A review of the use of different noise prediction models for windfarms and the effects of meteorology

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As a result of involvement in a specific wind farm development at Guestwick, Norfolk and a requirement to determine the efficacy of competing noise prediction models a review of the potential impacts of a six-turbine wind farm was carried out. The paper considers the results of comparing three specific noise prediction methods and algorithms and determines the extent to which adherence to either one of the methodologies could result in relatively large differences in predicted noise levels under varying wind conditions and accordingly the potential for differing conclusions being reached as to the acceptability of the wind farm with respect to the ETSU-R-97 assessment methodology. The paper also examines other noise modelling research carried out on behalf of ETSU.

1 Introduction

A recent wind farm development proposed at Guestwick, Norfolk for six wind turbines resulted in the use of three different noise prediction models and algorithms being used by the various consultants involved in the project through the Environmental Statement stage and up to the Public Inquiry. The use of the different methodologies resulted in relatively large differences in predicted noise levels under different wind conditions and accordingly the potential for different conclusions with respect to the ETSU-R-97 assessment methodology. ETSU-R-97 is silent on an approved approach to noise predictions. This paper examines the differences between the models and considers the efficacy of an agreed approach to modelling in order to ensure that consistent decisions are made at Public Inquiry. The paper also considers previous research on the subject.

2 The ETSU-R-97 'The Assessment and Rating of Noise from Wind Farms'

The ETSU-R-97 Document 'The Assessment and Rating of Noise from Wind Farms' is the approved document for the assessment of wind farms as referenced in **Planning Policy Statement 22 - Renewable Energy** (PPS22). The Final Report was produced in 1996 and the recommendations of the Working Group on Noise from Wind Turbines (WGNWT) was that, generally, noise limits should be set relative to the existing background noise at the nearest noise-sensitive properties, subject to a fixed minimum limit, and that these limits should reflect the variation in both turbine source and background noise with wind speed. The wind speed range that should be considered ranges between the cut-in speeds for the turbines and up to 12m/s with wind speeds being referenced to a 10 metre measurement height.

The predicted wind farm noise level is compared with the identified wind farm noise limit for the particular residential property and the assessment completed accordingly.

It is recommended that noise limits should be applied to external locations used for relaxation or where a quiet environment is highly desirable. These limits should be set relative to background noise and should reflect the variation in both turbine source noise and background noise with wind speed. It is not, however necessary to use a margin above background in particularly quiet areas as such low limits are not necessary in order to offer a reasonable degree of protection to wind farm neighbours.

Separate noise limits apply for day-time and for night-time as during the night the protection of external amenity becomes less important and the emphasis should be on preventing sleep disturbance. For day-time hours, the suggested noise limits are 35-40 dB(A) or 5dB(A) above the prevailing background. In practice most consultants apply the lower limit as any other consideration would be judgmental and would result in even more protracted discussions at Public Inquiry.

For night-time periods the recommended noise limit is 43 dB(A) or 5dB(A) above the prevailing background, whichever is the greater. The 43 dB(A) lower limit is based on a sleep disturbance criteria of 35 dB(A) with an allowance of 10dB(A) for attenuation through an open window and 2dB(A) subtracted to account for the use of LA90 rather the LAeq .

The suggested noise limits take into account the fact that all wind turbines exhibit the character of noise described as blade swish to a certain extent. The WGNWT recommended that a penalty should be added to the predicted noise levels, where any tonal component is present. The level of this penalty is described and is related to the level by which any tonal components exceed audibility. Most wind turbine manufacturers warrant their products such that the tonality correction as described in ETSU-R-97 should not need to be applied.

When wind speeds are high this is not always a problem since any noise may be masked by wind induced noise effects. At lower wind speeds, however, or in particularly sheltered locations, the wind induced background noise may not be sufficient to mask the noise from the turbines.

3 The Planning Context

3.1 Planning Policy Statement

During the planning process there was considerable debate about what method of impact assessment should be applied. The publication of the PPS22 and its Companion Guide (which provides more detail than the PPS) has at least ensured that the impact assessment method, even if flawed in part, is now done in a consistent way. The Companion Guide provides a general overview of the effects of noise from wind farms and the following paragraphs are relevant:

'41.Well-specified and well-designed wind farms should be located so that increases in ambient noise levels around noise-sensitive developments are kept to acceptable levels with relation to existing background noise………… Noise levels from turbines are generally low and, under most operating conditions, it is likely that turbine noise would be completely masked by wind-generated background noise.'

42. ………… Since the early 1990s there has been a significant reduction in the mechanical noise generated by wind turbines and it is now usually less than, or of a similar level to, the aerodynamic noise. Aerodynamic noise from wind turbines is generally unobtrusive – it is broad-band in nature and in this respect is similar to, for example, the noise of wind in trees.

43. Wind-generated background noise increases with wind speed, and at a faster rate than the wind turbine noise increases with wind speed. The difference between the noise of the wind farm and the background noise is therefore liable to be greatest at low wind speeds. Varying the speed of the turbines in such conditions can, if necessary, reduce the sound output from modern turbines.

44. The report, 'The Assessment and Rating of Noise from Wind Farms' (ETSU-R-97), describes a framework for the measurement of wind farm noise and gives indicative noise levels calculated to offer a reasonable degree of protection to wind farm neighbours, without placing unreasonable restrictions on wind farm development or adding unduly to the costs and administrative burdens on wind farm developers or planning authorities. The report presents the findings of a cross-interest Noise Working Group. This methodology overcomes some of the disadvantages of BS 4142 when assessing the noise effects of windfarms, and should be used by planning authorities when assessing and rating noise from wind energy developments (PPS22, paragraph 22).

4 Prediction of Noise

The assessment procedure for rating the impact of wind turbine noise (ETSU-R-97) relies upon a comparison of the predicted noise levels emitted from the wind farm and those background noise levels (LA90) which would occur at any specific receptor area as a result of increased wind speeds. As has previously been identified the ETSU document is silent on which noise model or set of algorithms should be used. Accordingly, a range of approaches are used by different acoustic consultants and these approaches to noise modelling range in the complexity and potentially the accuracy of the predicted noise levels.

It is accepted that downwind of a noise source the noise levels will be augmented depending on the wind speed, the direction of the wind and the distance to the receptor. This effect is often observed under adverse wind conditions when a specific noise source may be judged to be particularly loud on one day and not on another. It is therefore imperative that noise predictions should take account of the noise augmentation effects of wind.

At Guestwick the approach adopted by the consultant in their noise reporting for the Environmental Statement was to use a proprietary computer programme, known as Site Noise. Site Noise implements the procedures in BS 5228 and accordingly does not take account of meteorological conditions.

The reason that wind speed and direction are so important to predicted noise levels at this site is that the prevailing wind is from the south west quadrant resulting in turbine noise increasing for those receptors to the east of the proposed site. The site layout is shown in Figure 1 below:

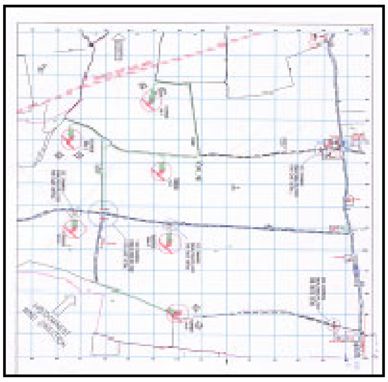

Figure 1: Wind Farm Site Layout

4.1 BS 5228: Part 1:1997 'Noise and vibration control on construction and open sites'

The BS 5228 does not take account of meteorological conditions, such as wind direction and temperature inversions. Figure 2 below details the distance attenuation utilized for the prediction methodology and it can readily be seen that the attenuation rate is a standard 6dB/doubling of distance where the ground effect is not taken into account.

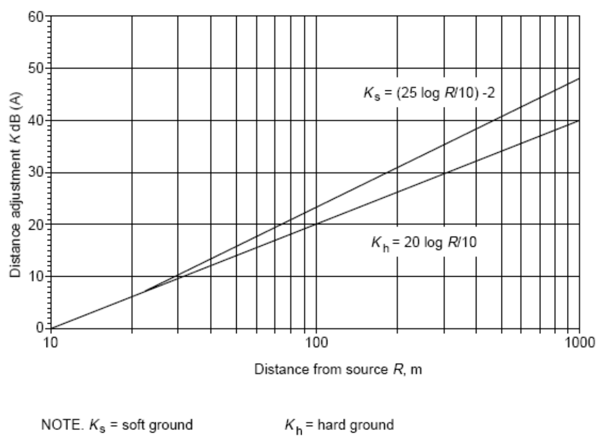

Figure 2: BS5229 distance adjustment

The implications of prevailing wind direction will need to be taken into account, when considering the likely environmental impact of a wind farm. The effect of prevailing wind will be to augment the noise to people living downwind of it and BS 5228 will not predict this. Meteorological records of wind speed and direction can provide a useful reference from which planning authorities may recommend that a fixed allowance of 2 dB(A) should be incorporated into predictive modelling, having first considered site-specific conditions, e.g. elevation, general topography, and natural or artificial wind shielding.

In the case of the predictions for windfarm noise provided for the windfarm development no wind effect was taken into account thus under predicting the potential noise impact of the development.

4.2 CONCAWE (Conservation of Clean Air and Water in Europe)

CONCAWE was established in 1963 by a small group of oil companies to carry out research on environmental issues relevant to the oil industry. In 1981 they published Report 4/81 'The Propagation of Noise from Petroleum and petrochemical Complexes to Neighbouring Communities.' That work had been extensively validated and has been utilised as the basis of a number of prediction models for a variety of noise sources including, industry, railway noise and gunfire, since its first publication.

The method requires that the sound pressure level at a remote point is calculated according to

$$Lp = Lw + D - \Sigma k$$

The directivity index is generally taken to be 0, where Σk is the sum of the individual attenuations due to seven mechanisms:

Geometric spreading

Atmospheric absorption

Ground effects

Meteorological effects

Source height effects

Barriers

In-plant screening

<u>Geometrical spreading</u>

This assumes spherical radiation from source and the reflection due to the ground surface is taken into account in the grounds effects.

<u>Atmospheric Absorption</u>

Values for atmospheric absorption are tabulated in the -CONCAWE report and it is recommended that the value of absorption corresponding to the lower 1/3 octave band should be used.

<u>Ground attenuation</u>

For acoustically hard surfaces, such as concrete the value for ground attenuation is -3dB effectively correcting geometrical spreading to be hemispherical radiation.

For soft ground the ground attenuation is obtained using the curves shown below.

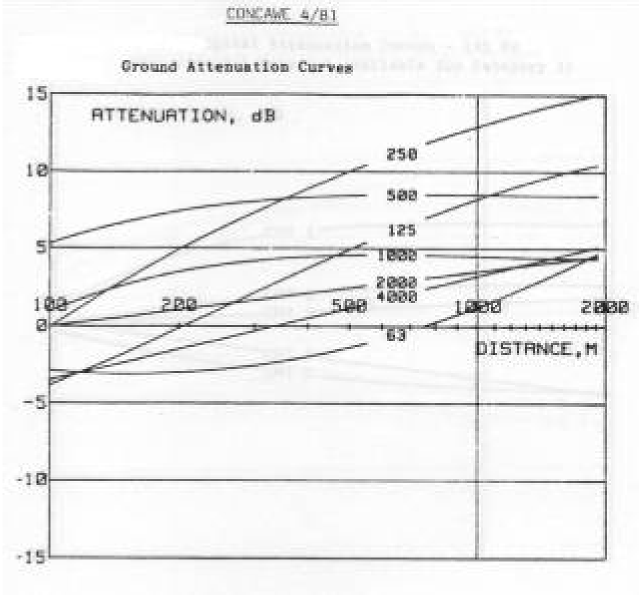

Figure 3: Ground attenuation curves

There are also a family of attenuation curves for the meteorological correction at different frequencies, an example of which is shown below in Figure 4.

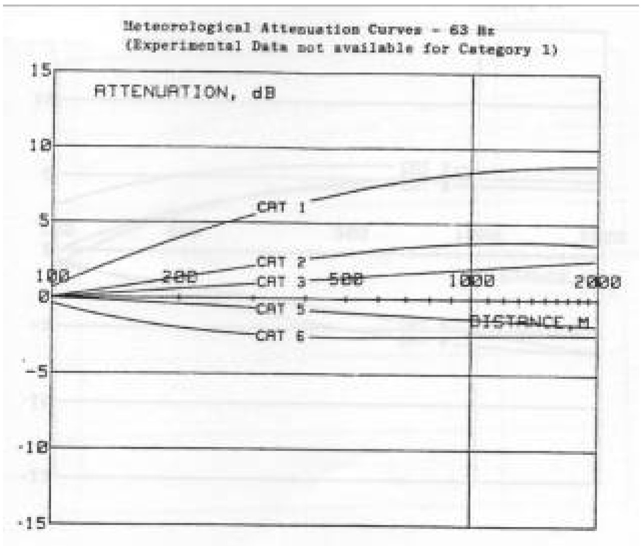

Figure 4: Meteorological attenuation curves

The categories defined as 1-6 include a range of meteorological categories which are further defined by the Pasquill Stability Factors shown in Tables 1 & 2 below.

Wind* Speed m/s	Day Time Incoming Solar Radiation mW/cm²				1 hour before Sunset or after Sunrise	Night Time Cloud Cover (octas)		
	> 60	30–60	< 30	Overcast		0–3	4–7	8
≤ 1.5	A	A–B	B	C	D	F or G**	F	D
2.0–2.5	A–B	B	C	C	D	F	E	D
3.0–4.5	B	B–C	C	C	D	E	D	D
5.0–6.0	C	C–D	D	D	D	D	D	D
> 6.0	D	D	D	D	D	D	D	D

* Wind speed is measured to the nearest 0.5 m/s.
** Category G is resticted to night-time with less thans 1 octa of cloud and a wind speed of less than 0.5 m/s.

Table1: Meteorological categories

Pasquill Stability Factors (A-G) as function of wind speed, time of day and cloud cover.

Meteorological Category	Pasquill Stability Category		
	A, B	C, D, E	F, G
1	$v < -3.0$	–	–
2	$-3.0 < v < -0.5$	$v < -3.0$	–
3	$-0.5 < v < +0.5$	$-3.0 < v < -0.5$	$v < -3.0$
4*	$+0.5 < v < +3.0$	$-0.5 < v < +0.5$	$-3.0 < v < -0.5$
5	$v > +3.0$	$+0.5 < v < +3.0$	$-0.5 < v < +0.5$
6	–	$v > +3.0$	$+0.5 < v < +3.0$

Decreasing Attenuation

* Category with assumed zero meteorological influence

Meteorological Categories (1-6) as function of wind speed and Pasquill Stability Factor.

Table2: Pasquill stability factors

4.3 ISO9613 Acoustics-'Attenuation of sound during propagation outdoors'

ISO 9613 consists of the following parts, under the general title above.

Part 1 - Calculation of the absorption of sound by the atmosphere

Part 2 – General method of calculation

Part 1 is a detailed treatment restricted to the attenuation by atmospheric absorption processes. Part 2 is a more approximate and empirical treatment of a wider subject – the attenuation by all physical mechanisms.

The standard specifies an engineering method for calculating the attenuation of sound during propagation outdoors in order to predict the levels of environmental noise at a distance from a variety of sources. The method predicts the equivalent continuous A-weighted sound pressure level under the meteorological conditions favourable to propagation from sources of known emission. These conditions are for downwind propagation or equivalently propagation under a well developed moderate ground based temperature inversion, such as commonly occurs at night. Inversion conditions over water surfaces are not covered and may result in higher sound pressure levels than predicted.

The method specified in ISO 9613-2 consists of octave band algorithms for calculating the attenuation of sound which originates from a point sound source, or an assembly of point sources. Specific terms are provided in the algorithms for the following physical terms:

Geometrical divergence;

Atmospheric absorption;

Ground effect;

Reflection from surfaces;

Screening by obstacles.

The following downwind propagation conditions for the method specified within ISO 9613-2 apply:

Wind direction within an angle of $\pm 45°$ of the direction connecting the centre of the dominant sound source and the centre of the specified receiver region, with the wind blowing from source to receiver,

Wind speed between approximately 1ms-1 and 5ms-1, measured at a height of 3m to 11m above the ground.

The meteorological correction (Cmet) is used to obtain a long term average A-weighted sound pressure level, where the period is several months. A value in decibels for Cmet is calculated using the term C0 (a factor in decibels which depends on local meteorological statistics for wind speed and direction, and temperature gradients) multiplied by terms including the height of both source and receiver and the distance between them as shown below:

$$C_{met} = C_0 \left[1 - 10(h_s + h_r)d_p\right]$$

if $d_p > 10(h_s + h_r)$

Where

h_s is the source height;

h_r is the receiver height;

d_p is the distance between source and receiver projected to the horizontal groundplane;

As stated in ISO 9613-2 'Experience indicates that values of C0 in practice are limited to the range from zero to approximately +5dB, and values in excess of 2dB are exceptional. Therefore only very elementary statistics of local meteorology are needed for a ± 1 dB accuracy'.

5 Predictions of noise levels for the wind turbine site

Comparing the noise predictions for a single receptor position located downwind of the proposed wind turbine site provided a range of noise levels under varying wind speeds. It can seen by reference to Table 3 that the difference in predicted noise levels occurs over a range of about 9 – 11.5 dB(A). The disparity in predicted noise levels could have a very significant impact on the efficacy of decisions made about specific wind farm developments.

Prediction source	Wind speed		
	6 m/s	8m/s	10m/s
BS5228	40.4	42.8	44.0
ISO 9613-2	43.4	46.1	49.7
CONCAWE	49.8	53.5	55.5

Table3: Predicted Noise Levels

6 Previous research work

Recognising that a specific difficulty standing in the way of many wind farm developments is the adverse effects of noise, ETSU managed a research programme on behalf of the DTI to provide 'A Critical Appraisal of Wind Farm Noise Propagation'. That appraisal utilised measurements of noise over distances up to about 1000 metres and compared the results against a number of noise prediction methods. Of particular interest is the comparison of results over flat terrain sites. The results are illustrated in the Figures 5 & 6 below which are taken directly from the research report.

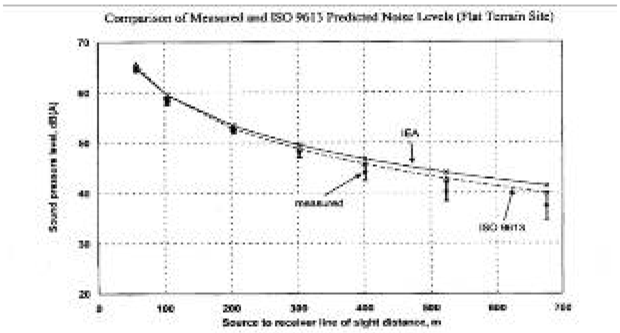

Figure 5: Comparison of measured and ISO 9613 predicted noise levels

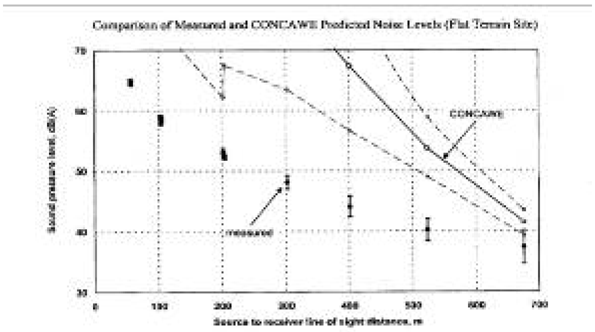

Figure 4: Comparison of measured and predicted CONCAWE noise levels

It can be seen that for those noise measurements carried out as part of the study the ISO 9613 methodology appears to provide the greatest confidence in predicting actual noise levels, although it should also be noted that the CONCAWE method converges towards the actual measured noise levels for distances approaching 700 metres. The 700 metre distance is often approximately the distance between the closest residential property and the closest wind turbine and this was the case for the Guestwick windfarm proposal.

7 Other effects

There are a number of other effects which are important in the consideration of the noise impact of windfarms. A research study by GP van den Berg of the University of Groningen, Holland, has reported that at night the wind speed at hub height could be up to 2.6 times higher than expected, resulting in noise levels 15dB higher than expected relative to the same reference wind speed in the daytime. It is reported that these high rotational speeds often result in a 'thumping' noise which is likely to result in increased annoyance. Accordingly, where good meteorological data is available it is possible to utilise the day and night-time wind profiles to more accurately predict the output noise from the turbines and to consider the way in which noise levels may be increased .

8 Conclusions

We conclude that despite the many studies which have been carried out within the UK and internationally to provide a more accurate method of predicting noise from wind turbines there are still too many differing approaches being adopted. There is still an urgent need to carry out further research to provide an agreed prediction methodology and this should be Government or European funded research in order to ensure that any approved methodology is robust and no debate about bias should ensue.

Acknowledgments

The author acknowledges the assistance provided by Andrew Ryan and Nick Hawkins in respect of the research and analysis of data carried out for the original project work.

References

[1] ETSU-R-97 Document 'The Assessment and Rating of Noise from Wind Farms' DTI, Sept 1996

[2] CONCAWE 'The Propagation of Noise from Petroleum and petrochemical Complexes to Neighbouring Communities.' Report 4/81,1981

[3] ISO9613 Acoustics-'Attenuation of sound during propagation outdoors'

[4] A Critical Appraisal of Wind Farm Noise Propagation'

[5] GP van den Berg of the University of Groningen, Holland