



SHAFTON TWO GATES WIND TURBINE

NOISE ASSESSMENT

Acoustics Report A572 R03

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Report to:

Engena Limited
The Old Stables
Bosmere Hall
CREETING ST MARY
IP6 8LL

Attention: John Fairlie

Prepared by:

Gavin Irvine BSc (Hons) MIOA

Checked by:

David O'Neill CEng, MSc, BEng, MIOA

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1 Introduction

This report describes the noise impact of a proposed single wind turbine on former mining land between Cudworth, Grimethorpe and Shafton Two Gates, South Yorkshire. The noise assessment has been carried out according to the requirements of the Energy Technology Support Unit (ETSU) report ETSU-R-97¹. The ETSU guidance advises on noise limits for wind turbines which are thought to *"offer a reasonable degree of protection to wind farm neighbours, without placing unreasonable restrictions on wind farm development"*.

For this scheme, which comprises a single turbine, the ETSU-R-97 simplified noise limit of 35 dB L_{A90} is appropriate. ETSU-R-97 states that *"if the noise is limited to an $L_{A90,10min}$ of 35dB(A) up to wind speeds of 10m/s at 10m height, then this condition alone would offer sufficient protection of amenity and background noise surveys would be unnecessary"*.

Noise predictions are presented here based on manufacturer's data for an EWT DW54 500kW wind turbine with a hub height of 50 metres (77m to blade tip). In addition to the operational noise assessed in this report, there will be a short-term noise impact from the construction of the wind turbine. This is not considered here as any construction noise generally occurs during the daytime and is short-term in nature.

A noise contour plot is presented in Figure 1. This shows noise levels at a wind speed of 10 m/s at 10m height for downwind conditions. These represent the worst case in terms of sound propagation. Figure 1 also shows the locations of nearby residential properties. A series of appendices provides further information on the data and methodology used in this assessment including a glossary of noise terms in Appendix A and an explanation of the ISO 9613-2 calculation parameters in Appendix B. This report has been prepared by Ion Acoustics Ltd for Engena Ltd.

2 Noise from Wind Turbines

Wind turbines are not noisy in absolute terms. It is possible to stand at the base of a turbine tower and hold a normal conversation. The proposed Shafton Two Gates Wind Turbine is far from residential properties and the noise level at the closest residential property is predicted to be around 34 dB L_{A90} under downwind conditions. This is put into context in Table 1 below and by reference to the National Noise Incidence Survey² carried out in 2000 / 2001 which indicated that 54% of the population were exposed to daytime noise levels at, or above, 55 dB $L_{Aeq, 16hour}$ and 67% of the population were exposed to night-time noise levels exceeding 45 dB $L_{Aeq, 8hour}$.

For these people, wind turbine noise would rarely be audible. However in the countryside and away from busy roads, there may be little other noise to mask the noise of wind turbines and in these circumstances, noise must be controlled to protect amenity. A description of various noise parameters such as L_{A90} and L_{Aeq} is provided in Appendix A.

1 ETSU-R-97 The Assessment and Rating of Noise from Wind Farms. ETSU for the Department of Trade and Industry (1996). Available online from: <http://www.berr.gov.uk/files/file20433.pdf>

2 "The National Noise Incidence Study 2000/2001 (United Kingdom): Volume 1 – Noise Levels" BRE Client report number 206344f

Table 1 – Noise from wind farms compared with other sources

Source/Activity	Indicative noise level dB (A)
Threshold of pain	120 - 140
Jet aircraft at 250 m	105
Pneumatic drill at 7m	95
Truck at 30 mph at 100 m	65
Busy general office	50 - 60
Car at 40 mph at 100 m	55
Wind farm at 500 m	35 – 45
Quiet bedroom	20
Rural night-time background	20 – 40
Threshold of hearing	0

Wind turbine noise comprises: aerodynamic noise from the turbine blades interacting with the wind and mechanical noise from the gearbox (if present) and generator. Over recent years, turbine manufacturers have succeeded in substantially reducing the mechanical noise sources so that for most modern turbines, aerodynamic noise predominates. Aerodynamic noise is characterised as a broadband sound not unlike wind blowing through trees, but modulated by a regular swishing sound. As the distance from the turbines increases, the swishing becomes less prominent.

The proposed EWT DW54 500kW wind turbine will 'cut-in' and start producing power at a hub height wind speed of approximately 2.5 m/s. The turbine has no gearbox and therefore the rotational speed can vary from around 12 to 28 rpm. The noise and power output increases with increasing wind speed until the rated power is reached at a wind speed of about 10 m/s. Above this, noise levels flatten off and there is little or no increase with wind speed as the turbine blades are pitched to shed energy and maintain the rated electrical power. To prevent damage, the turbine will shut down when the average wind speed exceeds 25 m/s at hub height.

3 Planning Guidance

3.1 National Planning Policy Framework

In March 2012, many previous Planning Policy Statements and Guidance notes were replaced with a single streamlined document entitled the National Planning Policy Framework (NPPF)³. This sets out an overall presumption in favour of sustainable development. In terms of noise impact, it states that planning policies and decisions should aim to:

- *"avoid noise from giving rise to significant adverse impacts on health and quality of life as a result of new development;*
- *mitigate and reduce to a minimum other adverse impacts on health and quality of life arising from noise from new development, including through the use of conditions;*

3 National Planning Policy Framework 2012 Department for Communities and Local Government. Available at: <http://www.communities.gov.uk/publications/planningandbuilding/nppf>

- *recognise that development will often create some noise and existing businesses wanting to develop in continuance of their business should not have unreasonable restrictions put on them because of changes in nearby land uses since they were established; and*
- *identify and protect areas of tranquillity which have remained relatively undisturbed by noise and are prized for their recreational and amenity value for this reason."*

In terms of climate change, the document states that local planning authorities should recognise the responsibility on all communities to contribute to energy generation from renewable or low carbon sources and *"design their policies to maximise renewable and low carbon energy development while ensuring that adverse impacts are addressed satisfactorily"*. A footnote in this section then states:

"In assessing the likely impacts of potential wind energy development when identifying suitable areas, and in determining planning applications for such development, planning authorities should follow the approach set out in the National Policy Statement for Renewable Energy Infrastructure".

3.2 National Policy Statement for Renewable Energy Infrastructure (NPS EN-3)

The National Policy Statement for Renewable Energy Infrastructure⁴ provides specific guidance on assessing noise from onshore wind farms. This document states:

"The method of assessing the impact of noise from a wind farm on nearby residents is described in the report, 'The Assessment and Rating of Noise from Wind Farms' (ETSU-R-97). This was produced by the Working Group on Noise from Wind Turbines Final Report, September 1996 and the report recommends noise limits that seek to protect the amenity of wind farm neighbours. The noise levels recommended by ETSU-R-97 are determined by a combination of absolute noise limits and noise limits relative to the existing background noise levels around the site at different wind speeds. Therefore noise limits will often influence the separation of wind turbines from residential properties.

The applicant's assessment of noise from the operation of the wind turbines should use ETSU-R-97, taking account of the latest industry good practice. This should include any guidance on best practice that the Government may from time to time publish."

In accordance with this document, and therefore current planning policy, the noise assessment has followed ETSU-R-97, taking into account industry good practice.

3.3 ETSU-R-97

ETSU Report ETSU-R-97 published in September 1996, was the result of deliberations of the Working Group on Noise from Wind Turbines, which was set up in 1993 by the Department of Trade and Industry to derive guidelines for assessing wind turbine noise. ETSU-R-97 is the recommended assessment method as stated in the National Policy Statement and the Government has reaffirmed that noise from wind farms should continue to be assessed according to the ETSU-R-97 guidance.

⁴ National Policy Statement for Renewable Energy Infrastructure (EN-3) Department for Energy and Climate Change July 2011. Available at: <http://www.decc.gov.uk/assets/decc/11/meeting-energy-demand/consents-planning/nps2011/1940-nps-renewable-energy-en3.pdf>

The ETSU limits are set in terms of the L_{A90} noise parameter. This is defined as the noise level exceeded for 90% of the measurement time. It is taken to represent the “background noise”, that is the underlying noise level in the absence of short-term events.

For single turbine (such as this one), or for remote sites a long way from residential properties, ETSU-R-97 reports the opinion of the noise working group that: *“if the noise is limited to an $L_{A90,10min}$ of 35dB(A) up to wind speeds of 10m/s at 10m height, then this condition alone would offer sufficient protection of amenity and background noise surveys would be unnecessary”*. Therefore, for this scheme, the proposed noise limit is 35 dB L_{A90} for wind speeds up to 10m/s at 10m height.

ETSU-R-97 allows for a higher limit where the residents are ‘financially involved’ with the wind turbine development. The suggested limit is 45 dB L_{A90} , or 5 dB above the background noise, whichever is the greater, for both the quiet day and night-time periods. However, in this case, noise levels are below 35 dB L_{A90} at all residential properties.

Where audible tones are present in the noise spectrum, ETSU-R-97 stipulates that a tonal penalty of up to 5dB be added to the predicted noise levels. The magnitude of the tonal penalty depends on the audibility of the tone. A tone is associated with the EWT DW54 500kW turbine at a wind speed of 5 m/s (only) at 10m height. According to EWT, the tone warrants a +2.5 dB penalty under the ETSU-R-97 rating system. Therefore the assessment includes a +2.5dB tonal penalty at a wind speed of 5 m/s. A statement regarding tonality is included in the manufacturer’s warranty in Appendix C.

3.4 The Acoustics Bulletin Article March / April 2009

The March / April 2009 issue of Acoustics Bulletin⁵, published by the Institute of Acoustics (IOA), included an article on wind turbine noise assessments authored by several noise consultants working on wind turbine developments for developers/applicants, local authorities and other groups. The purpose of the article was to agree various particulars to standardise noise assessments and avoid arguments at public inquiries. Following the recommendations of this article is an example of industry best practice referred to in the National Policy Statement guidance. The article clarified three main issues:

- That baseline noise measurements (where these are carried out) are preferably correlated with the derived wind speed at 10m height calculated using wind speed measurements at several heights, so that the readings are adjusted for the wind shear.
- ISO 9613-2 is to be used for wind turbine noise predictions, with certain stipulations and limitations. This is discussed below in Section 4 with supplementary information provided in Appendix B.
- Research into low frequency noise, infrasound and vibration was summarised, and it was concluded that none of these issues have had adverse effects on wind turbine neighbours.

The article should be regarded as a refinement of the ETSU-R-97 guidance to ensure consistency and this noise assessment follows the guidelines stated therein. The article is not official IOA guidance. For brevity, it will be referred to as the Acoustics Bulletin article in this report.

⁵ Dick Bowdler et. al. Prediction and assessment of wind turbine noise – agreement about relevant factors for noise assessment from wind energy projects. Acoustics Bulletin Vol 34 No. 2 March / April 2009.

4 Noise Predictions

4.1 Methodology

ETSU-R-97 does not prescribe a calculation method for predicting wind turbine noise. This study has used the prediction method ISO 9613-2 'Attenuation of sound during propagation outdoors' with certain input parameters and limitations stipulated in the agreement between various noise consultants reported in the Acoustics Bulletin article described above.

The propagation model, described in Part 2 of the ISO 9613 Standard, allows noise levels to be predicted for short-term downwind conditions, i.e. for wind blowing from the proposed turbine towards the houses. This provides a worst-case scenario and when the wind is blowing in the opposite direction, noise levels will be significantly reduced from that predicted.

Noise from wind turbines is reduced by distance, atmospheric losses, screening effects and other "miscellaneous" losses. Noise levels can be increased or reduced by the interaction of the sound waves with the ground. The ISO propagation model calculates the predicted sound pressure level at a specified distance by taking the sound power level in octave frequency bands and subtracting a number of attenuation factors according to the various losses and the ground effect as described above. The noise level in each octave band can be represented by the equation:

$$\text{Predicted Noise Level } L_{90} = L_{W(\text{eq})} + D - A_{\text{geo}} - A_{\text{atm}} - A_{\text{gr}} - A_{\text{bar}} - A_{\text{misc}} - 2\text{dB}$$

Where $L_{W(\text{eq})}$ represents the turbine sound power level, D , a directivity correction and A_{geo} , A_{atm} etc, the attenuation factors. The predicted A-weighted octave band levels are then summed together to give the overall A-weighted predicted sound level, L_{Aeq} . The correction of 2dB is used to convert the L_{Aeq} levels, as used to describe the turbine sound power, to the L_{90} parameter, used in the ETSU assessment. Appendix B describes the attenuation factors and prediction method in more detail.

Computer noise modelling software (IMMI⁶) implementing the ISO9613-2 methodology described above has been used to predict downwind noise levels from the proposed turbine. The following input parameters have been used in line with the current agreed best practice described in the Acoustics Bulletin article.

- A 4m receiver height and mixed ground absorption ($G=0.5$);
- Ambient air temperature of 10°C and 70% relative humidity;
- Barrier attenuation limited to 2dB although no barrier attenuation is applicable in this case.

To carry out the modelling, the terrain information has been obtained from Ordnance Survey digital data at a 50m resolution and imported into the model.

4.2 Turbine Noise Levels

A candidate turbine for this site is an EWT DW 54 500kW wind turbine with a 50m hub height (77 to blade tip) located at Ordnance Survey grid reference 439954E, 408340N. The EWT data sheet (provided in Appendix C) states a maximum sound power level of 100.5 dB L_{WA} for this wind turbine. This includes a factor for uncertainty. The sound power levels and frequency spectra for wind speeds between 5 and 10 m/s are stated in Table 2 below.

Table 2 – Sound Power Levels for EWT DW 54 500kW Turbine

Wind Speed (m/s) at 10m Height	Overall Sound Power Level dB L _{WA(eq)}	A-Weighted Sound Power Levels dB L _{WA(eq)} at Octave Band Centre Frequencies, Hz							
		63	125	250	500	1k	2k	4k	8k
5	99.5*	80.8	87.0	93.4	94.8	92.4	89.7	85.1	75.5
6	98.0	79.4	85.5	92.0	93.4	90.9	88.1	82.8	73.8
7	99.0	79.2	86.8	93.0	94.4	92.0	89.3	83.5	74.2
8	100.0	80.5	88.1	93.8	95.3	93.2	90.4	84.2	74.0
9	100.5	81.6	89.1	94.3	95.5	93.7	91.0	84.3	72.8
10	100.5	82.7	88.8	94.1	95.4	94.0	91.5	84.6	72.8

* Sound Power Levels at 5 m/s include a +2.5 dB tonal penalty as advised by the manufacturer.

EWT do not provide sound power data for wind speeds lower than 5 m/s. However, the EWT turbine is a variable speed turbine with noise levels dependent on the rotational speed. At low wind speeds, the turbine will be rotating slowly with lower noise levels than those stated at 5 m/s. Noise levels at wind speeds above 10 m/s do not increase significantly as the rated power is achieved and the turbine blades are pitched to control the rotational speed.

For commercial reasons, it is not possible at this stage to definitively state which turbine will be selected for the development. If planning permission were to be granted, the final choice of turbine for this site will depend on many factors, not least the noise output. The selected turbine model will be required to meet the ETSU-R-97 simplified limit of 35 dB L_{A90} at all residential properties for wind speeds up to 10 m/s at 10m height.

4.3 Predicted Noise Levels

Downwind noise predictions have been carried out according to the ISO 9613-2 methodology described above. The predictions have been carried out as a noise contour plot shown in Figure 1. The nearest residential properties are those in Moorland Terrace, Cudworth south-west of the turbine. There are several houses at this location, and noise predictions have been made for the nearest house which is around 460 metres from the proposed turbine.

Predictions for this location and other nearby residential streets in Cudworth are also shown below in Table 3 for wind speeds between 5 and 10 m/s at 10m height. There are several houses in West View, Stanley Street and Birkwood Avenue; the nearest property in each case has been used for the noise predictions. The distances from the houses to the proposed turbine are also shown. The distances indicated in Table 3 are the calculated plan distances from the turbine location to the receptor locations.

It should be noted that predictions have been made assuming downwind propagation, which, for these locations, will not occur often since this will require north-easterly winds. Noise levels under upwind conditions are generally much lower, by as much as 10dB and therefore noise levels under the prevailing wind condition (assumed to be south-westerlies) will be much lower than indicated in Table 3 for most of the time. Therefore it is likely that traffic noise and other urban noise sources will dominate the noise climate at these locations. There are no nearby residential properties to the east or north-east of the turbine which will be affected by the prevailing south-westerly wind conditions.

Table 3 – Predicted Downwind Noise Levels

Name	Easting	Northing	Distance to Turbine (metres)	Wind Speeds (m/s) at 10m Height					
				5	6	7	8	9	10
				Noise Levels dB L _{A90}					
Moorland Terrace nearest house	439546	408118	464	32.9	31.4	32.4	33.4	33.9	33.9
West View nearest house	439407	408241	556	31.2	29.7	30.7	31.7	32.2	32.2
Stanley Street nearest house	439407	408069	610	30.2	28.7	29.7	30.7	31.2	31.2
Birkwood Avenue nearest house	439383	408113	615	30.2	28.7	29.7	30.7	31.2	31.2

ETSU-R-97 states that if turbine noise is limited to a level of 35 dB L_{A90} at wind speeds up to 10m/s at 10m height, then this is sufficiently low to protect amenity irrespective of the background noise level. From Table 3, it can be seen that noise levels do not exceed 34 dB L_{A90} at any residential location. Therefore there will be no significant noise impact from the turbine at any residential location, although it is possible that turbine noise may be occasionally audible under certain wind conditions and when background noise levels from other sources are otherwise low.

5 Other Operational Noise Issues

5.1 Vibration

Vibration from wind farms has been measured by extremely sensitive measurement equipment such as seismic arrays but in terms of human perception, measured vibration levels are well below perception thresholds even on the actual wind farm sites. There is, therefore, no impact from vibration as a result of this single wind turbine proposal.

5.2 Low Frequency Noise and Infrasound

DEFRA commissioned a study to investigate complaints of infrasound and low frequency noise causing adverse health effects⁷. Of the 126 operational wind farms (at the time of the study) there were five with reported complaints from low frequency noise. The Hayes McKenzie report concluded that measured wind turbine noise at infra-sound frequencies (<20 Hz) is well below recognized perception thresholds and that there is no evidence of infrasound below perception thresholds having any health effects. Low frequency noise (20 Hz – 250 Hz) from wind farms was measurable and sometimes just above audibility thresholds but was below the DEFRA night-time low frequency noise criterion and below other sources of low frequency noise such as traffic. There is no evidence of health effects arising from infrasound or low frequency noise generated by wind turbines. Of the five sites with low frequency noise complaints, the likely source of the noise was amplitude modulation (described below).

The Acoustics Bulletin from March / April 2009 article also concludes: *"From examination of reports of the studies ... and other reports widely available on internet sites, we conclude that there is no robust*

⁷ The Measurement of Low Frequency Noise at Three UK Wind Farms Hayes McKenzie for DTI (Now BERR) Contract Number: W/45/00656/00/00 Published 2006.

evidence that low frequency noise (including 'infrasound') or ground-borne vibration from wind farms, generally has adverse effects on wind farm neighbours."

5.3 Amplitude Modulation

In July 2007, the Salford University Report on Amplitude Modulation was published. Amplitude modulation is described as a low frequency sound which varies in amplitude at, or above the blade passage frequency of the wind turbines, typically at 1Hz. The term excess or other amplitude modulation is sometimes used to distinguish the low frequency amplitude modulation at residential distances from blade swish. Blade swish is also a form of amplitude modulation but is only apparent relatively close to the turbine.

The Salford study comprised a survey of local authorities to reveal the extent of the problem, a literature review and further detailed investigation of the complaint logs from four affected sites. The report concluded that the mechanism for amplitude modulation was not fully understood, nor could it be predicted. However, there were only four confirmed cases causing complaints, and overall, the level of complaints regarding wind turbine noise was low compared to other noise sources. Furthermore, of the four wind farms where amplitude modulation occurred, the complaints at three of the sites had either subsided or had been resolved with noise control procedures.

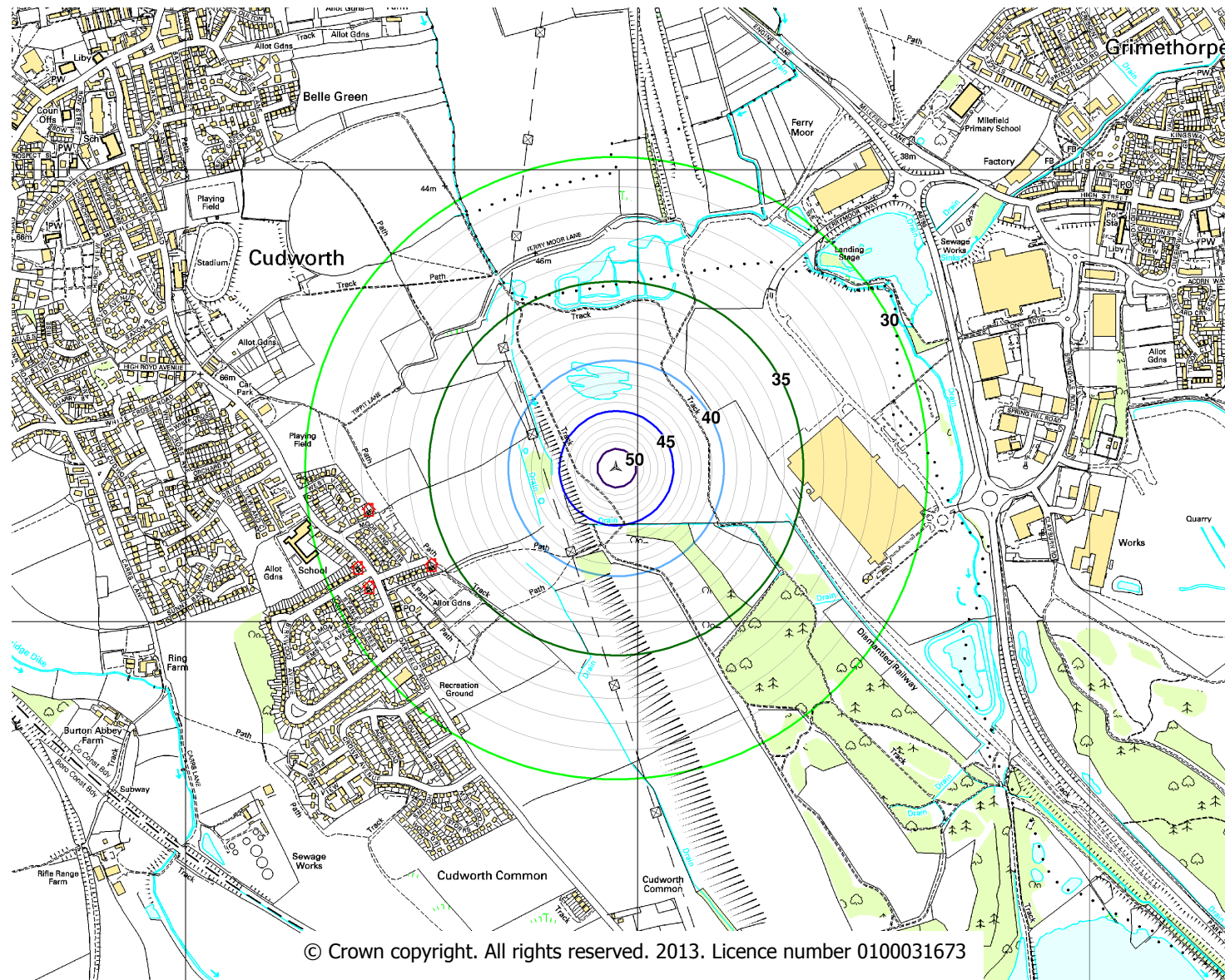
Following on from this report, the Government has stated that it did not consider there to be a need to assess this issue further, and the Government has confirmed ETSU-R-97 should continue to be used to assess noise from wind turbines. Given the number of operational wind turbines considered in the study, and the rarity of this problem, it is unlikely that excess amplitude modulation will occur at this site.

6 Conclusions

An assessment has been made of noise from a proposed single 500kW wind turbine on former mining land between Shafton Two Gates, Grimethorpe and Cudworth, South Yorkshire. The assessment has been carried out according to ETSU-R-97 which is the assessment method recommended in English planning advice. Predictions of the turbine noise have been carried out according to the agreed calculation method, ISO 9613-2, based on the candidate turbine, an EWT DW54 500kW turbine.

ETSU-R-97 states that "*if the noise is limited to an $L_{A90,10min}$ of 35dB(A) up to wind speeds of 10m/s at 10m height, then this condition alone would offer sufficient protection of amenity*". Predicted noise levels from the wind turbine do not exceed this level at any dwelling and are around 34 dB L_{A90} at the nearest residential locations. Therefore the simplified ETSU-R-97 limit is met at all residential locations. Noise from the wind turbine complies with all relevant guidance on noise and there is no reason to refuse this application on grounds of noise.

Figure 1 – Shafton Two Gates Wind Turbine Downwind Noise Contours dB L_{A90} at 10 m/s at 10m Height.



APPENDIX A – GLOSSARY OF NOISE TERMS

Decibel dB

Unit used to quantify sound pressure levels or noise levels. 0 dB is the approximate threshold of hearing and 120 – 140 dB is the threshold of pain. A decibel is a logarithmic quantity and for sound pressure is calculated relative to a reference sound pressure of 20 μ Pa. A change of 1 dB is just detectable under carefully controlled listening conditions.

A weighted decibel dB(A)

The dB(A) unit used to describe a sound pressure level with the frequency spectrum weighted to account for the sensitivity of human hearing at different frequencies. Human hearing is less sensitive at low and high frequencies and most sensitive at speech frequencies, typically 500 Hz to 2kHz. The dB(A) weighting better describes the subjective effect. A change of 3 dB(A) is typically the minimum noticeable difference for noises with a similar character. A change of 10 dB(A) is equivalent to a subjective doubling or halving of loudness. A-weighted noise levels are denoted by a suffix 'A' as in L_{Aeq} , L_{Amax} etc.

Hertz, Hz

Unit used to describe frequency of noise equivalent to the number of cycles per second. Human hearing is normally taken to extend from 20 Hz to 20,000 Hz but with reduced sensitivity at lower and higher frequencies (see dB(A) above). The 'Noise Spectrum' is the distribution of the noise across different frequency bands.

L_{A90} dB

The L_{A90} noise parameter is A-weighted noise level exceeded for 90% of the measurement period. This noise index is widely accepted as a descriptor of 'background' noise levels which is the underlying noise in the absence of short-term events. A "fast" time weighting is used unless stated otherwise.

$L_{Aeq,T}$ dB

The L_{Aeq} noise level is defined as the equivalent steady-state sound level over a specified measurement period with the same energy as the actual fluctuating noise over the same time period. This noise index is widely accepted as a descriptor of 'ambient' or average noise level. Note for wind turbine noise, the L_{Aeq} noise level is typically 2dB greater than the L_{A90} noise level. For other sources such as traffic, there is usually a greater variation.

Sound Power Level SWL or L_{WA} dB

The sound power level is the basic quantity describing the output of a noise source. Our ears hear sound *pressure* but a source emits sound *power*. It is a decibel unit relative to a reference level of 1×10^{-12} Watts or 1 picoWatt (1pW). Noise from wind turbines can be rated in terms of the sound power level. Note this is an energy average in that it is derived from L_{eq} measurements. The sound power in terms of the L_{90} parameter is 2dB less.

APPENDIX B – ISO 9613-2 CALCULATION PARAMETERS

The ISO 9613-2 method calculates the sound pressure level at a specified distance by taking the source sound power level for each turbine in octave frequency bands and subtracting a number of attenuation factors. The noise level in each octave band can be represented by the equation:

$$\text{Predicted Level } L_{90} = L_{w(\text{eq})} + D - A_{\text{geo}} - A_{\text{atm}} - A_{\text{gr}} - A_{\text{bar}} - A_{\text{misc}} - 2\text{dB}$$

The predicted octave band levels from each of the turbines are then summed together to give the overall 'A' weighted predicted sound level from all the turbines acting together. The correction of 2dB in the formula above is used to convert the L_{eq} levels, as used to describe the turbine sound power, to the background level L_{90} , used in the ETSU assessment. The various factors are now described in turn.

Source Data - $L_{w(\text{eq})}$

The sound power level of a noise source is normally expressed in dB re 1 pW (1×10^{-12} Watts). The predictions have been made using manufacturer's sound power data for an EWT DW 54 500kW turbine as detailed in the main report.

Directivity Factor - D

For some sources, a directivity factor, D, due to the source must be considered. However, for wind turbines, the sound power level is measured downwind and predicted in downwind conditions and therefore no directivity correction is necessary as any effect is inherent in the measurement. Therefore, D is taken as zero.

Geometrical Divergence (Distance Loss) - A_{geo}

Geometrical divergence is the name given to the distance loss which occurs as the source sound power is spread out over an increasing surface area as the distance from the source increases. This is the most significant loss associated with propagation and the loss rate is the same at all frequencies. A wind turbine is considered to be a point source and therefore there is a 6dB loss per doubling of distance. This is expressed mathematically according to:

$$A_{\text{geo}} = 20\log(d) + 11\text{dB}, \text{ where } d \text{ is the distance from the turbine, in metres.}$$

Atmosphere Attenuation - A_{atm}

Atmospheric losses occur as the energy in the sound wave is converted to heat. This is a frequency-dependent process and high frequencies are more readily attenuated than low frequencies. The losses are dependent on humidity and temperature and are represented by the following equation:

$$A_{\text{atm}} = d\alpha, \text{ where } d \text{ is distance from the turbine (in metres), and } \alpha \text{ is atmospheric absorption coefficient (dB/m).}$$

Part 1 of ISO 9613 provides tables with the values of α corresponding to various temperatures and humidity. The calculations take a conservative approach agreed between various wind farm noise consultants, assuming a temperature of 10°C and a relative humidity of 70% which gives low levels of atmospheric attenuation, as shown in the table below.

Atmospheric Absorption Coefficients at 10°C and 70% RH

Octave Band Centre Frequency (Hz)	63 Hz	125 Hz	250 Hz	500 Hz	1kHz	2kHz	4kHz	8kHz
Atmospheric Absorption Coefficient (dB/m)	0.0001	0.0004	0.001	0.0019	0.0037	0.0097	0.0328	0.117

It can be seen in the table that at low frequencies (63-125 Hz) atmospheric loss factors are very small compared with the values at higher frequencies. Over large distances, this has the effect of shifting the dominant sound of wind turbines downwards towards the lower frequencies.

Ground Effect - A_{gr}

This factor describes the effect of sound waves reflected off the ground interfering with the sound waves propagating directly from source to receiver. The prediction of ground effect depends on the source height, receiver height, and propagation distance between the source and receiver and the ground conditions.

The ground conditions are described according to a variable G which varies between 0 for "hard" ground (which includes paving, water, ice, concrete and any sites with low porosity) and 1 for "soft" ground (which includes ground covered by grass, crops, trees and other vegetation). For propagation close to soft ground, significant attenuation can occur, but this effect is diminished for an elevated source such as a wind turbine.

The predictions have been carried out using a source height corresponding to the proposed hub height and a receiver height of 4m which corresponds to the height of a 1st floor window. Mixed ground attenuation ($G = 0.5$) has been used which in accordance with the prediction method agreed between various consultants described in Acoustic Bulletin March / April 2009.

Barrier Attenuation - A_{bar}

When a source is not visible behind an impermeable element, a loss occurs as the sound waves are refracted around the barrier. A barrier could include screening by topographical features as well as other man-made objects such as fences and buildings. For wind farms, the ISO 9613-2 barrier attenuation factor has been shown to over-estimate the attenuation measured in practice under downwind conditions. The prediction method agreed between various wind farm noise consultants limits the barrier attenuation to 2dB.

Miscellaneous Losses - A_{misc}

Miscellaneous losses in the ISO 9613-2 calculation can be used to account for losses through propagation through trees and across housing and reflections off buildings. These losses are not considered in our calculations however. Reflections off buildings are not considered because in theory, the predictions (and baseline measurements as required by ETSU) are made in 'free-field' locations away from reflections.

APPENDIX C – MANUFACTURER’S NOISE DATA

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Sound power levels

The warranted sound power levels are presented with reference to IEC 61400-11:2002.

V _{wind} at 10m height	DW52	DW54
5 m/s	96,5 dB(A)	97,0 dB(A)
6 m/s	97,5 dB(A)	98,0 dB(A)
7 m/s	98,5 dB(A)	99,0 dB(A)
8 m/s	99,5 dB(A)	100,0 dB(A)
9 m/s	100,3 dB(A)	100,5 dB(A)
10 m/s	100,5 dB(A)	100,5 dB(A)

Sound power level L_w in dB(A)

The warranted sound power levels are based on actual measurements executed by an independent noise measurement institute according to the preferred methods set out in IEC-61400-11.

Uncertainty levels are included in the warranted sound power levels.

At 5m/s a maximum tonal noise penalty of 2,5dB shall be considered according to ETSU-R-97 guidelines.

The measured third octave sound power levels are available upon request.

The values given in the table are valid for normal operational mode (rotation speed 0-24 RPM)

The calculation of the standardized wind speed at 10m height according to IEC 61400-11 is based on a terrain roughness length $Z_0=0,05m$.

In case validation measurements have to be performed, they should be executed according to the preferred methods set out in IEC-61400-11 by an independent measurement institute which is accredited to ISO/IEC 17025 to conduct measurements of wind turbine noise emissions.

EWT reserves the right to make modifications or adjust settings in order to comply with the warranted sound power levels.