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Generating a better picture of noise immissions in post construction monitoring using statistical analysis

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Summary

Following recent work in developing data analysis techniques for long term noise immission measurements from wind turbines, a statistical methodology has been developed to help produce a more complete picture of the noise environment and the contribution of the turbine facility to the noise environment at the measurement position.

The analysis results in a detailed picture in which one can quantify the amount of time the contribution from wind turbines is at a given sound level. With this information, one can assess the state of compliance with regulatory limits. Furthermore, should non-compliance be identified, the specific situations, and the total probable duration of non-compliance can be inferred. This enables a turbine facility owner or a regulatory body to assess the severity and frequency of occurrence or exceedence, and better inform mitigation strategies.

1. Introduction

Wind turbine noise immission measurements carried out at affected residential dwellings often provide a challenging environment for obtaining uncontaminated data. Numerous extraneous noises often contaminate the measured levels, making obtaining reliable data more challenging. Previous work developing a methodology for providing consistent measured noise immission levels at distances up to 800m away from the closest turbine resulted in strategies to promote higher quality data. Data collection was limited to night time conditions, intervals shortened to 1 minute duration, during which no precipitation had occurred within an hour, and during which the wind speed maximum deviated from the mean by no more than 2m/s. Noise measurements are then binned into integer wind speeds. Arithmetic mean of the 1-minute LAeq levels are calculated and reported at each wind speed bin along with standard deviation for each bin.

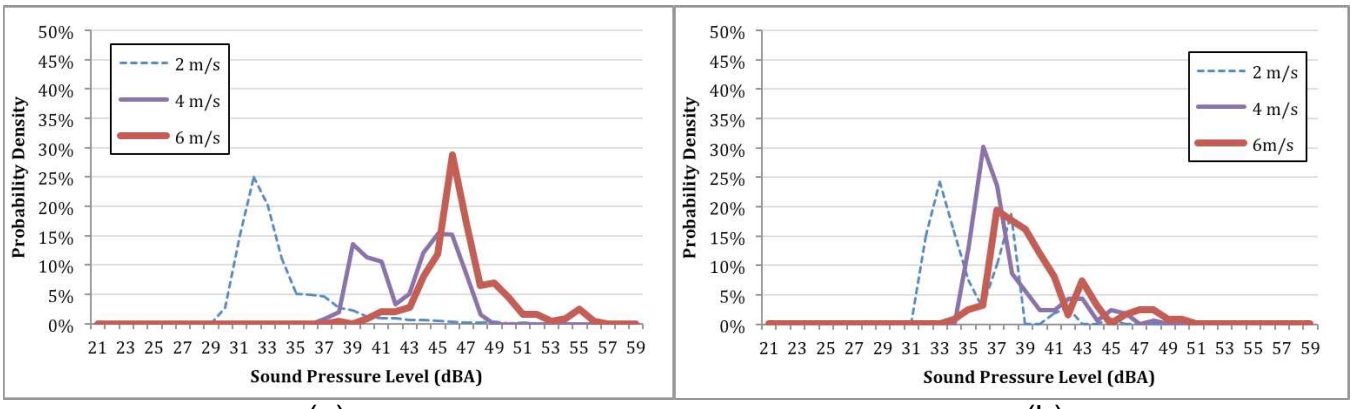
This approach provided regulatory bodies a simple way to assess whether the mean LAeq is within the applicable sound level limit. What it lacks is a good indication of the probability distribution within the data. The standard deviation gives an indication of the spread, but has some inherent assumptions that may not necessarily be true. Probability distribution functions need not be normally distributed.

2. Methodology overview

2.1 Probability density at a given wind speed

The proposed methodology to provide more insight into the variation of both the ambient noise and turbine noise contribution starts with generating the probability density function for the gathered data set. Measurements are carried out with the turbines operating, and subsequently with the turbines in the vicinity parked.

For each wind bin, the probability density is tabulated. For the example case below, they have been tabulated in 1 dBA increments. Figure1 shows probability densities for wind speeds of 2, 4, and 6m/s for turbines ON and OFF. It should be noted that the example location was measured in the middle of a field at approximately 450m from the closest turbine.



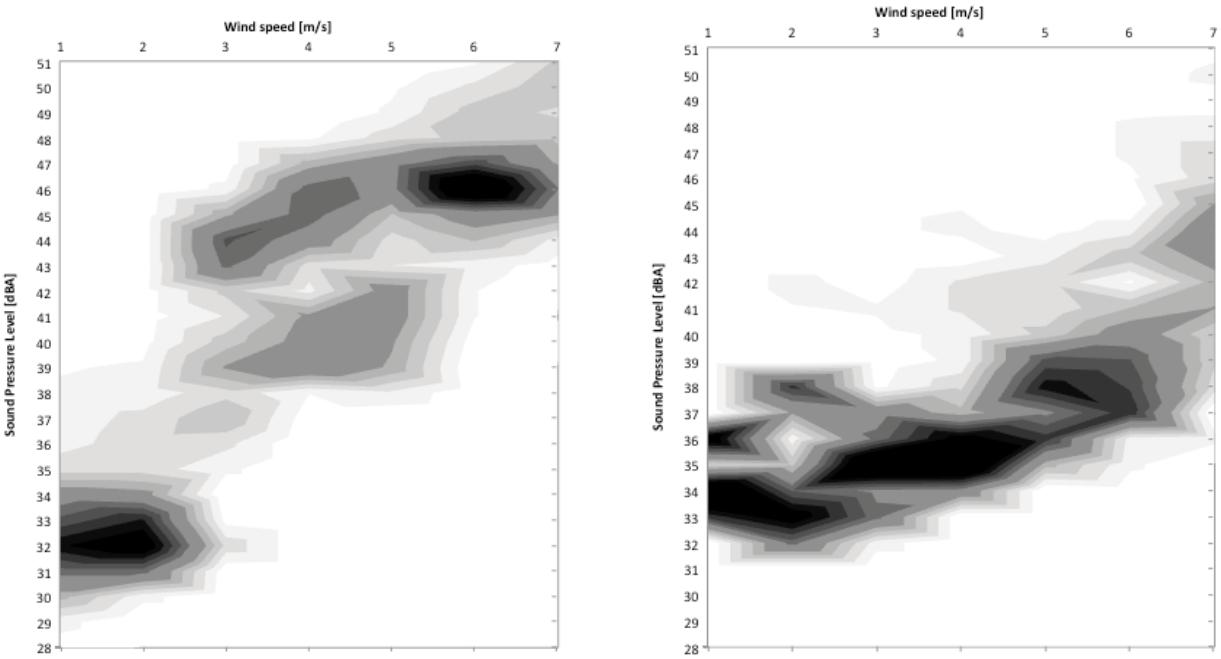
(a) (b)

Figure 1 (a) Probability density for sound pressure level measured with turbines ON
(b) Probability density for sound pressure level measured with turbines OFF

It can be seen from the figure above that, for example, at 6 m/s when the turbines are on, the sound pressure level has the highest probability at around 45dBA. Where as with the turbines OFF the highest probability is at around 37-39dBA. It can also be seen that the probability distribution is often not Gaussian. For example at 4m/s the turbine ON case shows 2 peaks: one at around 39dBA and another at 45dBA.

2.2 Probability density map

These probability density functions can be tabulated for each wind speed bin, and for both ON and OFF cases. Probability density maps can the be generated. Below are the maps for the same data set between 1 – 6m/s inclusive.



(a) (b)

Figure 2 (a) Probability map for sound pressure level measured with turbines ON
(b) Probability map for sound pressure level measured with turbines OFF

With this information one can see the variation in sound level measured both with and without the turbine facility operational. It should be noted that for the purposes of this analysis Turbine ON includes times where the wind was too low for the turbines to turn. It thus follows that at low wind speeds (below 3m/s) the ON and OFF data sets converge.

2.3 Reference sound pressure table

Given that a sufficient sample size is achieved, and that the turbine ON/OFF cases represent the same conditions with the exception of the existence of turbine noise, a method is devised for tabulating the discretized probability density for the turbine component at that measurement location.

First, a reference table is constructed by which a sound pressure level subtraction is tabulated. In Table 1 below, the column headings represent SPL_1, and the row headings represent SPL_2, and the individual entries represent $SPL_1 – SPL_2$ (logarithmically, of course). For example, if the level with the turbines ON (SPL1) was 39dBA and the level with the turbines OFF (SPL2) was 35, then the contribution of the turbines in that scenario was 37dBA. This example is highlighted in the table.

2.4 Combined probability table

A second table is then constructed that tabulates the probability of each permutation for a given wind speed. For example, a table is constructed for the 4m/s case. The columns would represent turbine ON levels, and the rows would represent turbine OFF levels. The individual entries would represent the probability of both occurring simultaneously based on the probability density maps developed for each case. Table 2 shows this constructed table for the 4m/s wind speed. In this case, one can see that there is a 4% probability that the Turbine ON level would be 39dBA and the turbine OFF level would be 35dBA. This value is obtained simply by multiplying the probability of each of the cases. A good check is ensuring that the sum of all the entries in the probability map adds to 100%.

Table 1: REFERENCE SPL CONTRIBUTION (SPL 1 - SPL2)

SPL 1

SPL 2 / dBA	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
20		14	18	20	22	23	25	26	27	28	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
21			15	19	21	23	24	26	27	28	29	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
22				16	20	22	24	25	27	28	29	30	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
23					17	21	23	25	26	28	29	30	31	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
24						18	22	24	26	27	29	30	31	32	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
25							19	23	25	27	28	30	31	32	33	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
26								20	24	26	28	29	31	32	33	34	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
27									21	25	27	29	30	32	33	34	35	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
28										22	26	28	30	31	33	34	35	36	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
29											23	27	29	31	32	34	35	36	37	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
30												24	28	30	32	33	35	36	37	38	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
31													25	29	31	33	34	36	37	38	39	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
32														26	30	32	34	35	37	38	39	40	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
33															27	31	33	35	36	38	39	40	41	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
34																28	32	34	36	37	39	40	41	42	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
35																	29	33	35	37	38	40	41	42	43	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
36																		30	34	36	38	39	41	42	43	44	46	47	48	49	50	51	52	53	54	55	56	57	58	59
37																			31	35	37	39	40	42	43	44	45	47	48	49	50	51	52	53	54	55	56	57	58	59
38																				32	36	38	40	41	43	44	45	46	48	49	50	51	52	53	54	55	56	57	58	59
39																					33	37	39	41	42	44	45	46	47	49	50	51	52	53	54	55	56	57	58	59
40																						34	38	40	42	43	45	46	47	48	50	51	52	53	54	55	56	57	58	59
41																							35	39	41	43	44	46	47	48	49	51	52	53	54	55	56	57	58	59
42																								36	40	42	44	45	47	48	49	50	52	53	54	55	56	57	58	59
43																									37	41	43	45	46	48	49	50	51	53	54	55	56	57	58	59
44																										38	42	44	46	47	49	50	51	52	54	55	56	57	58	59
45																											39	43	45	47	48	50	51	52	53	55	56	57	58	59
46																												40	44	46	48	49	51	52	53	54	56	57	58	59
47																													41	45	47	49	50	52	53	54	55	57	58	59
48																														42	46	48	50	51	53	54	55	56	58	59
49																															43	47	49	51	52	54	55	56	57	59
50																																44	48	50	52	53	55	56	57	58
51																																	45	49	51	53	54	56	57	58
52																																		46	50	52	54	55	57	58
53																																			47	51	53	55	56	58
54																																				48	52	54	56	57
55																																					49	53	55	57
56																																						50	54	56
57																																							51	55
58																																								52
59																																								

Table 2: probability @ 4 m/s

TURBINE ON LEVEL

TURBINE OFF LEVEL dBA	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
20																																								
21		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
22		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
23		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
24		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
25		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
26		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
27		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
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32		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
33		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
34		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	1%	1%	0%	1%	2%	2%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
35		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	4%	3%	3%	1%	2%	4%	5%	5%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
36		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	3%	2%	1%	1%	3%	4%	4%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
37		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	0%	0%	1%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
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39		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
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41		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
42		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	1%	1%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
43		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
44		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
45		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
46		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
47		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
48		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
49		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
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51		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
52		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
53		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
54		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
55		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
56		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
57		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
58		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
59		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

2.5 Turbine component probability density function

Once both these tables have been constructed for each wind speed, a probability density function can be obtained for the turbine component. Starting at the lowest discretized sound pressure level (in this case 21dBA), one can sum the probabilities of all the instances where the turbine component results in the sound level of interest. For example, in order to determine the probability of the turbine component being 38dBA, one would find all the instances in reference table 1 where the resulting component is 38, and add the corresponding probability from that same entry in Table 2. The sum, in this case would be 7.1%. This means that the probability of the turbine component being 38dBA is 7.1%. One can then repeat this process for each discrete sound pressure level. Once complete, the result is a discrete probability density function for the turbine component at that given wind speed. Figure 3 shows the probability density function for the turbine component at 2m/s, 4m/s, and 6m/s for comparison with Figure 1.

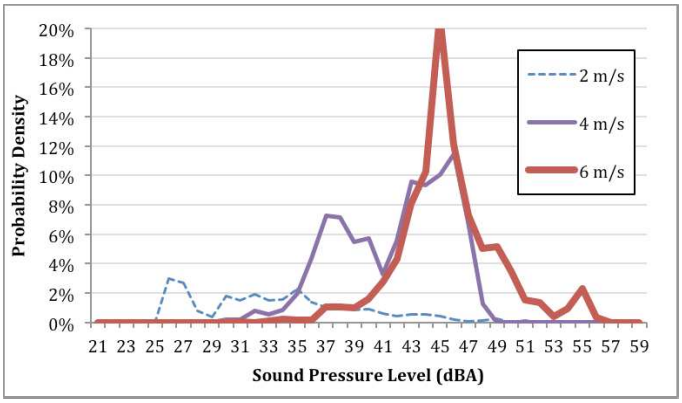

Figure 3 Probability density for sound pressure level contribution from turbines

Note that for 2m/s the turbine component does not have a strong component at any sound pressure level. At 4 and 6 m/s a strong component at 45dBA is discernable.

2.6 Turbine component probability map

As with the previous sets, one can construct a probability map for the turbine component to get a better picture of noise component at different wind speeds. Figure 4 below is the probability component for the turbine component only.

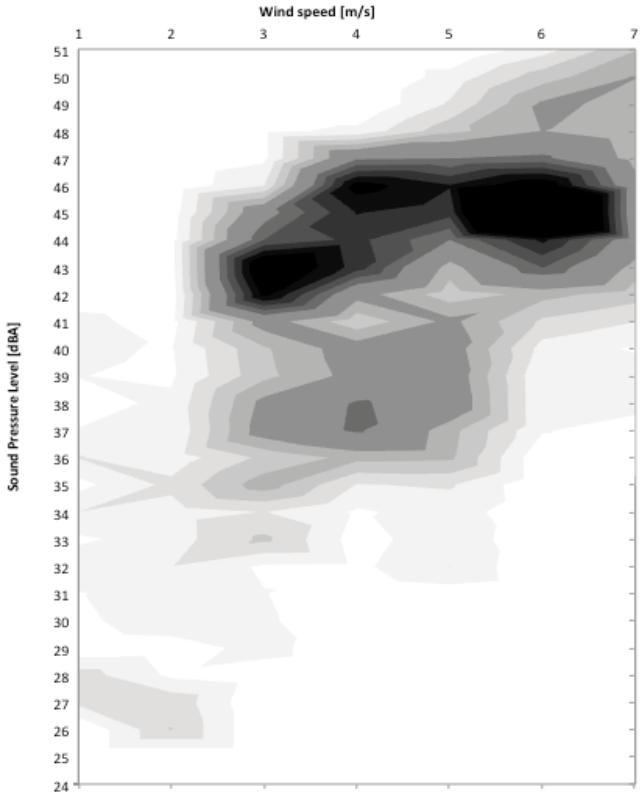

Figure 4 Probability map for turbine component. It can be seen that at 2m/s and below the turbines are probably not turning, and that by 4m/s (10m reference) they have probably reached maximum sound emission

3 Discussion

The analysis method presented in this paper aims to provide a more detailed statistical picture of the noise environment near wind facilities. This methodology can be applied to any noise source. The variation in ambient conditions and propagation conditions is too often overlooked or over simplified. Performing detailed statistical analysis gives an appreciation for the variation in noise levels already present, as well as the variation is sound emission levels.

Also it should be noted that the results of this analysis are not those of deterministic cases. That is to say, we cannot conclude that for, say, 30% of the time, the turbine component was at 45dBA. Instead, we would conclude that the probability of the turbine component being 45dBA is 30%. Although subtle, the distinction is important to make.

From a regulatory standpoint, this type analysis enables a sound level limit to be enforced with consideration of variability. For example, the if the exceedance above the limit had a probability of less than 10% it could be considered a minor or infrequent exceedence. Additionally, from the operator’s point of view, if the conditions of non-compliance are known in such detail mitigation measures could be developed to address those specific conditions.