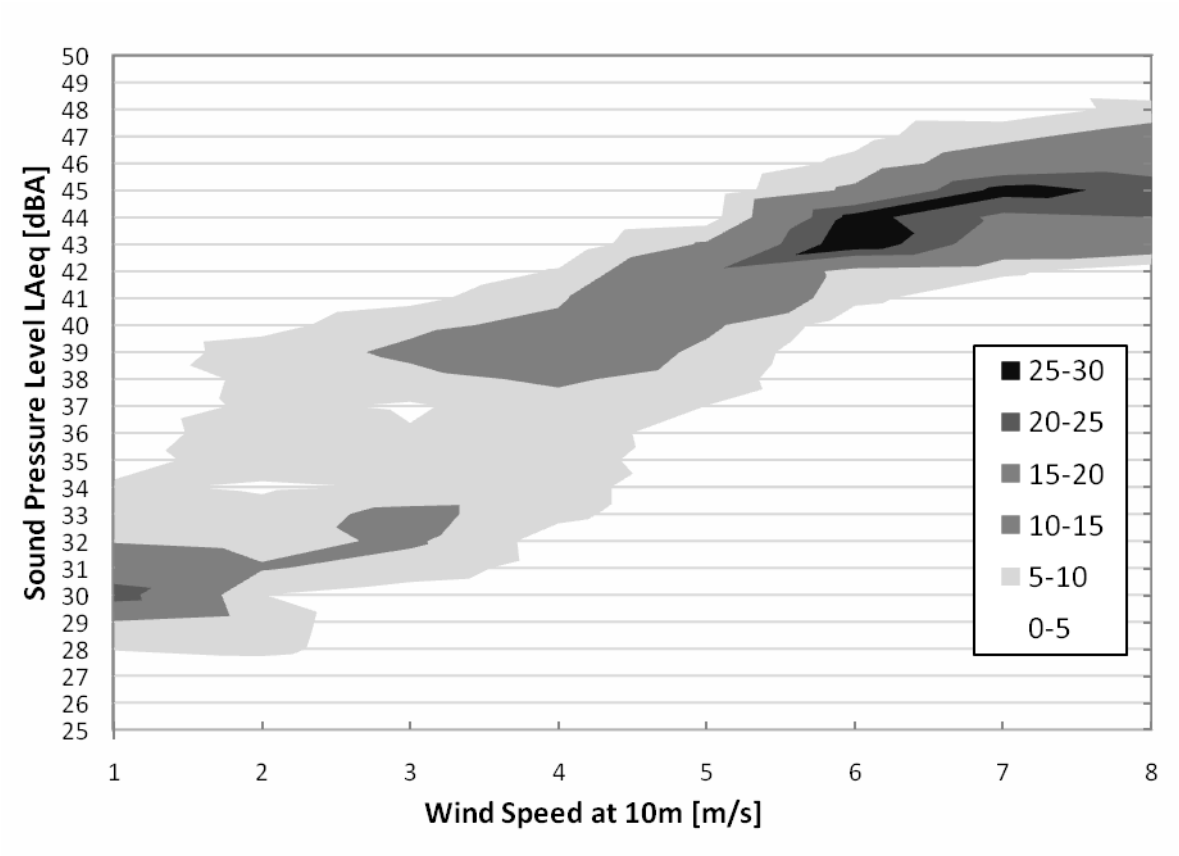

Figure 5: Probability density of the overall sound pressure level (LAeq) measured at 550m away from a wind facility. The probability density is broken into 1dB increments and the contours represent the percentage of time the level fell within an integer wind speed bin.

This method focuses on the variability of the data and shows the expected level within each wind speed. The main advantage of this method is that with it one can develop a percentage of time that the sound level exceeds a certain level. The percentage can be also obtained for a noise limit that changes with wind speed (as is the case for Ontario). The challenge is quantifying the contribution of the ambient when two sets of such data are available, and developing a statistical curve for the contribution of the turbines alone. This approach may be worth considering for a protocol that compares the percentage of time the noise level exceeds the prescribed limit with and without the turbines operating. Such a comparison would give a real world impact on the change in the overall ambient environment with the introduction of wind turbines. The drawback of this method is that it is difficult to design for such a case during the prediction and modeling stage. Modeling statistical variation in atmospheric conditions or source levels is not usually carried out.

5. Conclusions

The first conclusion is that quantifying the ambient noise level is critical. Without this information, it is difficult and speculative to claim a reliable quantification of the sound level contribution from the wind turbines – this is especially the case at wind speeds above 4m/s.

In the absence of ambient noise data, three methods of analysis were carried out. Each has merits worth considering. The methods range from the simple to complex. The simplicity focuses on reporting a usable quantity whereas the complex focuses on quantifying the variability.

6. Future Work

As part of the current research contract, more sites will be measured with a heavier focus on obtaining adequate ambient noise. More work will also be carried out to identify if better filtering will give a more convincing picture of the turbine noise without available background contribution.

The self noise of the microphone windscreen and the Insertion Loss performance of the wind screen are also areas to be addressed.