APPENDIX 19-1

OPERATIONAL AIRBORNE TURBINE NOISE ASSESSMENT

Sceirde Rocks.
Operational airborne turbine noise assessment.

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Audit sheet.

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Contents.

Executive Summary

Hoare Lea (HL) have been commissioned by Xodus Group Limited (Xodus) to undertake an assessment of airborne noise from the proposed wind turbines from the Sceirde Rocks Offshore Wind Farm. The report specifically considers the impact of airborne noise from the offshore turbines on onshore noise-sensitive residential receptors. Other impacts of the offshore turbines (such as on offshore receptors) have either been scoped out or are considered elsewhere.

Operational turbines emit noise from the rotating blades as they pass through the air. This noise can sometimes be described as having a regular 'swish'. The amount of noise emitted tends to vary depending on the wind speed. When there is little wind the turbine rotors will turn slowly and produce lower noise levels than during high winds when the turbine reaches its maximum output and maximum rotational speed. Background noise levels at nearby properties will also change with wind speed, increasing in level as wind speeds rise, due to wind in trees and around buildings, etc.

Noise levels from operation of the turbines have been predicted for onshore noise-sensitive properties potentially affected by noise, on the basis of worst-case assumptions: this included assuming a large turbine with relatively high noise emissions, with the wind blowing from the turbines towards the shore and the receptors considered. Account was taken of the potential for enhanced noise propagation which can occur over water.

Noise limits have been derived based on the assessment method stipulated in national planning guidance and accepted good practice, using noise measurements undertaken at representative receptors on the coastline. Predicted operational noise levels have been compared to the limit values to demonstrate that turbines of the type and size which would be installed can operate within the limits so derived. It is therefore concluded that operational noise levels from the wind farm will be within levels recommended in national guidance for wind energy schemes.

It is not recommended to consider post-construction onshore noise measurements of the operational noise from the offshore turbines, due to the practical difficulties involved with such measurements.

1. Introduction

1.1.1 This report presents an assessment of the potential operational noise impacts of the offshore turbines of the Sceirde Rocks Offshore Wind Farm (the Proposed Development) on the residents of onshore dwellings. Assessment of operational or construction impacts of the onshore components are considered elsewhere and are not part of the scope of the study.

1.1.2 The turbines would not be installed on the seabed using piled foundations and instead use a gravity-base system, with corresponding lower noise emissions compared with piled foundations. Given that these construction activities would not generate elevated noise levels and would be undertaken more than 3 km from the nearest noise-sensitive receptors, it is considered that the associated construction noise levels would be negligible and do not require further consideration.

1.1.3 The Proposed Development will include a substation which will be located within the wind turbine array at more than 6 km from the nearest noise-sensitive receptors and this is considered likely to represent negligible noise levels and does not require further consideration.

1.1.4 No other wind turbine developments are located in such proximity to the receptors considered such that significant cumulative operational noise impacts are likely and this is therefore also not considered further in the present assessment.

2. Policy and Guidance Documents

2.1 Planning Policy and Advice Relating to Noise – Ireland

2.1.1 The 2006 Wind Energy Development Guidelines (WEDG)[1] from the Department of the Environment, Heritage and Local Government (DoEHLG) include some recommendations on noise. They require that an appropriate balance is achieved between power generation and noise impacts.

2.1.2 The guidance essentially proposes limits of 45 dB(A) or 5 dB above the background, subject to lower limits of 35-40 dB(A) for day-time periods or 43 dB(A) at night, which may apply in low noise environments. The noise limits are defined in terms of the L_{A90} noise metric (defined in Annex A). Whilst subject to a degree of interpretation, these guidelines seem based on the ETSU-R-97 recommendations which apply in the UK and which are described in further detail below. These more detailed UK guidelines, and related good practice measures, will therefore be referenced when applying the (still extant) 2006 WEDG guidelines in the assessment of the proposed development.

2.2 Draft Ireland noise guidelines

2.2.1 The Department for Housing Local Government and Heritage (DHLGH) has been preparing a review of the 2006 WEDG, with draft guidelines submitted for consultation in December 2013. A "Preferred Draft Approach" was published in June 2017 by the DHPCLG. On noise, the preferred draft approach is described as:

> *'The "preferred draft approach" proposes noise restriction limits consistent with World Health Organisation standards, proposing a relative rated noise limit of 5dB(A) above existing background noise within the range of 35 to 43dB(A), with 43dB(A) being the maximum noise limit permitted, day or night.'*

2.2.2 In December 2019, revised Wind Energy Development Guidelines have been published in draft form. Although subject to some interpretation, they appear to suggest "rated noise limits" which are based on a noise limit which is 5 dB(A) above existing background noise but subject to lower and upper bounds of 35 and 43 dB(A) respectively. This would therefore make them consistent with the 2017 preferred

1 Wind Energy Development Guidelines (WEDG) from the Department of the Environment, Heritage and Local Government (DoEHLG), 2006.

approach set out above. The “rated” noise level refers to a metric based on adding penalties for Special Audible Characteristics (such as tonality) and these are discussed further in this report. However, the 2019 guidelines were published in draft form only at this stage.

2.3 Wind Farm Noise Guidance - UK

2.3.1 ETSU-R-97 represents current government policy in the UK for the assessment of wind farm noise. The basic aim of the ETSU Report, ETSU-R-97 'The Assessment and Rating of Noise from Wind Farms'[2], is to provide:

> *Indicative noise levels thought 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 local authorities.*

2.3.2 The report ETSU-R-97 makes it clear from the outset that any noise restrictions placed on a wind farm must balance the environmental effects of the wind farm against the national and global benefits which would arise through the development of renewable energy sources, stating:

> *‘The planning system must therefore seek to control the environmental impacts from a wind farm whilst at the same time recognising the national and global benefits that would arise through the development of renewable energy sources and not be so severe that wind farm development is unduly stifled.’*

2.3.3 Guidance on good practice on the application of ETSU-R-97 has been provided by the Institute of Acoustics (IOA Good Practice Guide or GPG)[3]. This was subsequently endorsed by the UK Government[4] as current industry good practice and will therefore be referenced in the present assessment.

2.3.4 The ETSU-R-97 assessment procedure specifies that noise limits should be set relative to existing background noise levels at the nearest properties and that these limits should reflect the variation in both turbine source noise and background noise with wind speed. The wind speed range which should be considered is between the cut-in speed (the speed at which the turbines begin to operate) for the turbines and 12 m/s (43.2 km/h), where all wind speeds are referenced to a ten metre measurement height (refer to Annex F for a discussion of how wind speeds are referenced to a ten metre height).

2.3.5 Separate noise limits apply for the day-time and night-time. Day-time limits are chosen to protect a property’s external amenity whilst outside their dwellings in garden areas and night-time limits are chosen to prevent sleep disturbance indoors. Absolute lower limits, different for day-time and night-time, are applied where the line of best-fit representation of the measured background noise levels equates to very low levels (< 30 dB(A) to 35 dB(A) for day-time, and < 38 dB(A) during the night).

2.3.6 The day-time noise limit is derived from background noise data measured during the ‘quiet periods of the day’: these comprise weekday evenings (18:00 to 23:00), Saturday afternoons and evenings (13:00 to 23:00) and all day and evening on Sundays (07:00 to 23:00). Multiple samples of ten-minute background noise levels using the $L_{A90,10min}$ measurement index are measured contiguously over a wide range of wind speed conditions (a definition of the $L_{A90,10min}$ index is given in Annex A). The measured noise levels are then plotted against the simultaneously measured wind speed data and a ‘best-fit’ curve is fitted to the data to establish the background noise level as a function of wind speed. The ETSU-R-97 day-time noise limit is then set to the greater of either: a level 5 dB(A) above the best-fit curve to the

2 ETSU-R-97, the Assessment and Rating of Noise from Wind Farms, Final Report for the Department of Trade & Industry, September 1996. The Working Group on Noise from Wind Turbines.

3 A Good Practice Guide to the Application of ETSU-R-97 for the Assessment and Rating of Wind Turbine Noise, M. Cand, R. Davis, C. Jordan, M. Hayes, R. Perkins, Institute of Acoustics, May 2013.

4 Letter from Secretary of State for the Department of Energy and Climate change, 20 May 2013.

background noise data over a 0-12 m/s wind speed range <u>or</u> a fixed level in the range 35 dB(A) to 40 dB(A).

2.3.7 The precise choice of the fixed lower limit within the range 35 dB(A) to 40 dB(A) under ETSU-R-97 depends on a number of site-specific factors: the number of noise-affected properties, the likely duration and level of exposure and the consequences of the choice on the potential power generating capability of the wind farm. This range will be considered in the assessment below.

2.3.8 The night-time noise limit is derived from background noise data measured during the night-time periods (23:00 to 07:00) with no differentiation being made between weekdays and weekends. The ten-minute $L_{A90,10min}$ noise levels measured over these night-time periods are again plotted against the concurrent wind speed data and a 'best-fit' correlation is established. As with the day-time limit, the ETSU-R-97 night-time noise limit is also set as the greater of: a level 5 dB(A) above the best-fit background curve <u>or</u> a fixed level of 43 dB(A). This fixed lower night-time limit of 43 dB(A) was set on the basis of World Health Organization (WHO) guidance[5] for the noise inside a bedroom and an assumed difference between outdoor and indoor noise levels with windows open. WHO guidelines were revised to suggest a lower internal noise level, but conversely, a higher assumed difference between outdoor and indoor noise levels.

2.3.9 The exception to the setting of both of these day-time and night-time lower fixed limits occurs in instances where a property occupier has a financial involvement in the wind farm development. Where this is the case then the lower fixed portion of the noise limit at that property may be increased to 45 dB(A) during both the day-time and the night-time periods alike.

2.3.10 ETSU-R-97 also offers an alternative simplified assessment methodology:

> *'For single turbines or wind farms with very large separation distances between the turbines and the nearest properties a simplified noise condition may be suitable. We are of the opinion 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. We feel that, even in sheltered areas when the wind speed exceeds 10m/s on the wind farm site, some additional background noise will be generated which will increase background levels at the property.'*

2.3.11 The noise limits defined in ETSU-R-97 relate to the total noise occurring at a dwelling due to the combined noise of all operational wind turbines. It is therefore necessary to consider the combined operational noise of the proposed development with other wind farms in the area to be satisfied that the combined cumulative noise levels are within the relevant criteria. ETSU-R-97 also requires that the baseline levels on which the noise limits are based do not include a contribution from any existing turbine noise, to prevent unreasonable cumulative increases.

2.3.12 It can therefore be concluded that the methodology and guidance within ETSU-R-97 is compatible with the 2006 WEDG but provides more detailed recommendations.

2.3.13 Note that in the above, and subsequently in this assessment, the term 'noise emission' relates to the sound power level actually radiated from each wind turbine, whereas the term 'noise immission' relates to the sound pressure level (the perceived noise) at any receptor location, due to the combined operation of all wind turbines.

2.4 Operational Noise Criteria

2.4.1 The acceptable limits for wind turbine operational noise are defined in the 2006 WEDG guideline document referenced above and these limits (defined below in section 3.4) should not be breached.

5 Environmental Health Criteria 12 – Noise. World Health Organisation, 1980.

2.4.2 Consequently, the test applied to operational noise is whether or not the calculated wind farm noise immission levels at nearby noise sensitive properties lie below these noise limits. Depending on the levels of background noise, the satisfaction of the derived noise limits can lead to a situation whereby, at some locations under some wind conditions and for a certain proportion of the time, the wind farm noise may be audible. However, noise levels at the properties in the vicinity of the proposed development must still be within levels considered acceptable under the applicable 2006 WEDG guidelines.

3. Baseline

3.1 General Description

3.1.1 The Proposed Development is located off a coastal area which is rural in nature, with isolated properties distant from villages and main settlements. The coastline is part of the Connemara region of County Galway.

3.1.2 The noise environment in the surrounding area is generally characterised by 'natural' sources, such as wind disturbed vegetation, birds, farm animals, and coastal water movements. Other sources of noise include intermittent local road and agricultural vehicle movements in the area.

3.2 Noise-sensitive properties considered

3.2.1 The assessment has considered operational noise from the Proposed Development at a selection of representative residential properties: these assessment locations are listed in Table 1 and shown on the map in Figure B1 in Annex B. Different groups of locations are set out in Table 1: these were considered representative of the closest properties on the shoreline of the islands or peninsulas of Ard, Mweenish and Mason, are detailed in Table 1. The list of receptor locations is therefore not intended to be exhaustive but sufficient to be representative of noise levels typical of those receptors closest to the Proposed Development.

3.2.2 Mason Island is understood to be generally uninhabited but includes some holiday cottages which are occasionally used for limited periods of time during the year. These would therefore potentially be considered less noise-sensitive but have been included in the study on a precautionary basis.

3.2.3 St MacDara's Island is not inhabited and has no residential properties but has occasional visitors because of the presence of a monastery on the island. It would therefore not normally be considered noise-sensitive in terms of the wind energy guidelines but will considered separately.

3.2.4 All of the residential properties considered are located approximately 5 km or more from the closest potential location of the offshore turbines of the Proposed Development, with locations on Mason Island approximately 4 km away.

Table 1 – Representative assessment properties considered at onshore locations nearest to the Proposed Development. Approximate Easting / Northing: Irish Transverse Mercator (ITM).

Property	Easting (ITM)	Northing (ITM)	Approximate Distance to Closest Turbine (m)	Closest turbine	Survey location (Table 2)
Mweenish 1	475960	729573	5560	T19	1
Mweenish 2	475623	729982	5530	T19	1
Mweenish 4	477082	728440	5530	T30	1
Mweenish 3	476947	728780	5660	T30	1

Property	Easting (ITM)	Northing (ITM)	Approximate Distance to Closest Turbine (m)	Closest turbine	Survey location (Table 2)
Ard 1	474642	730935	5520	T19	2
Ard 2	475352	730949	5990	T19	2
Ard 3	475595	730964	6170	T19	2
Ard 4	474041	731576	5580	T21	2
Lettermullan 1	482755	721411	10470	T30	n/a
Lettermullan 2	482899	721672	10520	T30	n/a
Lettermullan 3	483439	723768	10620	T30	n/a
Lettermullan 4	483018	725258	10160	T30	n/a
Aran 1	479086	711893	13820	T29	n/a
Aran 2	479410	712116	13800	T29	n/a
Mason 1*	474153	729437	4070	T19	2
Mason 2*	474040	729531	4060	T19	2
St MacDaras 1**	471725	730110	2970	T23	2
St MacDaras 2**	472044	729841	2980	T21	2
* Representing holiday cottages used occasionally. **Not residential					

3.3 Details of the Baseline Background Noise Survey

3.3.1 Two noise monitoring locations were installed at representative location by AWN Consulting Ltd[6] as being representative of the shoreline properties considered in Table 1 above. The locations are shown on Figure B2 in Annex B and listed in Table 2.

Table 2 – Background Noise Monitoring Locations (approximate Easting / Northing, Irish Transverse Mercator)

Reference	Location No.	Easting	Northing
NML 1	Location 1 – Mweenish	475610	729964
NML 2	Location 2 - Ard	474883	730847

3.3.2 The results obtained from both survey positions have been used to represent the background environment expected to occur at other nearby assessment locations, where relevant, as set out in Table 1. The use of the data in this way is justified by consideration of the terrain and the sources of background noise levels throughout the area. For properties located further away from the Proposed Development, such as those on Lettermullan, the simplified criteria of 35 dB L_{A90}, corresponding to the lowest limit defined in the WEDG guidelines or ETSU-R-97, was applied instead.

[6] Background noise surveys were completed by AWN Consulting Ltd with technical input from Hoare Lea.

3.3.3 The background noise monitoring exercise was conducted over the period 30/01/2024 to 19/02/2024. The equipment used for the survey comprised two Rion NL 52 logging sound level meters. All meters were enclosed in environmental cases with battery power and outdoor enhanced windshield systems were used to reduce wind induced noise on the microphones and provide protection from rain. These windshield systems were supplied by the sound level meter manufacturer and maintain the required performance of the whole measurement system when fitted. The environmental enclosures provided an installed microphone height of approximately 1.4 metres above ground level, consistent with the requirements of ETSU-R-97.

3.3.4 The sound level meters were located on side of the property facing the Proposed Development where possible, never closer than 3.5 metres from the façade of the property and as far away and screened as was practical from obvious atypical localised sources of noise such as running water, trees or boiler flues. A rain gauge was also installed at NML 1. Details and photographs of the measurement locations are presented in Annex C.

3.3.5 All measurement systems were calibrated on their deployment and upon collection of the equipment. No acoustically important (>0.4 dB(A)) drifts in calibration were found to have occurred on any of the systems. A total monitoring period of more than 2 weeks was obtained at each location, which is in excess of the minimum of one week suggested by ETSU-R-97 and is compliant with the IOA GPG requirements.

3.3.6 All measurement systems were set to log the $L_{A90,10min}$ and $L_{Aeq,10min}$ noise levels continuously over the deployment period. The internal clocks on the sound level meters were all synchronized with the wind data acquisition system described below.

3.4 Measured Background Noise Levels

3.4.1 The ETSU-R-97 assessment method requires noise data to be related to wind speed data at a standardised height of ten metres, with wind speeds either directly measured at a height of ten metres or by calculation from measurement at other heights, the appropriate choice being determined by practitioner judgement and the available data sources. Since the publication of ETSU-R-97, the change in wind speed with increasing height above ground level has been identified as a potential source of variability when carrying out wind farm noise assessments. The effect of site-specific wind shear can be appropriately addressed by implementing the ETSU-R-97 option of deriving ten metre height reference data from measurements made at taller heights. It is this method that has been used in the noise assessment for the Proposed Development to account for the potential effect of site-specific wind shear. This method is consistent with the preferred method described in the IOA GPG.

3.4.2 Wind speeds were measured using a LIDAR installed on a coastal location near the second monitoring location (approximate ITM Easting / Northing 475634 / 729990)). This coastal location was considered to provide a reasonable representation of winds which would be experienced by the turbines of the Proposed Development. Values of wind speed at a standardised height of ten metres were calculated from those measured on the LIDAR ("standardised wind speed") at elevated heights of 150 to 170 m which could be used to estimate wind speeds at the likely hub height of the turbines (190 m) which may be used for the Proposed Development. Full details of the calculation method are given in Annex F.

3.4.3 Figures D1 and D2 reproduced in Annex D show the range of wind conditions experienced during the noise survey period. During the quiet day-time and night-time periods wind speeds of up to 14 m/s were experienced. The strongest winds were observed to be directed mainly from the south-west over the survey period: this is considered representative of wind directions when the survey locations of Table 2 (and other nearby properties) would be downwind of the Proposed Development. In this context, winds blowing from the sea towards the land would be described as "onshore" winds. Some periods of north-east wind were experienced at times as well, but this would correspond to "offshore" wind conditions (*i.e.* winds blowing from the land towards the sea) which are less relevant to the assessment: as discussed below. The range of conditions and quantity of data obtained are in line with IOA GPG requirements.

3.4.4 Data from the survey locations were inspected to identify periods which may have been influenced by extraneous noise sources, giving rise to atypical and elevated levels. ETSU-R-97 requires that any data affected by rainfall be excluded from the analysis. Data from the rain gauge installed near one of the survey locations were therefore used to exclude those periods where rain was indicated in the area. There were no watercourse or roads influencing the noise environment at the survey location such that elevated noise would follow periods of rainfall.

3.4.5 The main influence on background noise levels was considered to be coastal water movements as well as wind around buildings and structures, which appears to be mainly influenced by the wind direction. Background noise levels were generally higher in onshore winds from the south-west, which corresponds to relevant conditions when the survey locations of Table 2 (and other nearby properties) would be downwind of the Proposed Development as discussed above. Therefore, periods of easterly winds coming from inland, although quieter, were excluded as not representative of conditions in which the noise from the offshore wind turbines could be experienced (see section 4.2 below).

3.4.6 Following removal of those data points, best fit lines were generated using a polynomial fit of a maximum of 2nd order. These lines of best fit were then used to derive the noise limits based on the applicable WEDG guidelines which apply during the day-time and night-time periods up to 12 m/s. The corresponding noise limits are summarised in Table 3 and Table 4. The noise limits have effectively been set at the prevailing measured background level plus 5 dB, as this was determined to be higher than the lower fixed limits which may apply based on the guidance set out in Section 2 of this report.

Table 3 – Day-time L_{A90} (dB) noise limits derived from the baseline noise survey.

Property	Standardised 10 m Wind Speed (m/s)											
	1	2	3	4	5	6	7	8	9	10	11	12
Location 1 – Mweenish	47.8	48.5	49.2	49.9	50.6	51.3	52.1	52.8	53.5	54.2	54.9	55.6
Location 2 - Ard	44.6	45.5	46.3	47.2	48.0	48.9	49.7	50.6	51.4	52.3	53.1	54.0

Table 4 – Night-time L_{A90} (dB) noise limits derived from the baseline noise survey.

Property	Standardised 10 m Wind Speed (m/s)											
	1	2	3	4	5	6	7	8	9	10	11	12
Location 1 – Mweenish	44.6	45.7	46.8	47.9	49.0	50.1	51.2	52.2	53.3	54.4	55.5	56.6
Location 2 - Ard	44.3	44.8	45.4	46.1	46.9	47.8	48.8	49.9	51.1	52.4	53.8	55.3

4. Operational noise assessment

4.1 Operational Wind Turbine Emissions Data

4.1.1 The exact model of turbine to be used at the site and their exact locations will be the result of a future detailed design and tendering process. Furthermore, the turbines considered could have a capacity of up to 21 MW, with a rotor diameter of 292 m. Wind turbines of this size and power are currently in development, therefore there is limited information available on their noise emissions and it is necessary to make some robust assumptions as part of this assessment, on a conservative basis.

4.1.2 The assessment in the present report was based the noise specification of the Siemens-Gamesa SG DD-236. The data provided is likely to be conservative, as it is likely to be estimated on the basis of calculated data, rather than detailed measurement, given that such turbines are unlikely to currently be at prototype stage. However, the data is thought to represent a worst-case interpretation of potential noise emissions levels for the type of turbine which may be installed for the Proposed Development.

4.1.3 A further +2 dB was added to the manufacturer data provided to obtain robust emission levels: this adjustment is recommended in the IOA GPG guidance in cases where no direct information is available on uncertainty in the data. The data was provided referenced to hub height wind speeds and corrected to a standardised 10 m wind speeds reference using the standard procedure of IEC 61400-11 based on a hub height of 190 m. The assumed sound power levels are up to 5 dB(A) noisier than those of a comparable model, a GE turbine of 18 MW with a rotor diameter of around 250 m. This is substantial considering it would require the acoustic energy to be about 3 times higher in magnitude. Therefore, the assessment is undertaken on a very conservative basis, in the absence of more definitive data at this stage.

4.1.4 In addition to the overall sound power data, reference has been made to the Siemens-Gamesa specification reports to derive a representative sound spectrum for the turbine. The resulting overall sound power and spectral data are presented in Table B2 and B3 in Annex B. Annex B also sets out the layout of 30 turbines which was modelled.

4.2 Choice of Wind Farm Operational Noise Propagation Model

4.2.1 The ISO 9613-2 model[7] has been used to calculate the noise immission levels at the selected nearest residential neighbours as advised in the IOA GPG. The model accounts for the attenuation due to geometric spreading, atmospheric absorption, and barrier and ground effects. All attenuation calculations have been made on an octave band basis and therefore account for the sound frequency characteristics of the turbines. All noise level predictions have been undertaken using a receiver height of four metres above local ground level and an air absorption based on a temperature of 10°C and 70% relative humidity. This follows the recommendations of the IOA GPG for noise predictions. Given that most of the propagation occurs offshore and given the nature of the onshore landscape, consideration of terrain screening effects was not included in the model.

4.2.2 All wind farm noise immission levels in this report are presented in terms of the L_{A90} noise indicator, in accordance with the recommendations of the ETSU-R-97 report, obtained by subtracting 2 dB(A) from the calculated L_{Aeq} noise levels, based on the sound power levels presented in Annex B.

4.2.3 As the proposed turbines are located offshore, propagation over water occurs and in that case a ground factor of G=0 was used (to represent acoustically reflective propagation). In addition, due to the wind speed profiles which can occur at sea, noise propagation can in some cases be enhanced compared with onshore propagation and does not reduce with distance as would normally be expected, due to the hemispherical spreading of sound. Several references[8,9,10] propose an additional factor of $+10\log(d/d_0)$ is added beyond a reference distance d_0: this represents the enhanced propagation corresponding to cylindrical rather than spherical spreading. Although the references cited above suggest d_0 values of 700 m to 1000 m, this is based on studies of sources of low height or using single

[7] ISO 9613-2:1996 'Acoustics – Attenuation of sound during propagation outdoors – Part 2: General method of calculation', International Standards Organisation, 1996.

[8] Institute of Acoustics Good Practice Guide, Supplementary Guidance Note 6, Noise Propagation Over Water for On-Shore Wind Turbines, July 2014.

[9] M. Boué (KTH/Vinforsk), Long-Range Sound Propagation Over the Sea with Application to Wind Turbine Noise, Final report for the Swedish Energy Agency project 21597-3.

[10] Swedish Environmental Protection Agency, Measuring and Calculating Sound from Wind Turbines, Guidance Document, June 2013.

frequencies of sound. It was considered, due to the height of the proposed source (with a typical hub height of 190 m), that this would be unrealistic.

4.2.4 Instead, additional corrections using the Danish BEK 135 prediction method[11] were used, as discussed below. This Danish method has been based on more complex propagation models, considers the height of the source and was validated through recent experimental studies.

4.2.5 In addition, a previous measurement study[9] points out that when the offshore noise propagation reaches the shore, reflection effects at the shoreline lead to reductions of typically 3 dB. Therefore, a further factor of 3 dB was considered at the sea-shore boundary.

4.2.6 Predictions have been made with the above assumptions of enhanced downwind propagation from all proposed offshore turbines to the onshore receptors at the same time as a worst case, which would therefore tend to occur in westerly winds. Under upwind propagation conditions between a given receiver and a given wind farm (offshore easterly winds), the noise immission levels at that receiver can be as much as 10 dB(A) to 15 dB(A) lower than these predictions.

4.3 Prediction and assessment of wind farm operational noise immission levels

4.3.1 Table 5 shows predicted noise immission levels from the proposed offshore turbines, on the basis of the assumptions discussed above, at each of the assessment locations of Table 1 for each wind speed over the range of wind speeds of up to 12 m/s. Table 6 then shows additional predictions which include a loss of 3 dB from likely reflections at the sea-shore boundary. The predictions of Table 5 are therefore considered relatively precautionary.

Table 5 - Predicted L_{A90} (dB) wind farm noise immission levels at each of the noise assessment locations as a function of standardised wind speed for the Proposed Development alone – precautionary basis.

Property	Standardised 10 m Wind Speed (m/s)									
	3	4	5	6	7	8	9	10	11	12
Mweenish 1	22.4	27.5	32.4	36.3	37.8	39.8	39.8	39.8	39.8	39.8
Mweenish 2	22.5	27.5	32.4	36.4	37.9	39.9	39.9	39.9	39.9	39.9
Mweenish 4	21.8	26.9	31.8	35.7	37.2	39.2	39.2	39.2	39.2	39.2
Mweenish 3	21.8	26.9	31.8	35.7	37.2	39.2	39.2	39.2	39.2	39.2
Ard 1	22.6	27.7	32.6	36.5	38.1	40.1	40.1	40.1	40.1	40.1
Ard 2	21.9	27.0	31.9	35.8	37.3	39.3	39.3	39.3	39.3	39.3
Ard 3	21.6	26.7	31.6	35.5	37.0	39.0	39.0	39.0	39.0	39.0
Ard 4	22.5	27.6	32.5	36.4	38.0	40.0	40.0	40.0	40.0	40.0
Lettermullan 1	16.6	21.7	26.6	30.5	32.0	34.0	34.0	34.0	34.0	34.0
Lettermullan 2	16.6	21.6	26.5	30.5	32.0	34.0	34.0	34.0	34.0	34.0
Lettermullan 3	16.5	21.5	26.4	30.4	31.9	33.9	33.9	33.9	33.9	33.9
Lettermullan 4	16.8	21.8	26.7	30.7	32.2	34.2	34.2	34.2	34.2	34.2
Aran 1	15.2	20.3	25.2	29.1	30.7	32.7	32.7	32.7	32.7	32.7
Aran 2	15.2	20.3	25.2	29.1	30.7	32.7	32.7	32.7	32.7	32.7
Mason 1	25.1	30.2	35.1	39.0	40.6	42.6	42.6	42.6	42.6	42.6
Mason 2	25.2	30.3	35.2	39.1	40.6	42.6	42.6	42.6	42.6	42.6
St MacDara's 1	27.9	33.0	37.9	41.8	43.3	45.3	45.3	45.3	45.3	45.3
St MacDara's 2	27.9	33.0	37.9	41.8	43.4	45.4	45.4	45.4	45.4	45.4

[11] BEK 135, 07/02/2019, Bekendtgørelse om Støj Fra Vindmøller (Executive Order on noise from wind turbines), Ministry of the Environment and Food, Denmark.

Table 6 - Predicted L_{A90} (dB) wind farm noise immission levels at each of the noise assessment locations as a function of standardised wind speed for the Proposed Development alone – including shoreline reflection loss of 3 dB.

Property	Standardised 10 m Wind Speed (m/s)									
	3	4	5	6	7	8	9	10	11	12
Mweenish 1	19.4	24.5	29.4	33.3	34.8	36.8	36.8	36.8	36.8	36.8
Mweenish 2	19.5	24.5	29.4	33.4	34.9	36.9	36.9	36.9	36.9	36.9
Mweenish 4	18.8	23.9	28.8	32.7	34.2	36.2	36.2	36.2	36.2	36.2
Mweenish 3	18.8	23.9	28.8	32.7	34.2	36.2	36.2	36.2	36.2	36.2
Ard 1	19.6	24.7	29.6	33.5	35.1	37.1	37.1	37.1	37.1	37.1
Ard 2	18.9	24.0	28.9	32.8	34.3	36.3	36.3	36.3	36.3	36.3
Ard 3	18.6	23.7	28.6	32.5	34.0	36.0	36.0	36.0	36.0	36.0
Ard 4	19.5	24.6	29.5	33.4	35.0	37.0	37.0	37.0	37.0	37.0
Lettermullan 1	13.6	18.7	23.6	27.5	29.0	31.0	31.0	31.0	31.0	31.0
Lettermullan 2	13.6	18.6	23.5	27.5	29.0	31.0	31.0	31.0	31.0	31.0
Lettermullan 3	13.5	18.5	23.4	27.4	28.9	30.9	30.9	30.9	30.9	30.9
Lettermullan 4	13.8	18.8	23.7	27.7	29.2	31.2	31.2	31.2	31.2	31.2
Aran 1	12.2	17.3	22.2	26.1	27.7	29.7	29.7	29.7	29.7	29.7
Aran 2	12.2	17.3	22.2	26.1	27.7	29.7	29.7	29.7	29.7	29.7
Mason 1	22.1	27.2	32.1	36.0	37.6	39.6	39.6	39.6	39.6	39.6
Mason 2	22.2	27.3	32.2	36.1	37.6	39.6	39.6	39.6	39.6	39.6
St MacDara's 1	24.9	30.0	34.9	38.8	40.3	42.3	42.3	42.3	42.3	42.3
St MacDara's 2	24.9	30.0	34.9	38.8	40.4	42.4	42.4	42.4	42.4	42.4

4.3.2 Figures E1 to E4 (Annex E) also show the calculated wind farm noise immission levels at a representative assessment location for the each of the two noise measurement locations. These correspond to the predictions of Tables 5 and 6 above, plotted as a function of standardised wind speed.

4.3.3 The precautionary predictions shown in Table 5 are below the lower threshold of 35 dB for receptors on Lettermullan and Aran, although actual levels are likely to be 3 dB lower as shown in Table 6.

4.3.4 For other properties on Mweenish and Ard, the assessment (shown in tabular form in Table 7 and Table 8) shows that the predicted wind farm noise immission levels meet the derived noise limits under all wind speeds and at all locations, by a large margin of 10 dB or more. For locations on Mason Island, which are discussed in section 3.2, although the noise limits derived may potentially not apply due to the limited occupation of the properties, predicted noise levels are substantially below the derived noise limits of Tables 3 and 4 and therefore levels are considered to be acceptable regardless.

Table 7 - Difference between the derived day-time noise limits (Table 3) and the predicted L_{A90} (dB) wind farm noise immission levels (Table 5, precautionary basis) at relevant noise assessment location. Negative values indicate the noise immission level is below the limit.

Property	Standardised 10 m Wind Speed (m/s)								
	4	5	6	7	8	9	10	11	12
Mweenish 1	-22.4	-18.2	-15.0	-14.2	-12.9	-13.6	-14.3	-15.1	-15.8
Mweenish 2	-22.4	-18.2	-15.0	-14.2	-12.9	-13.6	-14.3	-15.0	-15.7
Mweenish 4	-23.0	-18.8	-15.6	-14.8	-13.5	-14.2	-14.9	-15.7	-16.4
Mweenish 3	-23.1	-18.9	-15.7	-14.9	-13.6	-14.3	-15.0	-15.7	-16.4
Ard 1	-19.5	-15.4	-12.3	-11.7	-10.5	-11.4	-12.2	-13.0	-13.9
Ard 2	-20.2	-16.2	-13.1	-12.4	-11.3	-12.1	-13.0	-13.8	-14.7
Ard 3	-20.5	-16.4	-13.4	-12.7	-11.5	-12.4	-13.2	-14.1	-14.9

Property	Standardised 10 m Wind Speed (m/s)								
	4	5	6	7	8	9	10	11	12
Ard 4	-19.6	-15.5	-12.4	-11.8	-10.6	-11.5	-12.3	-13.1	-14.0
Mason 1	-17.0	-12.9	-9.8	-9.2	-8.0	-8.9	-9.7	-10.5	-11.4
Mason 2	-16.9	-12.9	-9.8	-9.1	-8.0	-8.8	-9.7	-10.5	-11.3

Table 8 - Difference between the derived night-time noise limits (Table 4) and the predicted L_{A90} (dB) wind farm noise immission levels (Table 5, precautionary basis) at relevant noise assessment location. Negative values indicate the noise immission level is below the limit.

Property	Standardised 10 m Wind Speed (m/s)								
	4	5	6	7	8	9	10	11	12
Mweenish 1	-20.4	-16.6	-13.8	-13.3	-12.4	-13.5	-14.6	-15.7	-16.8
Mweenish 2	-20.3	-16.5	-13.7	-13.3	-12.4	-13.5	-14.5	-15.6	-16.7
Mweenish 4	-21.0	-17.2	-14.4	-13.9	-13.0	-14.1	-15.2	-16.3	-17.4
Mweenish 3	-21.0	-17.2	-14.4	-14.0	-13.0	-14.1	-15.2	-16.3	-17.4
Ard 1	-18.4	-14.3	-11.3	-10.7	-9.8	-11.0	-12.3	-13.7	-15.2
Ard 2	-19.1	-15.0	-12.0	-11.5	-10.6	-11.8	-13.1	-14.5	-16.0
Ard 3	-19.4	-15.3	-12.3	-11.7	-10.8	-12.0	-13.3	-14.7	-16.2
Ard 4	-18.5	-14.4	-11.4	-10.8	-9.9	-11.1	-12.4	-13.8	-15.3
Mason 1	-15.9	-11.8	-8.8	-8.2	-7.3	-8.5	-9.8	-11.2	-12.7
Mason 2	-15.8	-11.7	-8.7	-8.2	-7.3	-8.5	-9.8	-11.2	-12.6

4.3.1 As discussed in section 2.2, the 2019 draft revised WEDG are subject to some interpretation. However, the predicted levels of Table 5 and 6 at residential locations do not exceed the upper threshold of 43 dB discussed in these draft guidelines, and, based on the comparison discussed above, do not exceed 5 dB(A) above existing background noise levels. On this basis, the Proposed Development is also considered likely to comply with the draft 2019 WEDG thresholds.

4.3.2 Given that predicted levels are substantially below typical background noise levels in comparable weather conditions it is not considered likely that special audible characteristics such as tonality or amplitude modulation, which are discussed in ETSU-R-97 and the draft 2019 WEDG thresholds, are likely to be relevant and these are not considered further in this assessment.

4.3.3 Given that St MacDara's Island is not inhabited/residential, the derived noise limits are not applicable for occasional visitors to this island. However, Figure E5 in Annex E shows that predicted noise levels, even on a precautionary basis, are below typical derived existing background noise levels during day-time periods (based on measurements on Ard which are considered to be representative). As the visits would only be undertaken during day-time hours, it is not necessary to consider night-time periods. On this basis, although turbine noise may potentially be audible, it is considered unlikely to represent a significant disturbance for visitors to the Island.

4.4 Finalised turbine layout and monitoring

4.4.1 The noise emission data assumed for the wind turbines on the Proposed Development are considered speculative but precautionary, given the current state of technology and the lack of tested prototype data at this stage. A finalised desktop assessment of predicted noise levels could be undertaken when the proposed turbine layout, position and extent has been finalised, and a turbine model selected for potential installation. At that stage, it is likely that more up-to-date noise emission information based on prototype tests would be available from the manufacturer, allowing a more realistic evaluation. For simplicity, the updated noise predictions could be checked against a maximum noise level of 43 dB L_{A90} at inhabited islands locations along the coastline.

4.4.2 Section 4 also explains that the assumed data is likely to be an over-estimate, even when accounting for the potential rotor diameter of the proposed turbines, and predicted levels were clearly below the derived noise limits. Therefore, an updated assessment is likely to conclude by predicting noise levels lower than those assessed within this report and so is not considered to be required (for example as a planning condition requirement).

4.4.3 Post-construction operational noise from the Proposed Development turbines would be very difficult to measure in practice, because of the levels of noise predicted (assuming precautionary and pessimistic predictive modelling, with lower levels likely in practice) and the elevated background noise levels for receptors on the shore in relevant downwind conditions. It is therefore not recommended to require post-construction noise monitoring to verify the above desktop analysis, given these factors which would make any measurements too uncertain.

5. Summary of Key Findings and Conclusions

5.1.1 Predicted operational noise levels have been compared to noise limits derived in accordance with the extant WEDG guidelines and consideration of the ETSU-R-97 guidance, either based on the lowest thresholds described therein, or derived relative to existing background noise levels measured at representative shoreline properties. These predictions were made based on conservative estimates of emission levels for the turbines of the type and size which would be installed offshore and accounted for enhanced propagation above the water surface.

5.1.2 The assessment demonstrates that the proposed turbines are likely to produce noise levels substantially below the limits derived at onshore locations, even in favourable propagation conditions. It is therefore concluded that operational noise levels from the Proposed Development are likely to be within levels recommended in national guidance for wind energy schemes.

5.1.3 It is not recommended to consider post-construction onshore noise measurements of the operational noise from the offshore turbines, due to the practical difficulties involved with such measurements.

Annex A - General Approach to Noise Assessment & Glossary

A.1. Some sound, such as speech or music, is desirable. However, desirable sound can turn into unwanted noise when it interferes with a desired activity or when it is perceived as inappropriate in a particular environment.

A.2. When assessing the effects of sound on humans there are two equally important components that must both be considered: the physical sound itself, and the psychological response of people to that sound. It is this psychological component which results in those exposed differentiating between desirable sound and unwanted noise. Any assessment of the effects of sound relies on a basic appreciation of both these components. This Annex provides an overview of these topics. A glossary of acoustic terminology is included at the end of this Annex.

A.3. The assessment of environmental noise can be best understood by considering physical sound levels separately from the likely effects that these physical sound levels have on people, and on the environment in general.

A.4. Physical sound is a vibration of air molecules that propagates away from the source. As acoustic energy (carried by the vibration back and forth of the air molecules) travels away from the source of the acoustic disturbance it creates fluctuating positive and negative acoustic pressures in the atmosphere above and below the standing atmospheric pressure. For most types of sound normally encountered in the environment these acoustic pressures are extremely small compared to the atmospheric pressure. When acoustic pressure acts on any solid object it causes microscopic deflections in the surface. For most types of sound normally encountered in the environment these deflections are so small they cannot physically damage the material. It is only for the very highest energy sounds, such as those experienced close to a jet engine for example, that any risk of physical damage exists. For these reasons, most sound is essentially neutral and has no cumulative damaging physical effect on the environment. The effects of environmental sound are therefore limited to its effects on people or animals.

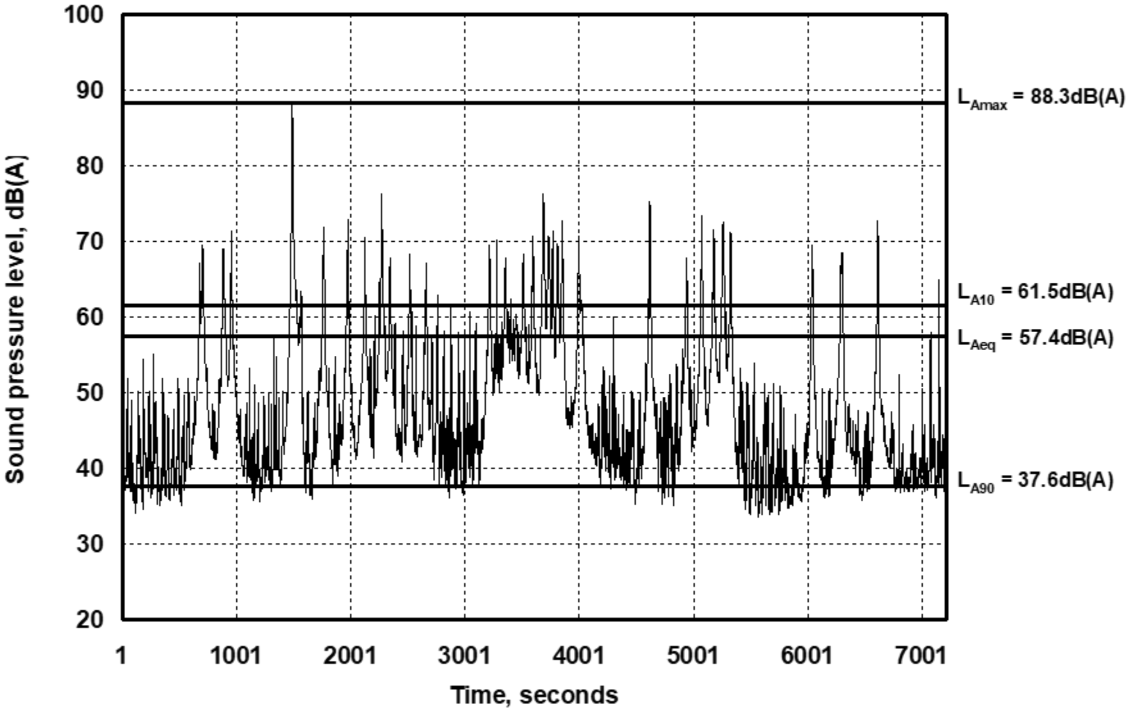
A.5. Before reviewing the potential effects of environmental sound on people, it is useful first to consider the means by which physical sound can be quantified.

Indicators of physical sound levels

A.6. Physical sound is measured using a sound level meter. A sound level meter comprises two basic elements: a microphone which responds in sympathy with the acoustic pressure fluctuations and produces an electrical signal that is directly related to the incident pressure fluctuations, and a meter which converts the electrical signal generated by the microphone into a decibel reading. Figure A1 shows an example of the time history of the decibel readout from a sound level meter located approximately 50 metres from a road. The plot covers a total time period of approximately 2 hours. The peaks in the sound pressure level trace correspond to the passage of individual vehicles past the measurement location.

A.7. Assigning a single value to the time varying sound pressure level presented in Figure A1 is clearly not straightforward, as the sound pressure level varies by over 50 dB with time. To overcome this, the measurement characteristics of sound level meters can be varied to emphasise different features of the sound that are thought to be most relevant to the effect under consideration.

Figure A1 Sample plot of the sound pressure level measured close to a road over a period of approximately two hours.



Objective measures of noise

A.8. The primary purpose of measuring environmental noise is to assess its effects on people. Consequently, any sound measuring device employed for the task should provide a simple readout that relates the objectively measured sound to human subjective response. To achieve this, the instrument must, as a minimum, be capable of measuring sound over the full range detectable by the human ear.

A.9. Perceived sound arises from the response of the ear to sound waves travelling through the air. Sound waves comprise air molecules oscillating in a regular and ordered manner about their equilibrium position. The speed of the oscillations determines the frequency, or pitch, of the sound, whilst the amplitude of oscillations governs the loudness of the sound. A healthy human ear is capable of detecting sounds at all frequencies from around 20 Hz to 20 kHz over an amplitude range of approximately 1,000,000 to 1. Even relatively modest sound level meters are capable of detecting sounds over this range of amplitudes and frequencies, although the accuracy limits of sound level meters vary depending on the quality of the unit. When undertaking measurements of wind turbine noise, as with all other noise measurements, it is important to select a measurement system that possesses the relevant accuracy tolerances and is calibrated to a matching standard.

A.10. Whilst measurement systems exist that are capable of detecting the range of sounds detected by the human ear, the complexities of human response to sound make the derivation of a likely subjective response from a simple objective measure a non-trivial problem. Not only does human response to sound vary from person to person, but it can also depend as much on the activity and state of mind of an individual at the time of the assessment, and on the 'character' of the sound, as it can on the actual level of the sound. In practice, a complete range of responses to any given sound may be observed. Thus, any objective measure of noise can, at best, be used to infer the average subjective response over a sample population.

Sound levels and decibels

A.11. Because of the broad amplitude range covered by the human ear, it is usual to quantify the magnitude of sound using the decibel scale. When the amplitude of sound pressure is expressed using decibels (dB) the resultant quantity is termed the sound pressure level. Sound pressure levels are denoted by a capital 'L', as in L dB. The conversion of sound pressure from the physical quantity of Newton per square metre, or Nm-2, to sound pressure level in dB reduces the range from 0 dB at the threshold of hearing to 120 dB at the onset of pain. Both of these values are derived with respect to the hearing of the average healthy young person.

A.12. Being represented on a logarithmic amplitude scale, the addition and subtraction of decibel quantities does not follow the normal rules of linear arithmetic. For example, two equal sources acting together produce a sound level 3 dB higher than either source acting individually, so 40 dB + 40 dB = 43 dB and 50 dB + 50 dB = 53 dB. Ten equal sound sources acting together will be 10 dB louder than each source operating in isolation. Also, if one of a pair of sources is at least 10 dB quieter than the other, then it will contribute negligibly to the combined noise level. So, for example, 40 dB + 50 dB = 50 dB.

A.13. An increase in sound pressure level of 3 dB is commonly accepted as the smallest change of any subjective significance. An increase of 10 dB is often claimed to result in a perceived doubling in loudness, although the basis for this claim is not well founded. An increase of 3 dB is equivalent to a doubling in sound energy, which is the same as doubling the number of similar sources. An increase of 10 dB is equivalent to increasing the number of similar sources tenfold, whilst an increase of 20 dB requires a hundredfold increase in the number of similar sources and an increase of 30 dB requires a thousand times increase in the number of sources.

Frequency selectivity of human hearing and A-weighting

A.14. Whilst the hearing of a healthy young individual may detect sounds over a frequency range extending from less than 20 Hz to greater than 20 kHz, the ear is not equally sensitive at all frequencies. Human hearing is most sensitive to sounds containing frequency components lying within the range of predominant speech frequencies from around 500 Hz to 4000 Hz. Therefore, when relating an objectively measured sound pressure level to subjective loudness, the frequency content of the sound must be accounted for.

A.15. When measuring sound with the aim of assessing subjective response, the frequency selectivity of human hearing is accounted for by down-weighting the contributions of lower and higher frequency sounds to reduce their influence on the overall reading. This is achieved by using an 'A'-weighting filter. Over the years, the A-weighting has become internationally standardised and is now incorporated into the majority of environmental noise standards and regulations in use around the world to best replicate the subjective response of the human ear. A-weighting filters are also implemented as standard on virtually all sound measurement systems.

A.16. Sound pressure levels measured with the A-weighting filter applied are referred to as 'A weighted' sound pressure levels. Results from such measurements are denoted with a subscripted capital A after the 'L' level designation, as in 45 dB LA, or alternatively using a bracketed 'A' after the 'dB' decibel designation, as in 45 dB(A).

Temporal variation of noise and noise indices

A.17. The simple A-weighted sound pressure level provides a snapshot of the sound environment at any given moment in time. However, as is adequately demonstrated by Figure A1, this instantaneous sound level can vary significantly over even short periods of time. A single number indicator is therefore required that best quantifies subjective response to time varying environmental noise, such as that shown in Figure A1. The question thus arises as to how temporal variations in level should be accounted for. This is most often achieved in practice by selecting a representative time period and calculating either the average noise level over that time period or, alternatively, the noise level exceeded for a stated proportion of that time period, as discussed below.

Equivalent continuous sound level, $L_{Aeq,T}$

A.18. The equivalent continuous sound level, or $L_{Aeq,T}$ averages out any fluctuations in level over time. It is formally defined as the level of a steady sound which, in a stated time period 'T' and at a given location, has the same sound energy as the time varying sound. The $L_{Aeq,T}$ is a useful 'general' noise index that has been found to correlate well with subjective response to most types of environmental noise.

A.19. The equivalent continuous sound level is expressed $L_{Aeq,T}$ in dB, where the A–weighting is denoted by the subscripted 'A', the use of the equivalent continuous index is denoted by the subscripted 'eq', and the subscripted 'T' refers to the time period over which the averaging is performed. So, for example, 45 dB $L_{Aeq,1hr}$ indicates that A-weighted equivalent continuous noise level measured over a one hour period was 45 dB.

A.20. The disadvantage of the equivalent continuous sound level is that it provides no information as to the temporal variation of the sound. For example, an $L_{Aeq,1hr}$ of 60 dB could result from a sound pressure level of 60 dB(A) continuously present over the whole hour's measurement period, or it could arise from a single event of 96 dB(A) lasting for just 1 second superimposed on a continuous level of 30 dB(A) which exists for the remaining 59 minutes and 59 seconds of the hour long period. Clearly, the subjective effect of these two apparently identical situations (if one were to rely solely on the L_{Aeq} index) could be quite different.

A.21. The aforementioned feature can produce problems where the general ambient noise level is relatively low. In such cases the $L_{Aeq,T}$ can be easily 'corrupted' by individual noisy events. Examples of noisy events that often corrupt $L_{Aeq,T}$ noise measurements in situations of low ambient noise levels include birdsong or a dog bark local to a noise monitoring point, or an occasional overflying aircraft or a sudden gust of wind. This potential downside to the use of $L_{Aeq,T}$ as a general measurement index is of particular relevance to the assessment of ambient noise in quiet environments, such as those typically found in rural areas where wind farms are developed.

A.22. Despite these shortcomings in low noise environments, the $L_{Aeq,T}$ index is increasingly becoming adopted as the unit of choice for both UK and European guidance and legislation, although this choice is often as much for reasons of commonality between standards as it is for overriding technical arguments. In the Government's current planning policy guidance notes the $L_{Aeq,T}$ noise level is the index of choice for the general assessment of environmental noise. This assessment is undertaken separately for day time ($L_{Aeq,16hr}$ 07:00 to 23:00) and night time ($L_{Aeq,8hr}$ 23:00 to 07:00) periods. However, it is often the case for quiet environments, or for non-steady noise environments, that more information than can be gleaned from the $L_{Aeq,T}$ index may be required to fully assess potential noise effects.

Maximum, L_{Amax}, and percentile exceeded sound level, $L_{An,T}$

A.23. Figure A1 shows, superimposed on the time varying sound pressure level trace and in addition to the $L_{Aeq,T}$ noise level, examples of three well established measurement indices that are commonly used in the assessment of environmental noise impacts. These are the maximum sound pressure level, L_{Amax}, the 90 percentile sound pressure level, $L_{A90,T}$ and the ten percentile sound pressure level, $L_{A10,T}$.

A.24. The $L_{Amax,F}$ readings is suited to indicating the physical magnitude of the single individual sound event that reaches the maximum level over the measurement period, but it gives no indication of the number of individual events of a similar level that may have occurred over the time period.

A.25. Unlike the $L_{Aeq,T}$ index and the $L_{Amax,F}$ indices, percentile exceeded sound levels, percentage exceeded sound levels provide some insight into the temporal distribution of sound level throughout the averaging period. Percentage exceeded sound levels are defined as the sound level exceeded by a fluctuating sound level for n% of the time over a specified time period, T. They are denoted by $L_{An,T}$ in dB, where 'n' can take any value between 0% and 100%.

A.26. The $L_{A10,T}$ and $L_{A90,T}$ indices are the most commonly encountered percentile noise indices used in the UK.

A.27. The 10%'ile index, or $L_{A10,T}$ provides a measure of the sound pressure level that is exceeded for 10% of the total measurement period. It therefore represents the typical upper level of sound associated with specific events, such as the passage of vehicles past the measurement point. It is the traditional index adopted for road traffic noise. This index is useful because traffic noise is not usually constant, but rather it fluctuates with time as vehicles drive past the receptor location. The $L_{A10,T}$ therefore characterises the typical level of peaks in the noise as vehicles drive past, rather than the lulls in noise between the vehicles.

A.28. The $L_{A90,T}$ noise index is the noise level exceeded for 90% of the time period, T. It provides an estimate of the level of continuous background noise, in effect performing the inverse task of the $L_{A10,T}$ index by detecting the lulls between peaks in the noise. It is for this reason that the $L_{A90,T}$ noise index is the favoured unit of measurement for wind farm noise where, for the reasons discussed above, the generally low $L_{Aeq,T}$ noise levels are easily corrupted by intermittent sounds such as those produced by livestock, agricultural vehicles or the occasional passing vehicle on local roads. The $L_{A90,T}$ noise level represents the typical lower level of sound that may be reasonably expected to be present for the majority (90%) of the time in any given environment. This is usually referred to as the 'background' noise level.

Temporal variations outside the noise index averaging periods, 'T'

A.29. Averaging noise levels over the time period 'T' of the $L_{Aeq,T}$ and $L_{An,T}$ noise indices can successfully account for variations in noise over the time period, T. Some variations, however, exhibit trends over longer periods. At larger distances from noise sources meteorological factors can significantly affect received noise levels. At a few hundred metres from a constant level source of noise the potential variation in noise levels may be greater than 15 dB(A). To account for this variability consideration must be taken of meteorological conditions, particularly wind direction, when measurements and predictions are undertaken. As a general rule, when compared with the received noise level under neutral wind conditions, wind blowing from the source to the receiver can slightly enhance the noise level at the receiver (typically by no more than 3 dB(A)), but wind blowing from the receiver to the source can very significantly reduce the noise level at the receiver (typically by 15 dB(A) or more).

A.30. A similar effect occurs under conditions of temperature inversion, such as may exist after sunset when radiative cooling from the ground lowers the temperature of the air lying at low level more quickly than the air at higher levels, by loss of temperature through convective effects. This results in the air temperature increasing with increasing height above the ground. Depending on the source to receiver distance relative to the heights of the source and receiver, this situation can lead to sound waves becoming 'trapped' in the layer of air lying closest to the ground. The consequence is that noise levels at receptor locations can increase relative to those experienced under conditions of a neutral temperature gradient or a temperature lapse. The maximum increases compared to neutral conditions are similar to those experienced under downwind conditions of no more than around 3 dB(A). It is also worth noting that temperature lapse conditions, which is the more usual situation where temperature decreases with increasing height, can result in reductions in noise level at receptor locations by 15 dB(A) or more compared with the neutral conditions. The similarity between the magnitude of potential variations in noise levels for wind induced and temperature induced effects is not surprising, as the physical mechanisms behind the variations in level are the same for both situations: both variations result from changes in the speed of sound as a function of height above local ground level.

A.31. Temperature inversions on very still days can also affect noise propagation over much larger distances of several kilometres. These effects can produce higher than expected noise levels even at these very large distances from the source. A classic example that many people have experienced is the distant, usually inaudible, railway train that suddenly sounds like it is passing within a few hundred metres of a dwelling. However, these situations must generally be considered as rare exceptions to the usually encountered range of noise propagation conditions, especially in the case of wind farm noise as they rely on calm wind conditions under which wind turbines do not operate.

Effects of sound on people

A.32. Except at very high peak acoustic pressures, the energy levels in most environmental sounds are too low to cause any physical disruption in any part of the body, just as they are too low to cause any direct physical damage to the environment. The main effects of environmental sound on people are therefore limited to possible interference with specific activities or to some kind of annoyance response. Some researchers have claimed statistical associations between environmental noise and various long term health effects such as clinical hypertension or mental health problems, although there is no consensus on possible causative mechanisms. Evidence in support of health effects other than annoyance and some indicators of sleep disturbance is weak. However, the theory that psychological stress caused by annoyance might contribute to adverse health effects in otherwise susceptible individuals seems plausible. Health effects in the 'more usual' definition of physiological health therefore remain as a theoretical possibility which has neither been proved nor disproved. However, the World Health Organisation (WHO) defines health in the wider context of:

> *'a state of complete physical, mental and social well-being and not merely the absence of infirmity'.*

And within this wider context potential health effects of environmental noise are summarised by the World Health Organisation as:

- interference with speech communications;
- sleep disturbance;
- disturbance of concentration;
- annoyance; and
- social and economic effects.

Speech interference

A.33. The instantaneous masking effects of unwanted noise on speech communication can be predicted with some accuracy by using specialist methods of calculation, but the overall effect of a small amount of speech interference on everyday life is harder to judge. The significance of speech masking depends on the context in which it occurs. For example, isolated noise events could interfere with telephone conversations by masking out particular words or parts of words but, because of the high redundancy in normal speech, the masking of individual words can often have no significant effect on the intelligibility of the overall message. Notwithstanding the above, noise levels from wind farms at even the closest located dwellings in otherwise quiet environments are usually no more than around 30 dB(A) indoors, even with windows open. This internal noise level is 5 dB(A) below the 35 dB(A) suggested by the World Health Organisation as the lowest potential cut-on level for issues relating to speech intelligibility.

Sleep disturbance

A.34. Although sleep seems to be a fundamental requirement for humans, the most significant effect of sleep loss seems to be increased sleepiness the next day. Sleep normally follows a regular cyclic pattern from awake through light sleep to deep sleep and back, this cycle repeating several times during the night at around 90 minute intervals. Most people wake for short periods several times every night as part of the normal sleep cycle without necessarily being aware of this the next day. REM, or rapid eye movement, sleep is associated with dreaming and occurs several times each night during the lighter sleep stages.

A.35. Electroencephalography (EEG) and similar techniques can be used to detect transient physiological responses to noise at night. Transient responses can be detected by short bursts of activity in the recorded waveforms which often settle back down to the same pattern as immediately before the event. Sometimes a transient response will be the precursor of a definite lightening of sleep, or even of an awakening, but often no discernible physical event happens at all.

A.36. These results suggest that at least parts of the auditory system remain fully operational even while the listener is asleep. The main purpose of this seems to be to arouse the listener in case of danger or in case some particular action is required which cannot easily be accomplished whilst remaining asleep. On the other hand, the system appears to be designed to filter out familiar sounds which experience suggests do not require any action. A very loud sound is likely to overcome the filtering mechanism and wake the listener, while intermediate and quieter sounds might only wake a listener who has a particular focus on those specific sounds. There is no evidence that the transient physiological responses to noise whilst asleep are anything other than normal. There is also considerable anecdotal evidence that people habituate to familiar noise at night, although some of the research evidence on this point is contradictory.

A.37. There is no consensus on how much sleep disturbance is significant. Some authorities take a precautionary approach, under which any kind of physiological response to noise is considered important, irrespective of whether there are any next day effects or not. Other studies suggest that transient physiological responses to unfamiliar stimuli at night are merely an indication of normal function and do not need to be considered as adverse effects unless they contribute to significant next-day effects. Recent World Health Organisation guidelines based mainly on laboratory studies suggest indoor limit values of 30 dB L_{Aeq} and 45 dB L_{Afmax} to avoid sleep disturbance, while other studies carried out in-situ, where habituation to the noise in question may have occurred, have found that much higher levels can be tolerated without any noticeable ill-effects.

Noise annoyance

A.38. Noise annoyance describes the degree of ‘unwantedness’ of a particular sound in a particular situation. People’s subjective response to noise can vary from not being bothered at all, through a state of becoming aware of the noise, right through to the point of becoming annoyed by the noise when it reaches a sufficiently high level. There is no statutory definition of noise annoyance.

A.39. Numerous noise annoyance surveys carried out over the last three decades have attempted to establish engineering relationships between the amount of noise measured objectively using sound level meters and the amount of community annoyance determined from questionnaires. The chief outcome of ‘reported annoyance’ has been measured using a very large range of different ideas. Both the wording of any questionnaire used and the context in which the question is put, and the manner in which it is therefore interpreted by respondents, can be very important. Some researchers are developing standardised questionnaire formats to encourage greater comparability between different studies, but this does not address the possibility of different contextual effects.

A.40. Notwithstanding these problems, there is a general consensus that average reported annoyance increases with aggregate noise level in long term static situations. However, there has been comparatively little research and consequently no real agreement on the effects of change. Some studies have found that even small changes in noise level can have unexpectedly large consequences on reported annoyance, while others have found the opposite. The most likely explanation for these apparent discrepancies is that underlying or true annoyance depends on many non-acoustic factors in addition to noise level alone, and that the extent to which reported annoyance actually represents underlying annoyance can be highly dependent on context. As a consequence, attempts to find a common relationship across all noise sources and listening situations have generally floundered. This task has been complicated by the great range of individual sensitivities to noise observed in the surveys, often affected as much by attitude as by noise level.

A.41. Whether or not an exposed individual has a personal interest in a given sound often has a significant bearing on their acceptance of it. For example, if recipients gain benefit from an association with the sound producer, or if they accept that the sound is necessary and largely unavoidable, then they are likely to be more tolerant of it. This is often the case even if they don’t necessarily consider it desirable.

A good example of this is road traffic noise which is the dominant noise heard by over 90% of the population but results in relatively few complaints.

A.42. Notwithstanding the fact that attitudes may be as important as overall levels in determining the acceptance of a particular noise, there still remains a need to objectively quantify any changes in noise level. Whilst it may not be possible to attribute a particular degree of annoyance to a given noise level, an objective measure of noise that bears some relationship to annoyance is still useful. This objective measure enables an assessment of the effect of changes to be assessed on the basis that any reduction in overall noise level must be beneficial. Possible noise mitigation measures form a central consideration of any noise assessment, so an appropriate methodology must be adopted for assessing the effectiveness of any noise mitigation measures adopted.

A.43. When assessing the potential effects of any new source of noise, it is common practice to compare the A-weighted 'specific' noise level produced by the new source (usually measured using the $L_{Aeq,T}$ index) against the existing A-weighted 'background' noise level measured using the $L_{A90,T}$ index, as this is the typical level of noise that can be reasonably expected to be present the majority of the time to potentially 'mask' the new 'specific' noise. The assessment is therefore undertaken within the context of the existing noise environment. In some circumstances, it may prove equally instructive to compare the absolute level of a new specific noise against accepted absolute levels defined in standards or other relevant documents. The assessment is therefore undertaken against benchmark values, rather than against the context of the existing noise environment. Whatever approach is actually adopted for final assessment purposes, and often a combination of the two approaches is appropriate, it is important that the relevance of both contextual and benchmark assessments is at least considered in all cases.

A.44. Table 4.1 of the 2000 WHO Guidelines for Community Noise presents guideline benchmark values for environmental noise levels in specific environments. The noise levels relevant to residential dwellings are listed here in Table A1.

Table A1 Relevant extracts from 'Table 4.1 - Guideline Values for Community Noise in Specific Environments'

Specific Environment	Critical Health Effects	$L_{Aeq,T}$	Time base (hrs)	L_{Amax} (dB)
Outdoor living area	Serious annoyance, day time and evening	55	16	-
	Moderate annoyance, day time and evening	50	16	-
Dwelling, <u>indoors</u>	Speech intelligibility and moderate annoyance, day time and evening	35*	16	-
	Sleep disturbance, night time	30*	8	45*
Outside bedrooms	Sleep disturbance, window open (outdoors)	45	8	60
School class rooms (included for potential effects on concentration) <u>indoors</u>	Speech intelligibility, disturbance of information extraction, message communication	35*	-	-

** N.B. the highlighted guideline values relate to internal noise levels within the relevant rooms, and corresponding external noise levels, even with windows open, would be at least 10 to 15dB (A) higher.*

A.45. The text accompanying the Table in the WHO Guidelines explains that the levels given in the Table are set at the lowest levels at which the onset of any adverse health due to exposure to noise has been identified. The text continues:

> *'These are essentially values for the onset of health effects from noise exposure. It would have been preferred to establish guidelines for exposure-response relationships. Such relationships would indicate the effects to be expected if standards were set above the WHO guideline values*

and would facilitate the setting of standards for sound pressure levels (noise immission standards)'.

A.46. More recently, Environmental Noise Guidelines for the European Region (2018) were published and include general recommendations for wind turbine noise. However, they are designed to inform policy on noise, at the population and strategic level. They are based on the Lden noise indicator, which requires knowledge of the noise levels experienced over the course of a full year. This type of noise index is more suitable for general strategic studies and not appropriate for assessing the acceptability of noise produced by any specific development. Furthermore, these guidelines do not provide recommendations for indoor noise levels and the 2000 WHO Guidelines for Community Noise remain applicable in this regard. For these reasons, the 2018 guidelines will not be referenced any further.

A.47. In addition to consideration of the absolute A-weighted level of a new specific source of noise, other properties of the noise can heighten its potential effects when introduced into an existing background noise environment. Such properties of noise are commonly referred to as 'acoustic features' or the 'acoustic character'. These acoustic features can set apart the new source of noise from naturally occurring sounds. Commonly encountered acoustic features associated with transport and machinery sources, for example, can include whistles, whines, thumps, impulses, regular or irregular modulations, high levels of low frequency sound, rumbling, etc.

A.48. Due to the potential of acoustic features to increase the effects of a noise over and above the effects that would result from an otherwise 'bland' broad band noise of the same A-weighted noise level, it is common practice to add a 'character correction' to the specific noise level before assessing its potential effects. The resulting character corrected specific noise level is often referred to as the 'rated' noise level. Such character corrections usually take the form of adding a number of decibels to the physically measured or calculated noise level of the specific source. Typical character corrections are around +5 dB(A), although the actual correction depends on the subjective significance of the particular feature being accounted for.

A.49. The objective identification and rating of acoustic features can introduce a requirement to analyse sound in greater detail than has thus far been discussed. To this point all discussion has focussed on the use of the overall A-weighted noise level. This single figure value is derived by summing together all the acoustic energy present in the signal across the entire audible spectrum from around 20 Hz to 20,000 Hz, albeit with the lower and higher frequency contributions down-weighted in accordance with the A-weighting filter characteristics to account for the reduced sensitivity of the human ear at these frequencies.

A.50. However, in order to identify the presence of tones (which are concentrations of acoustic energy over relatively small bands of frequency), or in order to identify excessive levels of low frequency noise, it may be necessary to determine the acoustic energy present in the noise signal across much smaller frequency bands. This is where the concept of octave band analysis, fractional (e.g. 1/3, 1/12, 1/24) octave band analysis, or even narrow band Fast Fourier Transform (FFT) analysis is introduced. The latter enables signals to be resolved in frequency bandwidths of down to 1 Hz or even less, thereby enabling tonal content to be more easily identified and measured. As standard, noise emission data for wind turbines is supplied as octave band data, with narrow band tests also being undertaken to establish the presence of any tones in the radiated noise spectrum.

Low frequency noise and vibration – wind farms

A.51. One issue that has increasingly been raised concerning potential noise effects of operational wind farms relates not to the overall noise levels, but to the specific issue of low frequency sound. However, confusion sometimes arises from the use of the generalised term 'low frequency sound' to describe specific effects that may, or sometimes may not, actually relate the low frequency character of the sound itself.

A.52. In this respect, there are three distinct characteristics of sound that should be clearly differentiated between:

- Low frequency sound in the range from around 20 Hz to 200 Hz, which therefore lies within the commonly referenced range of human hearing of around 20 Hz to 20,000 Hz;
- Very low frequency sound, or infrasound, below 20 Hz, which therefore lies below the commonly referenced lower frequency limit of human hearing;
- Amplitude modulated sound that characterises the 'swish, swish' sound sometimes heard from rotating wind turbine blades.

A.53. Looking at the first two of the three types of sound referred to in the preceding bullet points, a distinction is usually made between low frequency sound and very low frequency sound, otherwise termed infrasound. This distinction is based on the fact that the frequency range of audible noise is generally taken to be from 20 Hz to 20,000 Hz. Therefore, the range of frequencies from about 20 Hz to 200 Hz is usually taken to cover audible low frequency sound, whereas frequencies below 20 Hz are usually described as infrasound. The implication here is that low frequency sound is audible and infrasound is inaudible. However, this relatively arbitrary distinction between low frequency sound and infrasound can introduce some confusion in that frequencies below 20 Hz can still be heard provided they produce a sound pressure level at the ear of the listener that lies above the threshold of audibility of that listener to sound at that particular frequency.

A.54. The fact that low frequency sound and infrasound from wind farms has been highlighted as a potential problem by some groups does not mean that that the wind energy industry had not previously considered the issue. In fact, the issue of low frequency sound was one of the predominant technical hurdles associated with the some of the earliest larger scale wind turbines installed in the USA. These turbines were of the 'downwind' type, 'downwind' referring here to the fact that the rotor blades were located downwind of the turbine tower rather than upwind of it, as is the case for current machines. It was found that the interruption of wind flow past the tower resulted in a region of lower than average wind speed immediately in the wake of the tower. The passage of the blades into this region of lower wind speed in the wake of the tower, then back into the higher wind speed as they emerged from the wake of the tower back into the main wind stream, resulted in the generation of low frequency sound, often in the subjective form of a distinctive impulse, often referred to as a 'thump' or 'tower thump'. It was for this reason that modern day turbine configurations now have the blades upwind of the tower, as research and measurements demonstrated that low frequency sound radiation is reduced to sub-audible levels once the interaction of downwind tower wake effects with the rotating blades are removed from the design.

A.55. One of the problems inherent in the assessment of both low frequency sound and infrasound is the variability of hearing sensitivity across human subjects with otherwise healthy hearing. This threshold for sound below 200 Hz varies significantly more between different subjects than does the hearing threshold at higher frequencies. However, what is always true is that the perception threshold to lower frequency noise is much higher than the perception threshold for speech frequencies between around 250 Hz to 4,000 Hz. For example, the average person with healthy hearing is some 70 dB less sensitive to sounds at 20 Hz than to sounds that fall within the range of speech frequencies. An additional factor relevant to the perception of infrasound is that, although audibility remains below 20 Hz, tonality is lost below 16 Hz to 18 Hz, thus losing a key element of perception.

A.56. Both low frequency sound and infrasound are generally present all around us in modern life. They may be generated by many natural sources, such as thunder, earthquakes, waves and wind. They may also be produced by machinery including household appliances such as washing machines and air conditioning units, all forms of transport and by turbulence. The presence of low frequency sound and infrasound in our everyday lives is heightened by the fact that the attenuation of sound in air is significantly lower at low frequencies than at the mid to high frequencies. As a result, noise which has travelled over long distances is normally biased towards the low frequencies. However, the fact that human hearing naturally down-weights, or filters out, sounds of such low frequencies means we are generally not aware of its presence. It is only under circumstances when it reaches a sufficiently high level, for example in the 'rumble' of distant thunder or the sound of large waves crashing on a shore, that we become aware of its presence.

A-weighting

A.57. It is because the human ear increasingly filters out sounds of lower frequencies that environmental noise measurements are undertaken as standard using sound level meters that apply the A-weighting curve, as it filters out lower frequency sounds to the same degree as the hearing of a healthy person with unimpaired hearing. The A-weighted sound level is used as a measure of subjective perception of sound unless there exists such a predominance of low frequency sound or infrasound relative to the level of sound at higher frequencies that the use of the A-weighting curve would down-weight the actual source of the problem to such a degree that the resultant objective noise levels do not truly reflect the potential subjective effects of the noise. It is for this reason that a number of alternative weighting curves have been developed, specifically aimed at better accounting for the assessment of low frequency sound and infrasound.

Alternative frequency weightings

A.58. One such curve is denoted C-weighting. Unlike the A weighting curve, which gradually reduces the significance of frequencies below 1000 Hz until at 10 Hz the attenuation is 70 dB, the C-weighting curve is flat to within 1 dB down to about 50 Hz and then drops by 3 dB at 31.5 Hz and 14 dB at 10 Hz. The C weighting curve was originally developed to reflect the fact that, at higher overall noise levels, low frequencies can have a greater subjective effect than at lower overall noise levels.

A.59. One relatively simple measure of undertaking a first-pass assessment as to whether low frequency sound is likely to be an issue is to determine the difference between the overall C weighted noise level and the overall A weighted noise level. The C weighted level includes contributions from low frequency sound, whereas the A weighted level filters it out. It has been suggested in that a level difference of more than 20 dB indicates that low frequency sound may be subjectively significant, but more detailed investigations are in practice required to determine whether or not this is actually the case.

A.60. Another curve, termed the G weighting curve, has been specifically derived to provide a measure of the audibility of infrasound when considered separately from higher frequency noise. The G weighting curve falls off rapidly above 20 Hz and below 20 Hz it follows assumed hearing contours with a slope of 12 dB per octave down to 2 Hz.

Wind-farm infrasound and vibration

A.61. Over the past few years there has been considerable attention paid to the possibility that operational wind farms may radiate sufficiently high levels of infrasound or vibration to cause health problems. Dedicated research investigations have however repeatedly shown this not to be the case.

A.62. As early as 1997 a report by Snow[12] gave details of a comprehensive study of infrasound and low frequency sound (up to around 100 Hz) and vibration measurements made in the vicinity of a wind farm. Measurements were made both on the wind farm site, and at distances of up to 1 kilometre. During the experiments a wide range of wind speeds and directions were recorded. It was found that the vibration levels at 100 metres from the nearest turbine itself were a factor of 10 lower than those recommended for human exposure in the most critical buildings (i.e. laboratories for precision measurements), and lower again than the limits specified for residential premises. A similar comparison with recognised limits for assessing structural damage showed that the measured vibrations were a factor of 100 below the recommended guidelines at 100 metres from the turbines.

A.63. Noise and vibration levels were found to comply with recommended residential criteria even on the wind turbine site itself. Although low level infrasonic (i.e. below 20 Hz) periodic noise from the wind

12 'Low frequency noise and vibration measurements at a modern wind farm', D. Snow, ETSU Report ETSU W/13/00392/REP, 1997

farm was detected by instrumentation at distances up to 1 kilometre, the measuring instruments used were much more sensitive than human hearing. Based on his measurements Snow concluded that subjective detection of the wind turbines may be apparent at this distance, but if this is the case it will be due to higher frequency components (which are more readily masked by general ambient environmental noise) and not the low frequency components which lie below the threshold of audibility.

A.64. In 2003, findings on both low frequency sound and infrasound have been compiled into the previously referenced extensive review report commissioned by DEFRA and prepared by Dr G Leventhall[13]. Dr Leventhall notes that despite the numerous published studies there is little or no agreement about the biological effects of infrasound or low frequency sound on human health. Leventhall notes that direct evidence of adverse effects of exposure to low-intensity levels of infrasound (less than 90 dB) is lacking. He goes on to describe the low frequency hearing threshold i.e. the lowest levels which are audible to an average person with normal hearing. He notes the threshold at 4 Hz is about 107 dB, at 10 Hz it is about 97 dB and at 20 Hz it is 79 dB. As such, high levels of infrasound are required to exceed the hearing thresholds at such low frequencies. Leventhall therefore concluded that most people can be reassured that there will be no serious consequences to peoples' health from infrasound exposure.

A.65. Indeed, specifically in relation to wind farms and infrasound, Leventhall went further still with his statement of reassurance. This additional reassurance followed the voicing of concerns by some interested parties that, because infrasound and very low frequency vibrations could be measured from wind farms, then it must follow that these were a potential hazard and source of annoyance. In fact what those concerned observers failed to account for is that highly sensitive electronic measuring equipment designed solely to detect such infrasonic sounds and vibrations is orders of magnitude more sensitive than even the most sensitive human. Thus, whilst such measurement systems may be able to detect such low-level phenomena, the same stimuli can have no effect on humans. Typical levels of infrasound produced by a wind turbine at representative separation distances would not exceed 70 dB, and clearly below the perception thresholds discussed above. In the light of this, Leventhall issued an open statement:

'I can state quite categorically that there is no significant infrasound from current designs of wind turbines. To say that there is an infrasound problem is one of the hares which objectors to wind farms like to run. There will not be any effects from infrasound from the turbines'.

A.66. In 2004/2005 researchers from Keele University investigated the effects of the extremely low levels of vibration resulting from wind farms on the operation of a seismic array installed at Eskdalemuir in Scotland. This is one of the most sensitive ground-borne vibration detection stations in the world. The results of this study were initially misinterpreted, as just discussed for the DEFRA/Leventhall report, in that if infrasonic vibrations from wind farms can be measured, then they must consequentially have some potential effect on humans. In order to clarify their position, the authors subsequently explained[14] that:

'The levels of vibration from wind turbines are so small that only the most sophisticated instrumentation and data processing can reveal their presence, and they are almost impossible to detect'.

A.67. They then continue:

'Vibrations at this level and in this frequency range will be available from all kinds of sources such as traffic and background noise – they are not confined to wind turbines. To put the level of vibration into context, they are ground vibrations with amplitudes of about one millionth of a millimetre. There is no possibility of humans sensing the vibration and absolutely no risk to human health'.

13 'A review of published research on low frequency noise and its effects', G. Leventhall, report for DEFRA, 2003

14 'Wind farm noise', P. Styles, letter by Prof P Styles and S Toon printed in The Scotsman, August 2005.

A.68. In relation to airborne infrasound as opposed to ground-borne vibrations, the researchers are equally robust in their conclusions, stating:

> *'The infrasound generated by wind turbines can only be detected by the most sensitive equipment, and again this is at levels far below that at which humans will detect low frequency sound. There is no scientific evidence to suggest that infrasound [at such an extremely low level] has an impact on human health'.*

A.69. In 2006, the results of a study specifically commissioned by the UK Department of Trade and industry (DTI) to look at the effects of infrasound and low frequency noise (LFN) arising from the operation of wind farms have been published in what is commonly referred to as the DTI LFN Report[15]. This Report is quite categorical in its findings: infrasound is not the perceived health threat suggested by some observers, nor should it even be considered a potential source of disturbance. Quoting from the Executive Summary to the DTI LFN Report:

> *'Infrasound noise emissions from wind turbines are significantly below the recognised threshold of perception for acoustic energy within this frequency range. Even assuming that the most sensitive members of the population have a hearing threshold which is 12 dB lower than the median hearing threshold, measured infrasound levels are well below this criterion.*
>
> *The document "Community Noise" prepared for the World Health Organisation, states that "there is no reliable evidence that infrasound below the hearing threshold produce physiological or psychological effects". Other detection mechanisms of infrasound only occur at levels well above the threshold of audibility.*
>
> *It may therefore be concluded that infrasound associated with modern wind turbines is not a source which will result in noise levels which may be injurious to the health of a wind farm neighbour'.*

A.70. This has been subsequently confirmed by many international studies and reviews. For example, a study for the National Institute for Public Health and the Environment (RIVM) in the Netherlands[16] published in 2020 concluded in this regard that:

> *'Although low frequency sound and infrasound might have other effects than 'normal' sound has, these effects are highly unlikely at sound levels typical for wind turbines. Brain studies show that low frequency and infrasound are processed in the same parts of the brain as 'normal' sound and there is no evidence that infrasound elicits any reaction at sub-audible levels.'*

A.71. In conclusion, whilst is known that infrasound can have an adverse effect on people (potential adverse health impacts are listed by the World Health Organisation as stress, irritation, unease, fatigue, headache, possible nausea and disturbed sleep), these effects can only come into play when the infrasound reaches a sufficiently high level. This is a level above the threshold of audibility. However, all available information from measurements on current wind turbines reveals that the level of infrasound emitted by these wind turbines lies below the threshold of human perception.

Low frequency sound

A.72. A report prepared for DEFRA by Casella Stanger[17] lists wind farms as a possible source of audible low frequency sound (20 Hz to 200 Hz). However, this is one possible source in a list of many commonly encountered sources such as pumps, boilers, fans, road, sea and rail traffic, the wind, thunder, the sea, etc. The report only considers the general issues associated with low frequency sound and makes no

15 'The measurement of low frequency noise at three UK wind farms', M. Hayes, DTI Report W/45/00656/00, 2006

16 Health effects related to wind turbine sound: an update, I. van Kamp, G.P. van den Berg, National Institute for Public Health and the Environment (RIVM), RIVM report 2020-0150, October 2020.

17 'Low frequency noise', Report by Casella Stanger for DEFRA, 2001.

attempt to quantify the potential problem associated with each of these sources. This is in contrast to other reports which have considered the specific situation associated with wind farms.

A.73. In respect of low frequency sound as opposed to infrasound, the DTI LFN Report identified that wind farm noise levels at the studied properties were, under certain conditions, measured at a level just above the threshold of audibility. The report therefore concluded that 'for a low frequency sensitive person, this may mean that low frequency sound associated with the operation of the three wind farms could be audible within a dwelling'. This conclusion was, however, placed into some context with the qualifying statement that 'at all measurement sites, low frequency sound associated with traffic movements along local roads has been found to be greater than that from the neighbouring wind farm'. In particular, it was concluded that, although measurable and under some conditions may be audible, levels of low frequency sound were below permitted night time low frequency sound criteria, including the latest UK criteria resulting from the 2003 DEFRA study into the effects of low frequency sound.

A.74. Based on the findings of the DTI LFN Report, low frequency sound in the greater than 20 Hz frequency range may, under some circumstances, be measured to be of a comparable or higher level than the threshold of audibility. On such occasions this low frequency sound may become audible to low frequency sensitive persons who may already be awake inside nearby properties, but not to the degree that it will cause awakenings. However, such noise should still be assessed for its potential subjective effects in the conventional manner in which environmental noise is generally assessed. In particular, the subjective effects of this audible low frequency sound should not be confused with the claimed adverse health effect arguments concerning infrasound which, in any event, have now been shown from the results of the DTI LFN Report to be wholly unsubstantiated.

A.75. In November 2006, the UK Government released a statement[18] concerning low frequency sound, reiterating the conclusion of the DTI LFN report that:

> *'there is no evidence of health effects arising from infrasound or low frequency sound generated by wind turbines'.*

A.76. The Government statement concluded the position regarding low frequency sound from wind farms with the definitive advice to all English Local Planning Authorities and the Planning Inspectorate that PPS22 and ETSU-R-97 should continue to be followed for the assessment of noise from wind farms.

Blade swish (amplitude modulation)

A.77. The noise assessment methodology presented in ETSU-R-97, sets out noise limits which already account for typically encountered levels of blade swish. Notwithstanding the conclusions and advice presented in the preceding paragraphs concerning both infrasound and low frequency sound, the DTI LFN Report went on to suggest that, where complaints of noise at night had occurred, these had most likely resulted from an increased amplitude modulation of the blade passing noise, making the 'swish, swish, swish' sound (often referred to as 'blade swish') more prominent than normal.

A.78. Since then, this aspect of wind turbine noise has become the subject of several research projects in the UK and abroad in the past years and the state of knowledge on the subject is still evolving. In Ireland, however, there is currently no fixed guidelines on the assessment of AM from wind farms.

18 'Advice on Findings of the Hayes McKenzie Report on Noise Arising from Wind Farms', URN 06/2162 (November 2006).

Glossary of Acoustics Terminology

Terminology	Description
A-weighting	A filter that down-weights low frequency and high frequency sound to better represent the frequency response of the human ear when assessing the likely effects of noise on humans
Acoustic character	One or more distinctive features of a sound (e.g. Tones, whines, whistles, impulses) that set it apart from the background noise against which it is being judged, possibly leading to a greater subjective effect than the level of the sound alone might suggest
Acoustic screening	The presence of a solid barrier (natural landform or manmade) between a source of sound and a receiver that interrupts the direct line of sight between the two, thus reducing the sound level at the receiver compared to that in the absence of the barrier
Ambient noise	All-encompassing noise associated with a given environment, usually a composite of sounds from many sources both far and near, often with no particular sound being dominant
Annoyance	A feeling of displeasure in this case evoked by noise
Attenuation	The reduction in level of a sound between the source and a receiver due to any combination of effects including: distance, atmospheric absorption, acoustic screening, the presence of a building façade, etc.
Audio frequency	Any frequency of a sound wave that lies within the frequency limits of audibility of a healthy human ear, generally accepted as being from 20 Hz To 20,000 Hz
Background noise	The noise level rarely fallen below in any given location over any given time period, often classed according to day time, evening or night time periods (for the majority of the population of the UK the lower limiting noise level is usually controlled by noise emanating from distant road, rail or air traffic)
Db	Abbreviation for 'decibel'
Db(a)	Abbreviation for the decibel level of a sound that has been a-weighted
Decibel	The unit normally employed to measure the magnitude of sound
Directivity	The property of a sound source that causes more sound to be radiated in one direction than another
Equivalent continuous sound pressure level	The steady sound level which has the same energy as a time varying sound signal when averaged over the same time interval, t, denoted by $L_{Aeq,t}$
External noise level	The noise level, in decibels, measured outside a building
Filter	A device for separating components of an acoustic signal on the basis of their frequencies
Frequency	The number of acoustic pressure fluctuations per second occurring about the atmospheric mean pressure (also known as the 'pitch' of a sound)
Frequency analysis	The analysis of a sound into its frequency components
Ground effects	The modification of sound at a receiver location due to the interaction of the sound wave with the ground along its propagation path from source to receiver
Hertz	The unit normally employed to measure the frequency of a sound, equal to cycles per second of acoustic pressure fluctuations about the atmospheric mean pressure
Impulsive sound	A sound having all its energy concentrated in a very short time period
Instantaneous sound pressure	At a given point in space and at a given instant in time, the difference between the instantaneous pressure and the mean atmospheric pressure
Internal noise level	The noise level, in decibels, measured inside a building
L_{Aeq}	The abbreviation of the a-weighted equivalent continuous sound pressure level
L_{A10}	The abbreviation of the 10 percentile noise indicator, often used for the measurement of road traffic noise
L_{A90}	The abbreviation of the 90 percentile noise indicator, often used for the measurement of background noise
Level	The general term used to describe a sound once it has been converted into decibels
Loudness	The attribute of human auditory response in which sound may be ordered on a subjective scale that typically extends from barely audible to painfully loud

Terminology	Description
Noise	Physically: a regular and ordered oscillation of air molecules that travels away from the source of vibration and creates fluctuating positive and negative acoustic pressure above and below atmospheric pressure.
	Subjectively: sound that evokes a feeling of displeasure in the environment in which it is heard, and is therefore unwelcomed by the receiver
Noise emission	The noise emitted by a source of sound
Noise immission	The noise to which a receiver is exposed
Noise nuisance	An unlawful interference with a person's use or enjoyment of land, or of some right over, or in connection with it
Octave band frequency analysis	A frequency analysis using a filter that is an octave wide (the upper limit of the filter's frequency band is exactly twice that of its lower frequency limit)
Percentile exceeded sound level	The noise level exceeded for n% of the time over a given time period, t, denoted by $L_{An,t}$
Receiver	A person or property exposed to the noise being considered
Residual noise	The ambient noise that remains in the absence of the specific noise whose effects are being assessed
Sound	Physically: a regular and ordered oscillation of air molecules that travels away from the source of vibration and creates fluctuating positive and negative acoustic pressure above and below atmospheric pressure
	Subjectively: the sensation of hearing excited by the acoustic oscillations described above (see also 'noise')
Sound level meter	An instrument for measuring sound pressure level
Sound pressure amplitude	The root mean square of the amplitude of the acoustic pressure fluctuations in a sound wave around the atmospheric mean pressure, usually measured in pascals (Pa)
Sound pressure level	A measure of the sound pressure at a point, in decibels
Sound power level	The total sound power radiated by a source, in decibels
Spectrum	A description of the amplitude of a sound as a function of frequency
Standardised wind speed	Values of wind speed at hub height corrected to a standardised height of ten metres using the same procedure as used in wind turbine emission testing
Threshold of hearing	The lowest amplitude sound capable of evoking the sensation of hearing in the average healthy human ear (0.00002 Pa)
Tone	The concentration of acoustic energy into a very narrow frequency range

Annex B – Location Map and Turbine Details

Figure B1 Map showing the layout of the turbines (green circles) and the noise assessment locations (red dots). Background mapping © OpenStreetMap contributors.

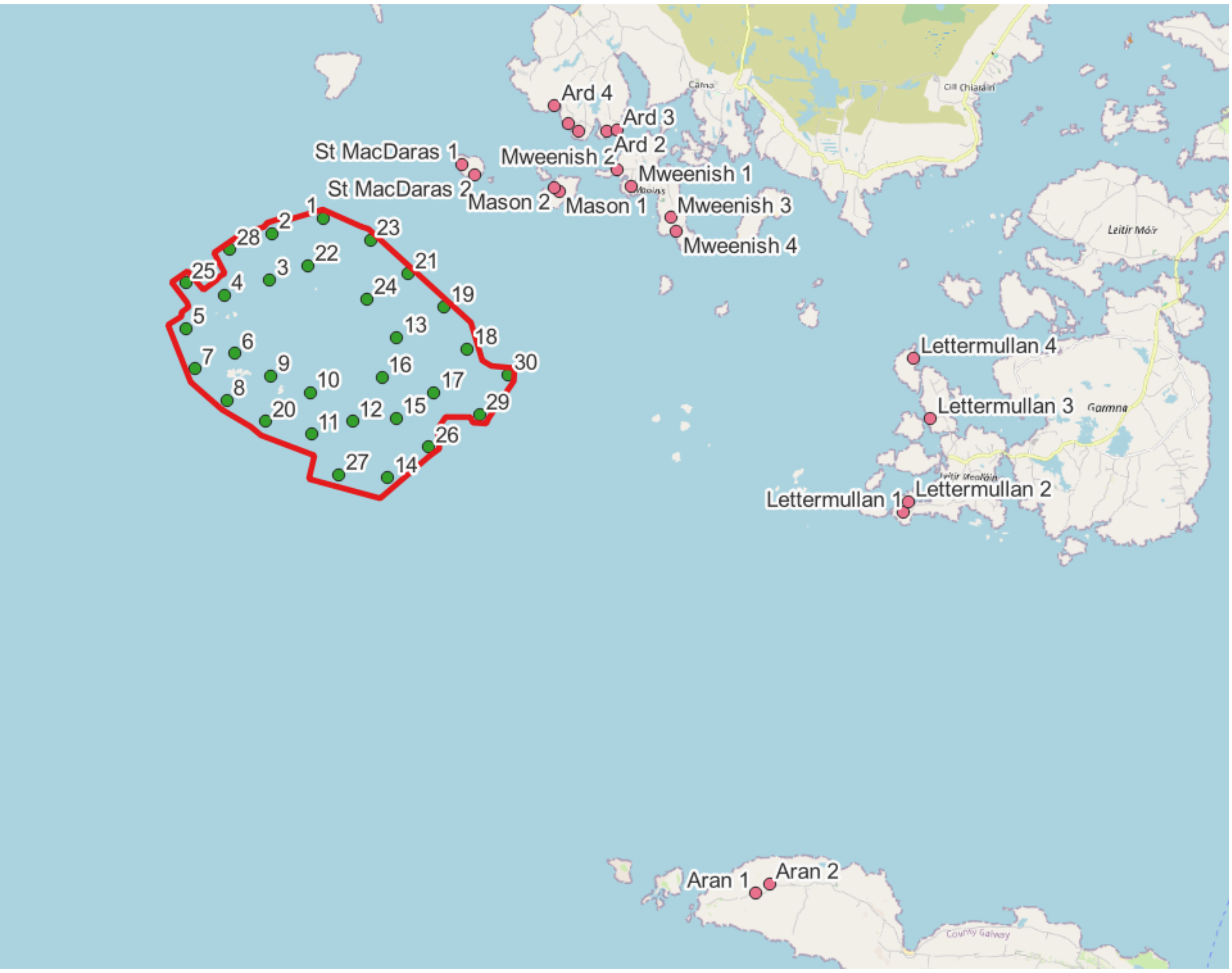
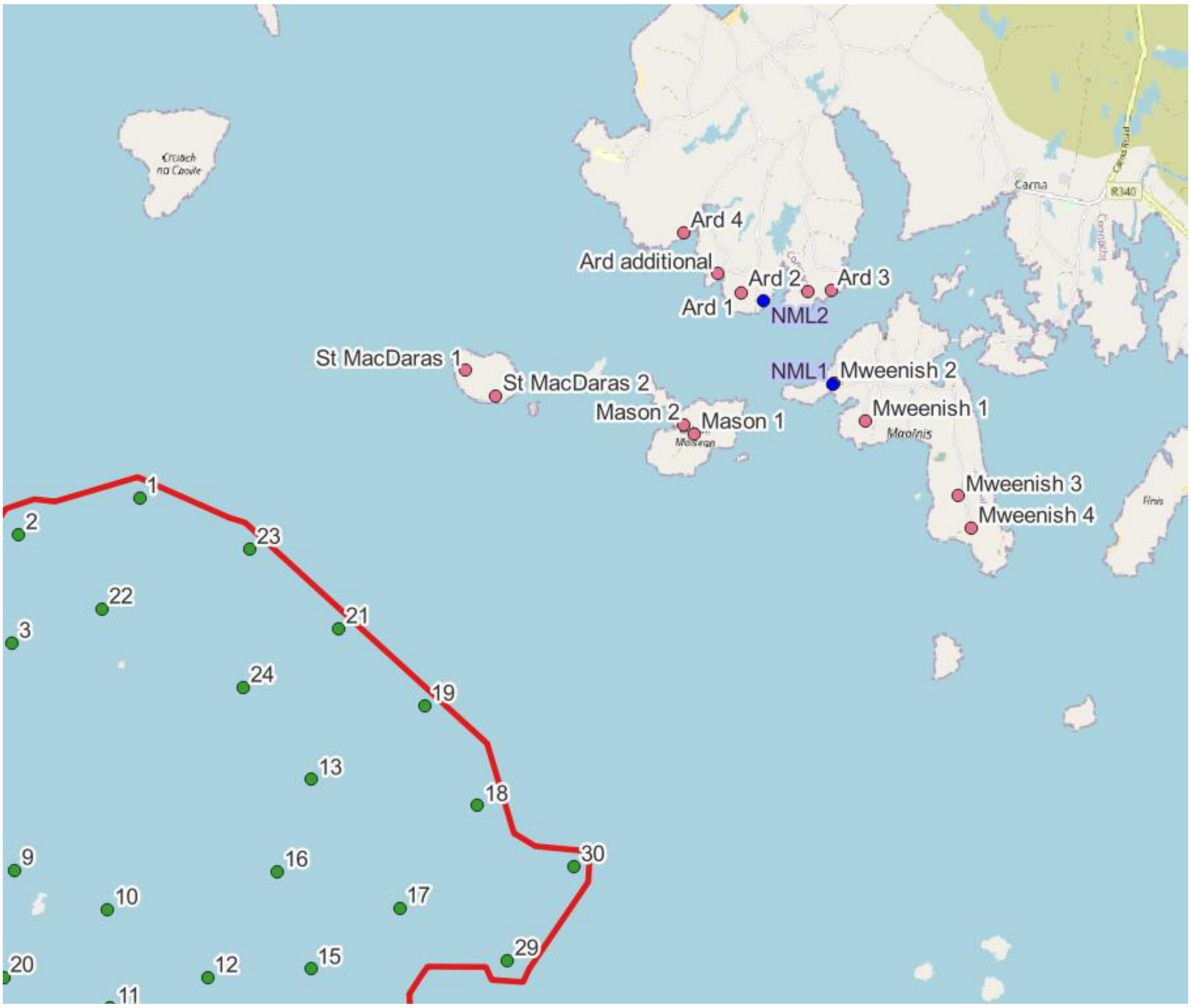


Figure B2 Close up view showing the layout of the turbines (green circles), the noise assessment locations (red dots) and the noise monitoring locations (NML, blue dots). The LIDAR was installed near NML1. Background mapping © OpenStreetMap contributors.



Turbine & Propagation Details

Table B1 – Turbine coordinates (Irish Transverse Mercator) – Proposed Development

Turbine	Easting	Northing	Turbine	Easting	Northing
T1	468273	728762	T16	469729	724795
T2	466995	728377	T17	471028	724413
T3	466926	727227	T18	471855	725497
T4	465807	726838	T19	471291	726554
T5	464828	726013	T20	466832	723678
T6	466067	725377	T21	470381	727374
T7	465073	724993	T22	467879	727582
T8	465853	724201	T23	469438	728223
T9	466954	724814	T24	469370	726751
T10	467929	724403	T25	464820	727140
T11	467961	723361	T26	470907	723039
T12	468992	723683	T27	468665	722344
T13	470096	725777	T28	465925	727980
T14	469882	722289	T29	472170	723862
T15	470084	723769	T30	472872	724859
All turbines modelled using the hub height of 190 m.					

Table B2 - Wind turbine sound power levels (dB L_{Aeq}) used in the noise assessment – Siemens-Gamesa SG DD-236.

Turbine operational mode	Standardised 10 m Wind Speed (m/s)											
	1	2	3	4	5	6	7	8	9	10	11	12
Standard	-	-	106.7	111.8	116.7	120.6	122.1	124.1	124.1	124.1	124.1	124.1
Derived from: Siemens-Gamesa document reference AE-ie-17187-110000105398-00, 06/12/2023. +2 dB margin added to account for uncertainties.												

Table B3 - Octave band sound power spectrum (dB L_{Aeq}) for reference wind speed conditions (v_{10} = 8 m/s) - Siemens-Gamesa SG DD-236.

Octave Band Centre Frequency (Hz)								
63	125	250	500	1000	2000	4000	8000	A
107.9	111.6	114.6	116.2	117.9	119.8	109.3	91.4	124.1
Derived from: Derived from: Siemens-Gamesa document reference AE-ie-17187-110000105398-00, 06/12/2023.								

Annex C – Noise Monitoring Information

Annex D – Wind Speeds and Directions

Figure D1 Wind speed and direction range during all quiet day-time periods (Location 1 – similar conditions experienced at Location 2)

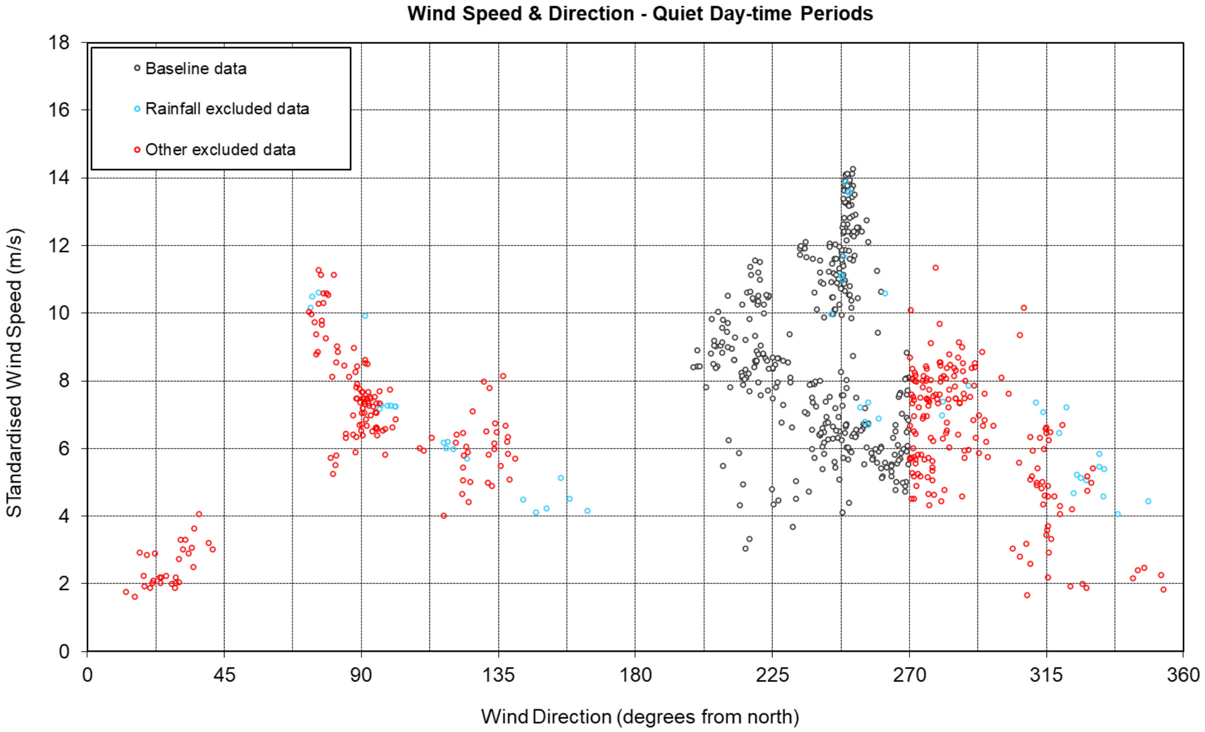
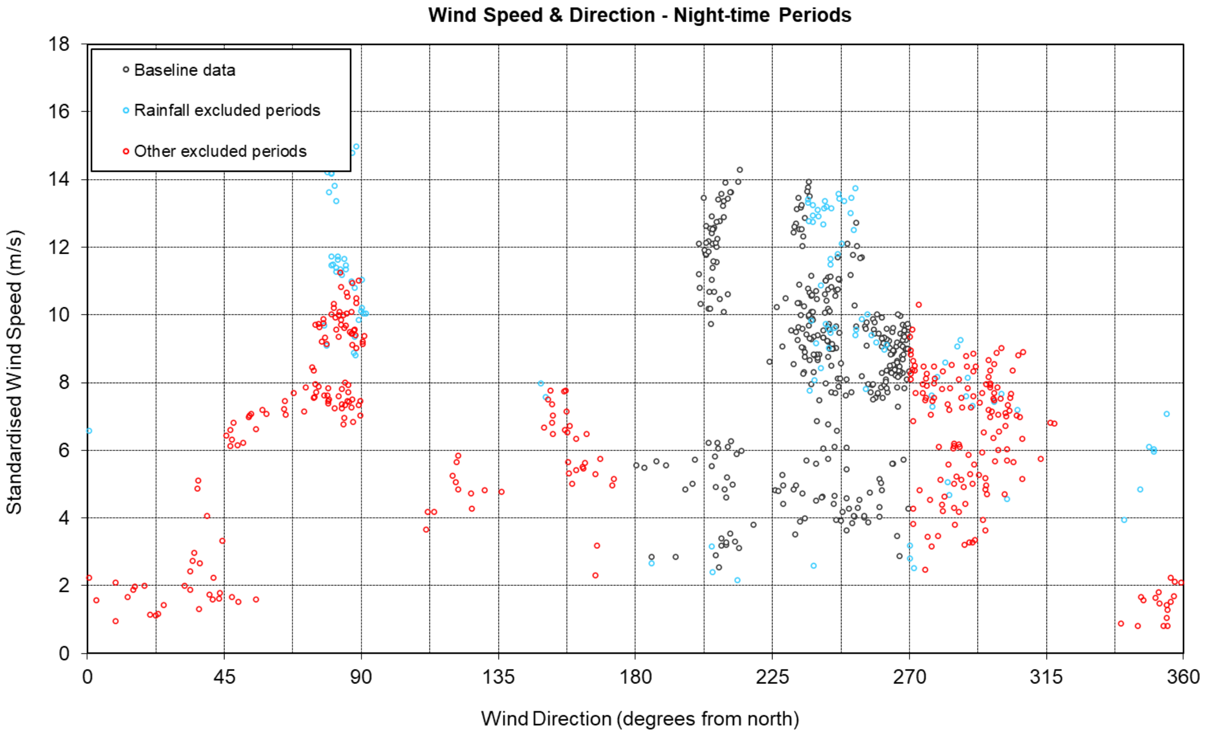


Figure D2 Wind speed and direction range during all night-time periods (Location 1 – similar conditions experienced at Location 2)



Annex E – Background Noise and Noise Limits

Figure E1 - Chart of background noise levels against wind speeds, the best fit curve to the data, the derived noise limit curve for location 1 (Mweenish) during quiet day-time periods. Predicted immission noise levels are also shown for the Proposed Development, both with (blue) and without (green) a correction for shoreline reflection effects.

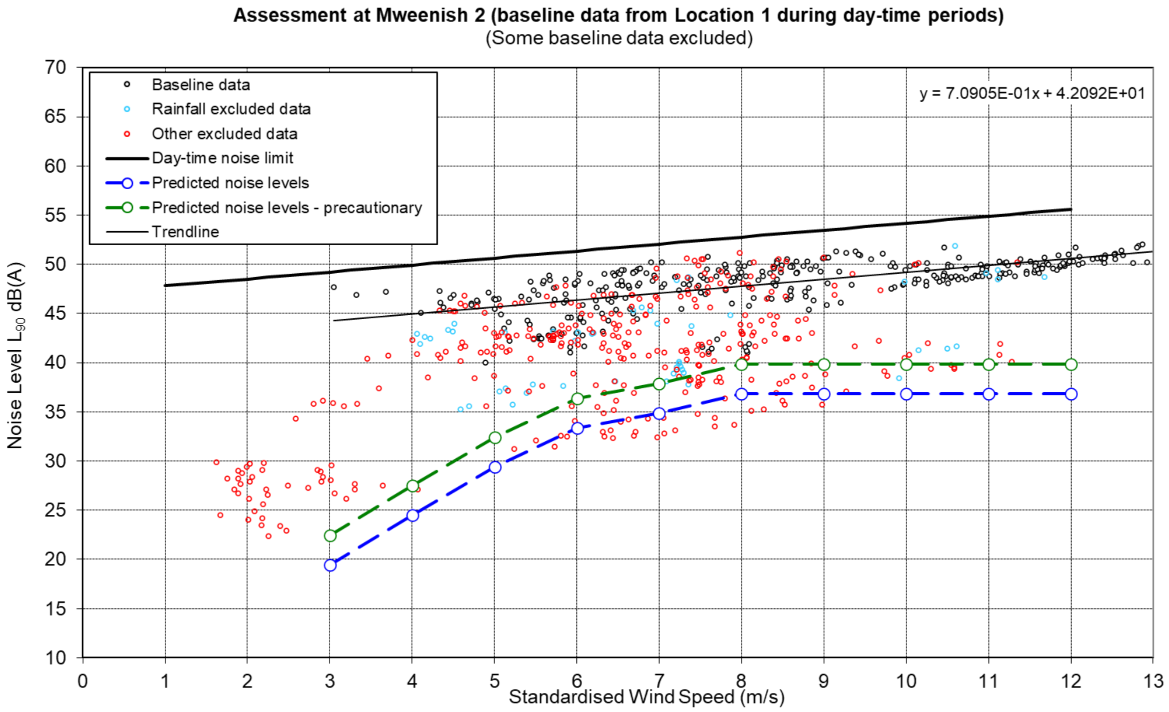


Figure E2 - Chart of background noise levels against wind speeds, the best fit curve to the data, the derived noise limit curve for location 1 (Mweenish) during night-time periods. Predicted immission noise levels are also shown for the Proposed Development, both with (blue) and without (green) a correction for shoreline reflection effects.

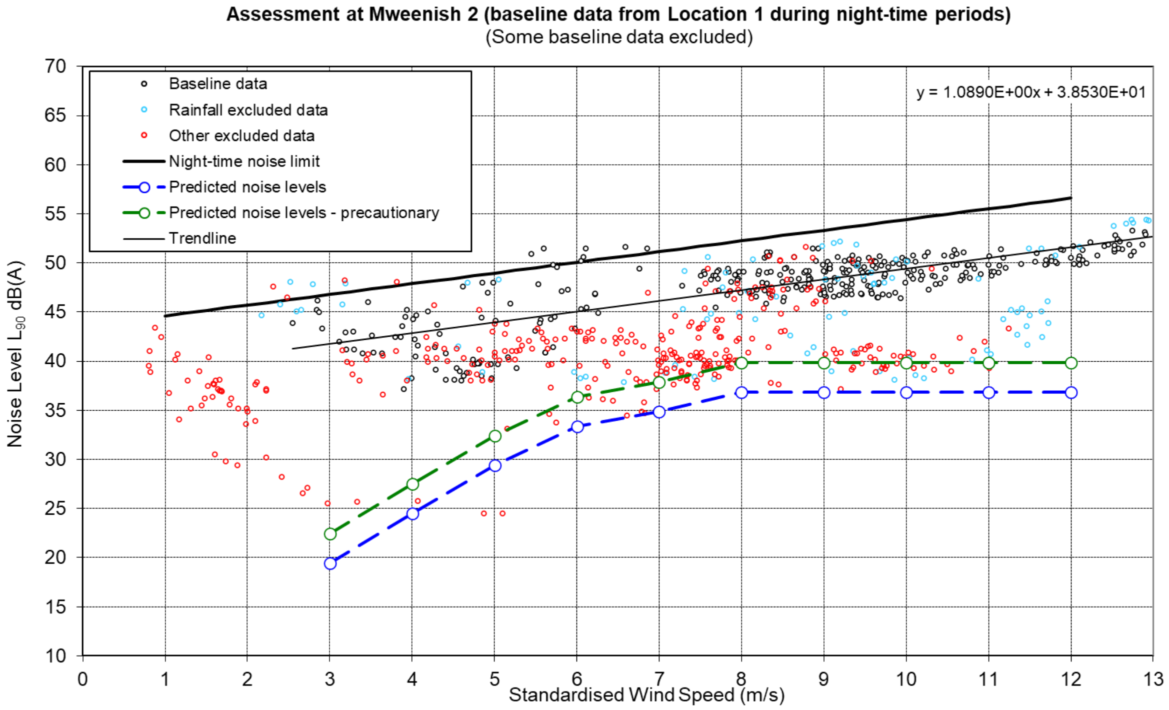


Figure E3 - Chart of background noise levels against wind speeds, the best fit curve to the data, the derived noise limit curve for location 2 (Ard) during quiet day-time periods. Predicted immission noise levels are also shown for the Proposed Development, both with (blue) and without (green) a correction for shoreline reflection effects.

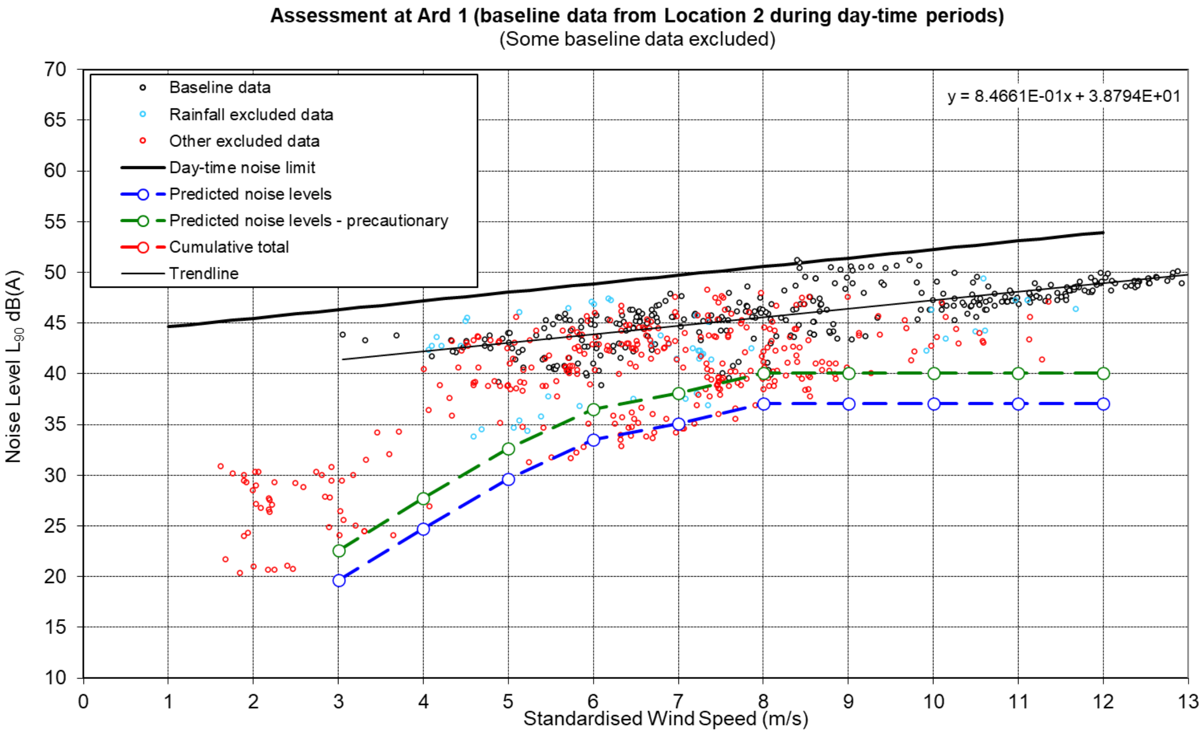


Figure E4 - Chart of background noise levels against wind speeds, the best fit curve to the data, the derived noise limit curve for location 3 (Ard) during night-time periods. Predicted immission noise levels are also shown for the Proposed Development, both with (blue) and without (green) a correction for shoreline reflection effects.

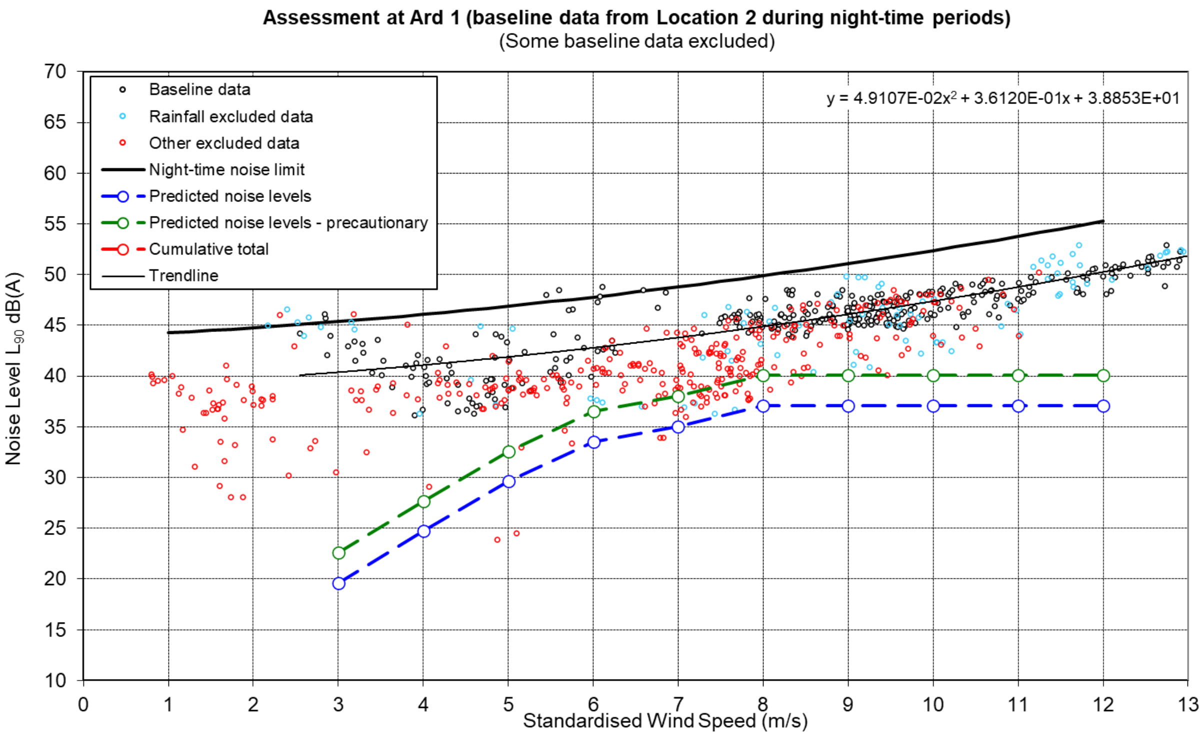
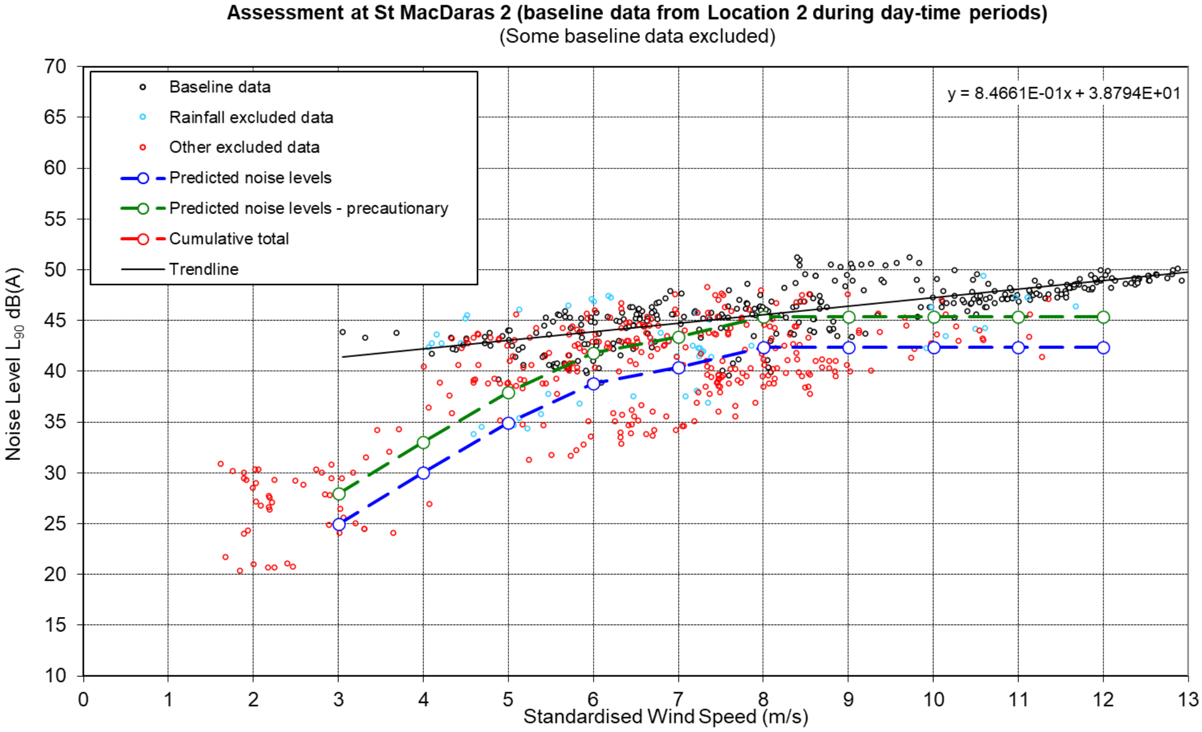


Figure E5 - Chart of background noise levels measured at location 2 (Ard) against wind speeds, the best fit curve to the data during quiet day-time periods. Predicted immission noise levels are also shown for the Proposed Development at St Macdara's Island, both with (blue) and without (green) a correction for shoreline reflection effects. As the Island is not residential, no noise limit derived in accordance with the WEDG is shown.



Annex F – Wind Speed Calculations

F.1 The IOA GPG[19] requires that noise data recorded every 10 minutes are related to standardised ten metre wind speeds experienced at the hub height of the turbines, at a location on the wind farm representative of the wind turbines. These wind speeds can be either measured directly at the turbine hub height or derived by calculation from measurements at two heights, with measurements at the upper height not less than 60% of the turbine hub height and measurements at least 15 metres below that. These are referred to as 'Method A' or 'Method B' in the IOA GPG which describes these as the preferred methods to use. IOA GPG SGN4[20] provides additional guidance on these methods.

F.2 The site of the Proposed Development has a temporary LIDAR remote sensing measuring system installed which measured wind conditions at various heights including:

- 150 metre wind speed and wind direction
- 170 metre wind speed and wind direction

F.3 These measurement heights meet the requirements of the IOA GPG: the upper measurement height being at least 60% of the proposed candidate hub height of 190 metres and the 150 metres height measurement being at least 15 metres lower than the upper measurement. The LIDAR meets the accuracy and calibration requirements of the IOA GPG.

F.4 Wind speed data were used to perform a calculation of the shear exponent found between the two wind speed measurement heights for every ten-minute period, by using Equation 3 of IOA GPG SGN4. Where wind speeds were the same at both heights or lower at greater height, the shear exponent was assumed to be zero. The shear exponent so calculated for every ten-minute period was then used to calculate the hub height wind speed using Equation 2 of SGN4 for each ten-minute period. Equation 1 of SGN4 was then used to calculate a standardised ten-metre height wind speed from the hub height wind speed every ten minutes assuming the reference roughness length of 0.05 metres.

F.5 Wind speeds are standardised to a height of ten metres assuming a reference ground roughness length of 0.05 metres as described in the IOA GPG. This approach is of the same form as that given in BS EN 61400-11:2003[21] for calculating ten metre wind speeds related to hub height wind speeds when providing source noise emission data for wind turbines.

F.6 By using this method, measured background noise levels were correlated to ten metre wind speeds calculated from wind speeds at hub height. Any likely difference in the shear profile during the 24 hours of the day will be accounted for within the method and be reflected in the resulting standardised ten metre wind speed data. The method used to calculate ten metre wind speeds from those at hub height is the same as that used when deriving noise emission data for the turbines. Because the same method has been used, direct comparison of background noise levels, noise limits and predicted turbine noise immission levels may be undertaken. This method is consistent with guidance published in the IOA GPG.

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19 A Good Practice Guide to the Application of ETSU R 97 for the Assessment and Rating of Wind Turbine Noise, M. Cand, R. Davis, C. Jordan, M. Hayes, R. Perkins, Institute of Acoustics, May 2013.

20 A Good Practice Guide to the Application of ETSU R 97 for the Assessment and Rating of Wind Turbine Noise - Supplementary Guidance Note 4: Wind Shear, M. Cand, R. Davis, C. Jordan, M. Hayes, R. Perkins, Institute of Acoustics, July 2014.

21 IEC 61400 11:2003 Wind turbine generator systems - Part 11: Acoustic noise measurement techniques.

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