



# **Sporad na Mara Offshore Wind Farm**

## **Offshore Project**

### **Environmental Impact Assessment Report**

#### **Chapter 19.2: Noise Modelling and Prediction, Volume 2c**

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# 1 INTRODUCTION

## 1.1 OVERVIEW

1.1.1.1 This appendix of the Environmental Impact Assessment Report (EIAR) presents the offshore airborne noise modelling and prediction method for construction piling noise and operational wind turbine noise of the proposed Spiorad na Mara Offshore Wind Farm (hereafter referred to as 'the Offshore Project') with respect to Offshore Airborne Noise. This appendix accompanies **Chapter 19: Offshore Airborne Noise, Volume 2a** of the EIAR.

1.1.1.2 This appendix should be read in conjunction with the project description provided in **Chapter 3: Project Description, Volume 1a** and the relevant parts of the following chapters and appendices:

- **Chapter 19, Volume 2a;**
- **Appendix 19.1: Policy, Guidance and Legislative Context, Volume 2c;**
- **Appendix 19.3: Baseline Noise Survey, Volume 2c;**
- **Appendix 19.4: Wind Shear Correction, Volume 2c;**
- **Appendix 19.5: Baseline Noise Conditions – All Wind Directions, Volume 2c;**
- **Appendix 19.6: Baseline Noise Analysis Comparison - Design Option 1 vs Design Option 2, Volume 2c;**
- **Appendix 19.7: Baseline Noise Conditions - Directional Split, Volume 2c;**
- **Appendix 19.8: Existing Wind Turbine Contribution Check, Volume 2c;**
- **Appendix 19.9: Modelled Receptor Noise Levels, Volume 2c;**
- **Appendix 19.10: Noise Limits, Volume 2c;**
- **Appendix 19.11: Cumulative Wind Turbine Noise Assessment, Volume 2c.**

## 1.1.2 PROJECT BACKGROUND

1.1.2.1 Spiorad na Mara Limited (hereafter referred to as 'the Applicant') is proposing to develop the Project. The Project is an offshore wind farm (OWF) that will consist of up to 60 fixed-bottom wind turbine generators (WTGs).

1.1.2.2 The Project will include both offshore and onshore infrastructure. This EIAR supports the application for the offshore components of the Project as outlined in **Chapter 1: Introduction, Volume 1a**. The offshore components of the Project (the 'Offshore Project') includes all infrastructure and activities located seaward of Mean High Water Springs (MHWS) within the Array Area and Offshore Cable Area of Search (OCAS) (**Figure 1.2: Offshore Project Location, Volume 1b**). Further detailed information is provided in **Chapter 3, Volume 1a**.

1.1.2.3 The Offshore Project is situated off the northwest coast of Isle of Lewis/*Eilean Leòdhais* and the Array Area is located approximately 5-13 km offshore and is approximately 161 km<sup>2</sup> in size. It will

comprise WTGs, foundations, Offshore Cables, Offshore Substation Platform (OSP) (if required), and Landfall. The Array Area combined with the OCAS is defined as the Offshore Project Boundary. The water depths across the Turbine Area range from 37 m-67 m with the southwest corner of the Array Area reaching 72 m. The proposed WTGs and fixed foundations will be located within a Turbine Area of approximately 140 km<sup>2</sup>, within the Array Area.

## 1.2 PURPOSE OF THIS APPENDIX

1.2.1.1 This appendix describes the following:

- Details the 2 WTG bounding scenarios;
- Details the piling noise modelling method;
- Details the onshore wind turbine noise modelling method;
- Details the offshore wind turbine noise modelling method.

## 2 WIND TURBINE GENERATOR OPTIONALITY

2.1.1.1 The Offshore Project considers the 2 WTG bounding scenarios detailed in **Chapter 3, Volume 1a**, comprising a smallest and largest WTG type. Intermediate configurations may also be deployed, on the basis that they fall within these bounding scenarios. The key WTG parameters for the noise assessment are summarised in **Table 2-1**.

Table 2-1 WTG parameters for the noise assessment

Parameter	Option 1 (smallest WTG type)	Option 2 (largest WTG type)
Number of turbines	60	44
Turbine power rating (MW)	15	22
Maximum rotor diameter	236	280
Maximum hub height for option (m)	175.8	198.4
Maximum sound power level (dB(A))	115.3	122 (assumed*)
* Manufacturers' sound power level data is not available for the Option 2 candidate turbine model, an assumed maximum sound power level has been adopted.		

2.1.1.2 The Option 1 (smallest WTG type) turbine locations (easting and northing) are presented in, **Table 2-2** and **Plate 2-1**, further details are given in **Chapter 3, Volume 1a**.

2.1.1.3 The Option 2 (largest WTG type) turbine locations are presented in **Table 2-3** and **Plate 2-2**, further details are given in **Chapter 3, Volume 1a**.

Table 2-2 Option 1 (smallest WTG type) turbine locations for noise modelling (British National Grid references)

Option 1: Wind turbine number	Easting (m)	Northing (m)	Option 1: Wind turbine number	Easting (m)	Northing (m)
1	109342	953821	31	122072	961863
2	110518	952962	32	121442	953407
3	111309	955137	33	122139	958675
4	111918	952134	34	122269	955531
5	112309	954211	35	122954	960806
6	113320	956370	36	123072	957653
7	113493	953235	37	123768	962937
8	114247	955349	38	123215	954409
9	114483	952252	39	123836	959750
10	115311	957624	40	124650	961882
11	115236	954327	41	124745	958713
12	116166	956507	42	125464	964011
13	116213	953347	43	124944	955454
14	116983	958640	44	125535	960827
15	117073	955468	45	125667	957683

Option 1: Wind turbine number	Easting (m)	Northing (m)	Option 1: Wind turbine number	Easting (m)	Northing (m)
16	117118	952347	46	126347	962956
17	117863	957583	47	126481	959814
18	117992	954436	48	127161	965085
19	118679	959714	49	126658	956459
20	118003	951347	50	127231	961901
21	118759	956535	51	127365	958759
22	118872	953359	52	128044	964030
23	119560	958657	53	128171	960884
24	119690	955512	54	128320	957597
25	120376	960788	55	128928	962976
26	119800	952230	56	129063	959834
27	120442	957601	57	129877	961964
28	120571	954455	58	129992	958725
29	121257	959732	59	130761	960910
30	121387	956586	60	131645	959856

Plate 2-1 Option 1 (smallest WTG type) turbine layout

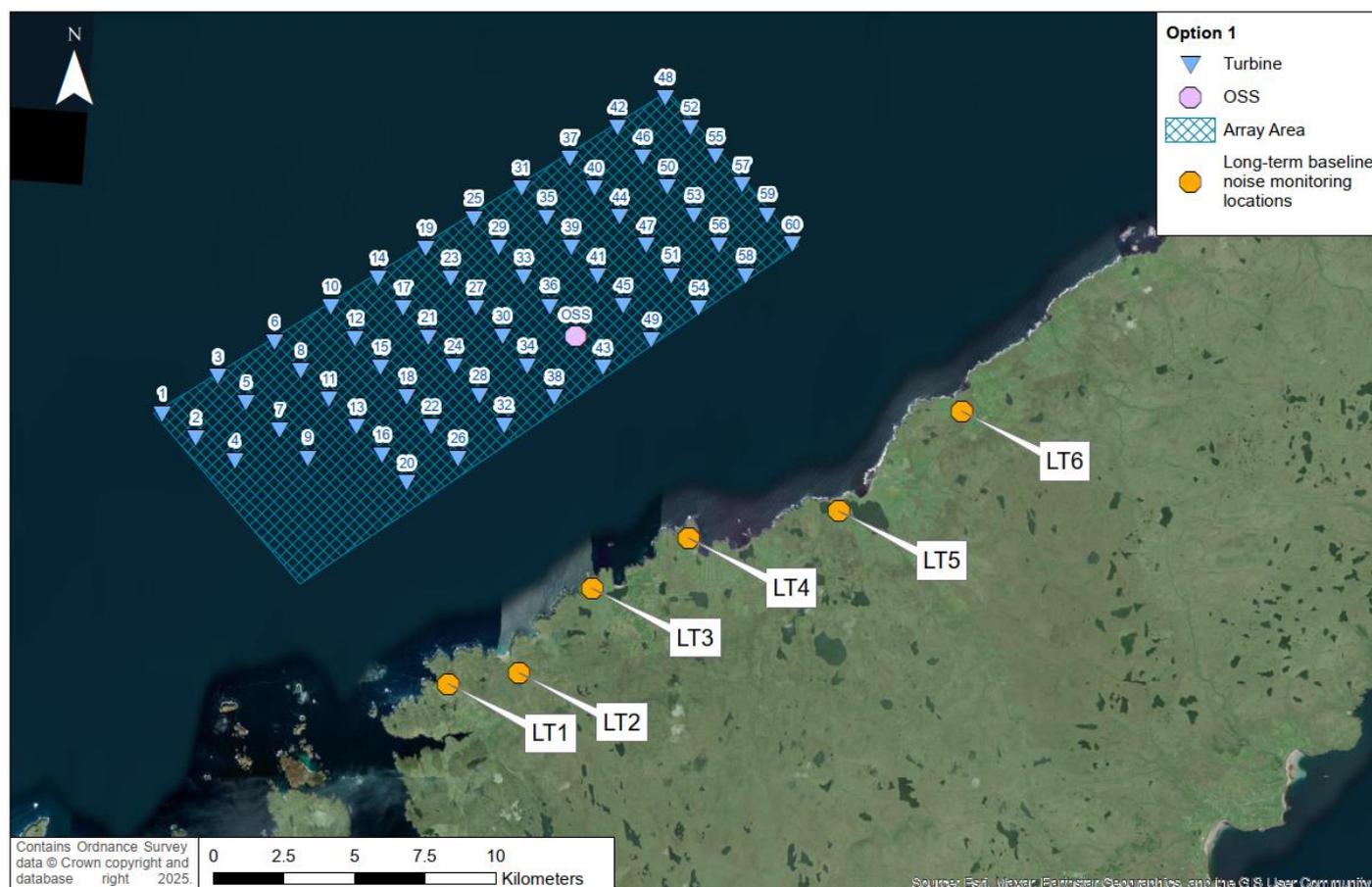
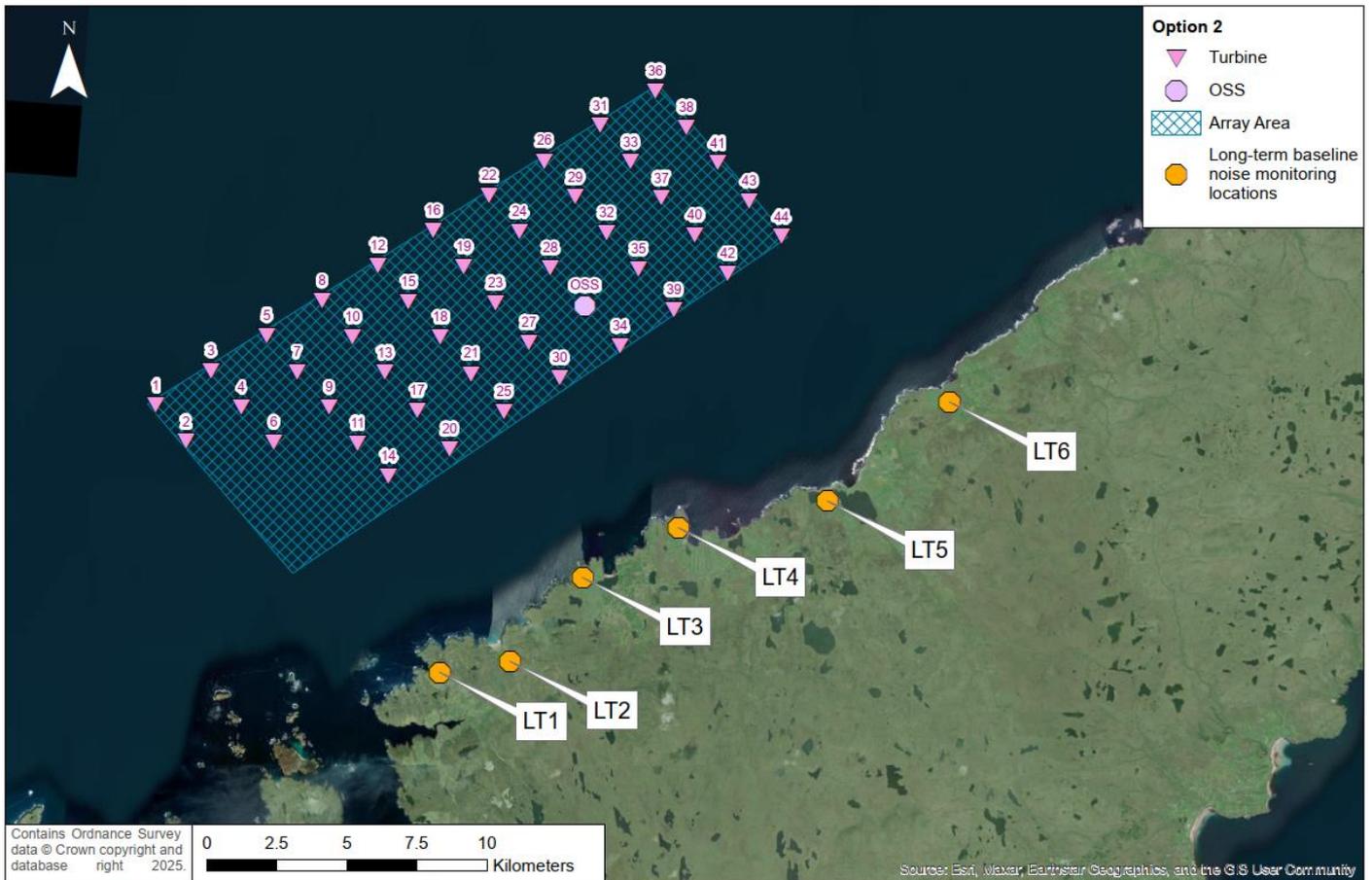


Table 2-3 Option 2 (largest WTG type) turbine locations for noise modelling (British National Grid references)

<b>Option 2: Wind turbine number</b>	<b>Easting (m)</b>	<b>Northing (m)</b>	<b>Option 2: Wind turbine number</b>	<b>Easting (m)</b>	<b>Northing (m)</b>
1	109309	953788	23	121451	957487
2	110407	952486	24	122299	960019
3	111292	955045	25	121746	953562
4	112380	953736	26	123192	962580
5	113276	956300	27	122632	956067
6	113531	952470	28	123409	958726
7	114364	954992	29	124283	961275
8	115259	957556	30	123734	954771
9	115514	953726	31	125175	963836
10	116348	956249	32	125413	959996
11	116525	952445	33	126266	962532
12	117242	958812	34	125892	955911
13	117493	954979	35	126549	958687
14	117625	951257	36	127158	965091
15	118331	957506	37	127375	961237
16	119226	960068	38	128250	963788
17	118646	953613	39	127806	957219
18	119479	956237	40	128552	959903
19	120315	958762	41	129375	962505
20	119806	952228	42	129735	958537
21	120575	954935	43	130496	961143
22	121208	961324	44	131655	959855

Plate 2-2 Option 2 (largest WTG type) turbine layout



### 3 PILING NOISE MODELLING METHOD

3.1.1.1 The indicative piling schedule detailed in **Table 3-1** is based on the Option 1 (smallest WTG type) bounding scenario, the layout with the highest number of turbines and piles. The turbine layout is indicative and will be further developed through detail design. Piling is programmed to take place between April-October over a 2-year period, further details are given in **Chapter 3, Volume 1a**.

Table 3-1 Indicative piling schedule – Option 1 (smallest WTG type) for noise modelling

Indicative piling schedule	Number
Maximum number of pin piles	256
Maximum number of drill and grout pin piles <sup>1</sup>	100 <sup>2</sup>
Maximum number of percussive pin piles	156 <sup>3</sup>
Piling years	2030/2031
Piling months	April-October
Pile duration	A maximum of 5.5 hrs for one pile, or 4.5 hours for a casing, driven in a 24-hour period.

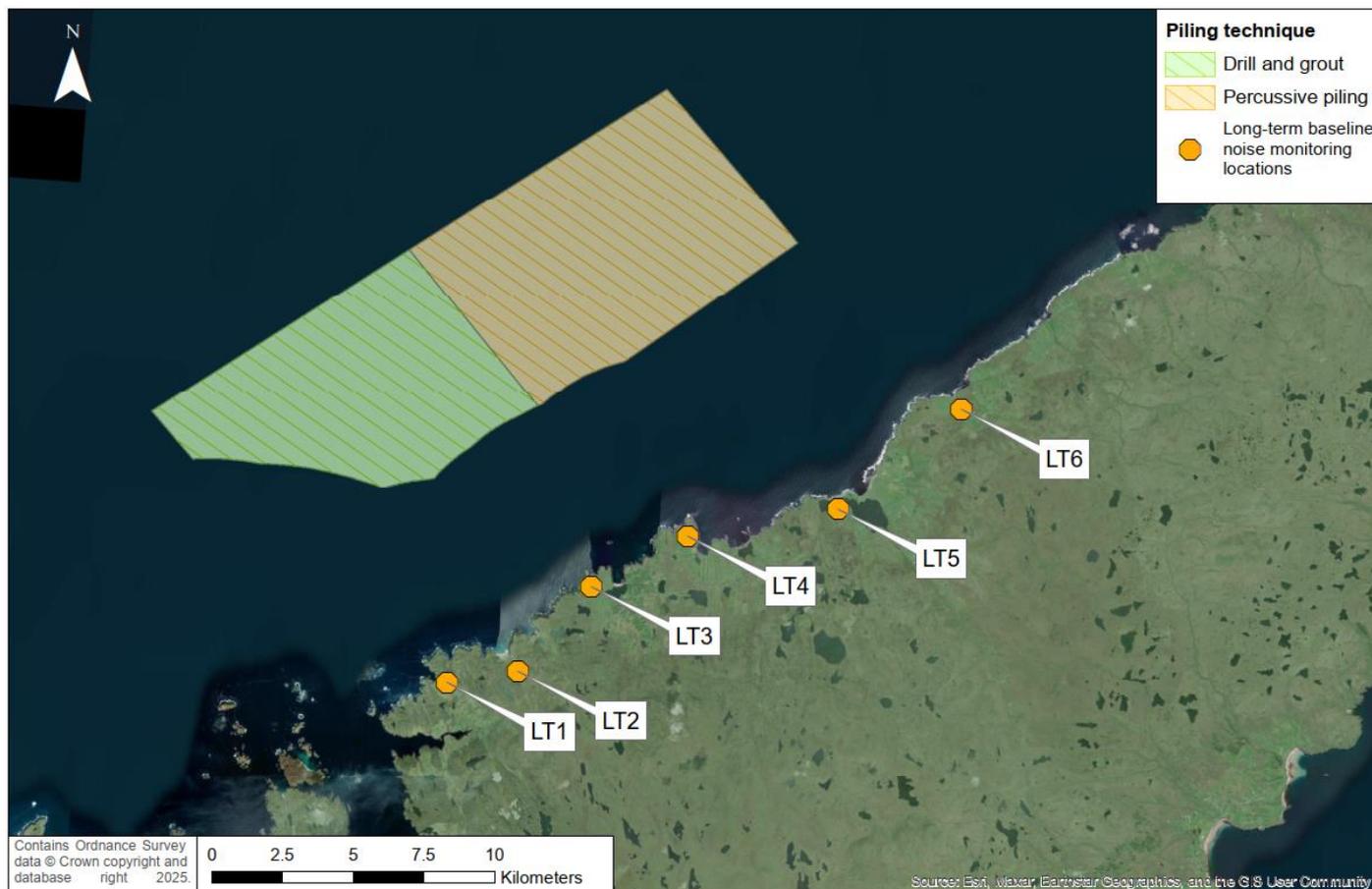
<sup>1</sup> The casing installation in the drill and grout area is not percussive.

<sup>2</sup> 25 turbines, each with four piles (drill and grout).

<sup>3</sup> 35 turbines, each with four piles (percussive) and 1 OSP with 16 piles (percussive).

3.1.1.2 2 piling techniques will be employed within the Array Area, drill and grout piling in the southwest, and percussive piles in the northwest; as shown in **Plate 3-1**. Further details are given in **Chapter 3, Volume 1a**

Plate 3-1 Piling technique areas



3.1.1.3 This assessment of airborne construction noise is based on the maximum design scenario, percussive piling, which can generate airborne sound power levels up to 145 dBA. The broadband sound power source level is taken from Van Renterghem, T *et al.* 'Propagation distance-of-concern for offshore wind turbine airborne sound during piling and normal operation' in Proceedings of Forum Acousticum (2014).

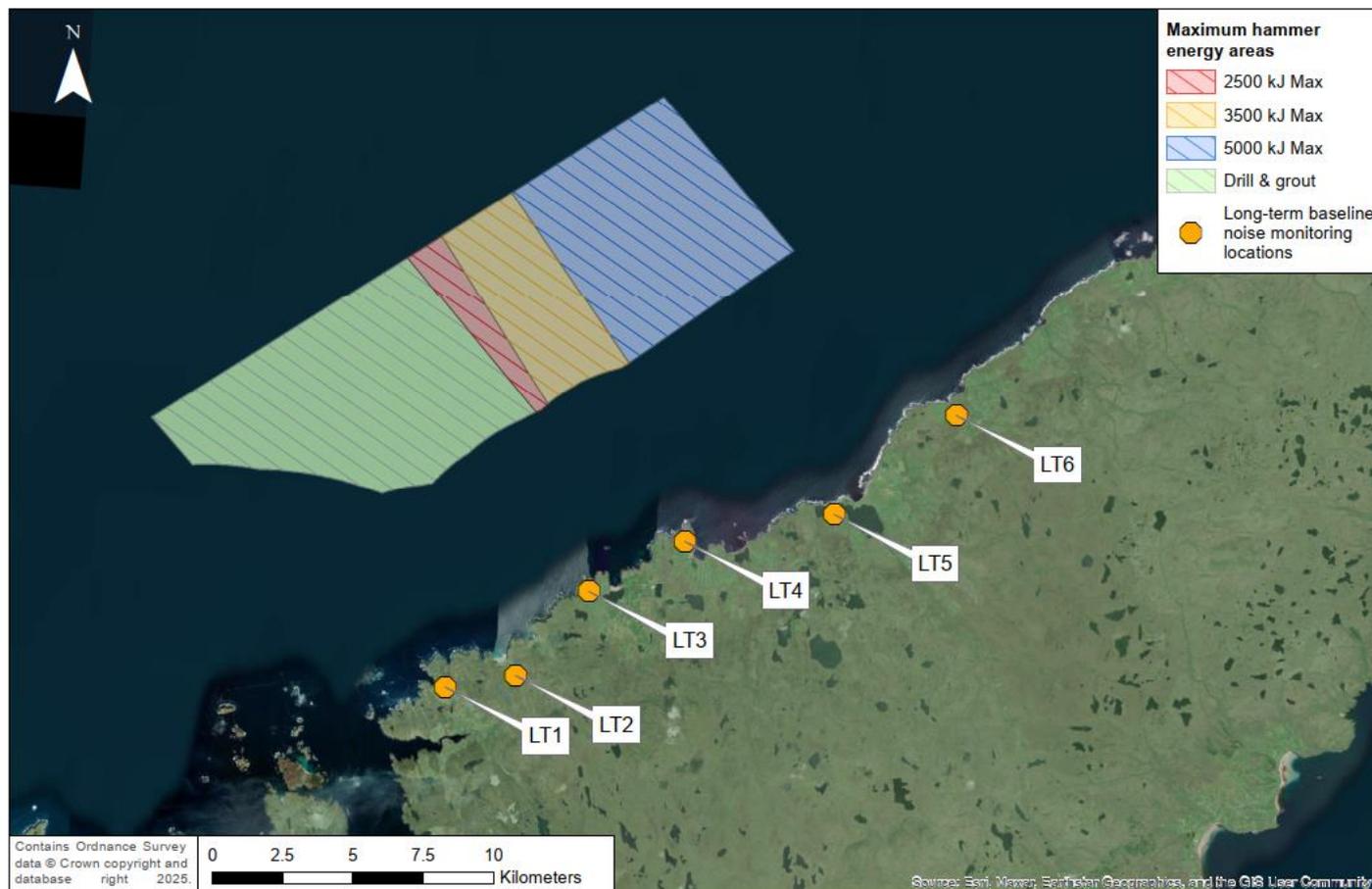
3.1.1.4 The indicative percussive pile programme is detailed in **Table 3-2**. There will be no concurrent percussive piling at different pile locations. There may be concurrent installation of piling of up to 1 percussive and 1 drill and grout pile.

Table 3-2 Indicative percussive pile programme for Noise Modelling and Prediction

Month	2030/2031 number of percussive piles
April	10
May	12
June	12
July	12
August	12
September	10
October	10

- 3.1.1.5 A geotechnical survey has identified a buried channel within the percussive piling area, dividing the area into 2 distinct regions which require different piling techniques. Additional buried channel information is given in **Appendix 3.1: Percussive Piling Installation Approach, Volume 1c** and **Appendix 13.3: Underwater Noise Modelling Assessment, Volume 2c**, including Figure 3-7.
- 3.1.1.6 All piles (within and outside the buried channel) will be installed at a strike rate of 34 blows per minute. Exception during the soft start, during which there is 1 strike per minute for 5 minutes, followed by the ramp up phase, during which there are 6 strikes per minute for 15 minutes.
- 3.1.1.7 Within the buried channel, 5 m diameter pin piles are proposed, installed using maximum blow energy of 2,500 kJ, 3,500 kJ, or 5,000 kJ and driving for up to 5.5 hours and 10,635 strikes within a day. The percussive piling hammer energy areas are illustrated in **Plate 3-2**.
- 3.1.1.8 Outside the buried channel, 5 m diameter piled casings are proposed, installed using a maximum blow energy of 3,500 kJ or 5,000 kJ and driving for up to 4.5 hours and 8,595 strikes within a day.

Plate 3-2 Piling hammer energy areas



3.1.1.9 Construction piling noise levels have been determined through application of the ISO 9613-2:1996 'Acoustics – Attenuation of sound during propagation outdoors. Part 2: General method of calculation' (ISO 9613-2) methodology, with an adaption applied for propagation over water to account for reduced distance attenuation (compared to propagation over land).

3.1.1.10 The propagation of piling noise over the sea is affected by several variables. Van Renterghem, T., *et al* in Journal of the Acoustical Society of America (JASA) conclude that a flat sea surface results in the highest noise levels. The presence of wind, even when blowing downwind to receivers, will increase attenuation of piling sound over the sea due to an increase in scattering of a non-flat sea surface.

3.1.1.11 The propagation method applied to piling noise is the same approach as detailed in Section 4.2 below for offshore wind turbine noise prediction. Under certain meteorological conditions, the sea surface acts as a reflective boundary, and the temperature gradient and/or wind direction refracts sound down toward the sea surface. During such conditions, sound 'bounces' over the sea surface multiple times, the resultant sound level at Noise sensitive receptors (NSRs) is increased compared to typical spherical spreading (reducing by 6 dB per doubling of distance).

- 3.1.1.12 To account for the multiple reflection phenomenon, a cylindrical radiation adaption factor is applied. For piling noise, the crossover distance from spherical to cylindrical propagation set at 1,000 m, based on the piling noise source height. Section 4.2 provides further details on cylindrical spreading and justification for the adopted prediction methodology.
- 3.1.1.13 Multiple reflections, modelled using cylindrical spreading, represent a worst-case scenario - typically occurring over flat sea surfaces and under downwind conditions. Outside these conditions, propagation will tend towards spherical radiation, with further reductions expected under upwind conditions. The construction piling noise assessment considers both cylindrical propagation (worst-case) and spherical propagation models, across varying hammer energy levels.
- 3.1.1.14 To provide further context, the proportion of time during which wind conditions are suitable for multiple reflections has been considered.
- 3.1.1.15 The Applicant has provided predicted 20-year wind distribution data for the Offshore Project maximum hub heights (175.8 m and 198.4 m). Analysis of the wind data has been completed to identify the percentage of time that atmospheric conditions are likely to result in increased sound propagation.
- 3.1.1.16 Calm conditions are required to enable a flat sea surface to occur, it is assumed that flat seas happen in wind speeds up to 2.5 m/s (all directions); these conditions occur for 8% of the time between April and October.
- 3.1.1.17 Multiple reflections (cylindrical spreading) are understood to occur under downwind conditions, for this analysis downwind conditions are taken to be wind directions between 270° and 0°, and for wind speeds between 2.5 m/s and 5.5 m/s; these conditions occur for 6% of the time between April and October.
- 3.1.1.18 It is concluded that atmospheric conditions that increase sound propagation occur for up to 14% of the time.

## 3.2 PERCUSSIVE PILING SPECTRAL DATA

- 3.2.1.1 The noise emission spectrum adopted in this assessment is WSP library measurement data of offshore piling. The measurement spectrum is normalised to a sound power level of 145 dB(A). The percussive piling spectral data is detailed in **Table 3-3**.

Table 3-3 Piling 1/1 octave band sound power level data ( $L_w$ , dB / dB(A)) for Noise Modelling and Prediction

Frequency (Hz)	Percussive piling $L_w$ (dB)
63	147.8
125	142.8
250	143.8
500	139.8
1,000	138.8
2,000	138.8
4,000	135.8
8,000	128.8
<b>Total <math>L_{WA}</math> dB</b>	<b>145.0</b>

## 4 WIND TURBINE NOISE MODELLING METHOD

### 4.1 ONSHORE WIND TURBINE NOISE CALCULATION METHOD

- 4.1.1.1 Onshore wind turbine noise level predictions have been undertaken for the cumulative development that has been scoped-in to the assessment (the Baile an Truiseil Energy Project (BaT Wind Farm) and Horshader wind turbine).
- 4.1.1.2 In accordance with the Institute of Acoustics: *A Good practice guide to the application of ETSU-R-97 for the assessment and rating of wind turbine noise* (IOA GPG), noise level predictions have been undertaken in accordance with the ISO 9613-2:1996 prediction method, applying the recommended parameter settings laid out in the IOA GPG, as summarised below.
- 4.1.1.3 The calculation method is used to determine the sound pressure level at the point of interest under downwind propagation conditions.

#### Noise Prediction Parameters

- 4.1.1.4 No topographic or barrier screening corrections are included in the calculations due to the generally flat topography between the BaT Wind Farm and its closest NSRs; or between the Horshader wind turbine and its closest NSRs. For the same reason, no corrections for propagation over concave ground profiles (valley corrections) have been included either.
- 4.1.1.5 For the BaT and Horshader wind turbines, no corrections have been applied to determine NSR levels under other (i.e. non-downwind) propagation directions.
- 4.1.1.6 The ISO 9613-2: 1996 prediction method determines the sound pressure level at the point of interest (receiver) based on the sound power level of the source and taking into account the effects of directivity, geometric divergence, atmospheric absorption, ground absorption, barrier attenuation and other miscellaneous factors. The following equation is applied:

- Predicted Octave Band Sound Pressure Level =  $L_W + D_c - A_{div} - A_{atm} - A_{gr} - A_{bar} - A_{misc}$

- 4.1.1.7 Each of the above terms are considered in more detail below.
- 4.1.1.8 Where there are multiple noise sources affecting the resulting noise level, the equation can be applied numerous times (once for each source), with the results combined to determine the final all-encompassing sound pressure level.
- 4.1.1.9 A 3D noise model has been generated for the Array Area and the northwest coast of Isle of Lewis/*Eilean Leòdhais* within the CadnaA® noise modelling suite. The model has been set to apply the ISO 9613-2: 1996 calculation method with the following setting made to ensure compliance with the IOA GPG:

- Ground absorption: land (G)=0.5;

- NSR calculation height: 4 m;
- Topography: none;
- A correction from  $L_{Aeq,T}$  to  $L_{A90,T}$  of -2 decibel (dB) was applied;
- Temperature: 10°C;
- Humidity: 70%.

4.1.1.10 Within the noise model, each wind turbine forming part of the BaT and Horshader Wind Farms were represented as individual, geographically located point source. The point source heights were set at hub height, as required by the IOA GPG.

#### **$L_w$ – Sound Power Level**

4.1.1.11 This is the octave band sound power level, in decibels, produced by the sound source (in this case the wind turbine), relative to a reference sound power of 1 picowatt (pW).

4.1.1.12 Sound power level data have been applied for each of the wind turbines modelled, with the source set at hub height. In accordance with the IOA GPG, checks have been carried out to determine whether appropriate corrections for uncertainty had been included within the adopted source data. Where this was found not to be the case, an appropriate uncertainty correction was added.

#### **$D_c$ – Directivity**

4.1.1.13 This is the directivity correction, in decibels, describing the extent to which the level from the source deviates depending upon the direction. In this case, the calculation assumes that the source is omnidirectional, i.e. sound is generated equally in all directions.

#### **$A_{div}$ – Geometric Divergence Attenuation**

4.1.1.14 As sound propagates from the source, the energy disperses resulting in sound levels reducing relative to distance. Over land, sound from point sources, such as wind turbines, propagates under the inverse square law (spherical spreading), reducing by 6 dB per doubling of distance.

#### **$A_{atm}$ – Atmospheric Attenuation**

4.1.1.15 This is the attenuation of sound, in decibels, due to energy absorption in the atmosphere. It is dependent upon both the temperature and the relative humidity. The selection of 10°C temperature and 70% relative humidity within the noise model ensures appropriate corrections are applied in the calculation in accordance with the IOA GPG.

#### **$A_{gr}$ – Ground Attenuation**

4.1.1.16 This is the attenuation of sound, in decibels, due to ground effects. This is taken into account through the application of a ground factor (G), representative of whether the ground is acoustically soft (absorbent) or acoustically hard (reflective). The selection of  $G=0.5$  within the noise model, in conjunction with a receiver height of 4 metres (m), ensures appropriate corrections are applied in the calculation in accordance with the IOA GPG.

### **A<sub>bar</sub> – Barrier Attenuation**

- 4.1.1.17 This is the attenuation of sound, in decibels, due to barriers, for example that which could arise as a result of a building or landform between the source and the receiver position. The level of attenuation afforded is dependent upon a number of factors including the geometric relationship between the source and the receiver and the degree to which the barrier obscures the line of sight between the 2. The ISO 9613-2 prediction method can account for large degrees of screening attenuation (e.g. 10 dB and greater) which have been found to be significantly greater than those measured for wind turbines noise under downwind propagation conditions. The IOA GPG therefore advises that, unless there is reasoned justification, the barrier attenuation should be capped at 2 dB, with this level only applied where the barrier (e.g. topography) fully obscures the line of sight between the receiver and the wind turbine tip height.
- 4.1.1.18 The noise model outputs have therefore been adjusted such that the full ISO 9613-2 barrier attenuations are not applied, instead being capped at a maximum 2 dB, and reduced to 0 dB where if there is any of sight to the wind turbine tip height. In this case, there is line of sight between the tip of the closet BaT and Horshader Wind Farm turbines and the nearest NSR, so all barrier attenuations have been reduced to 0.

### **A<sub>misc</sub> – Miscellaneous Attenuations**

- 4.1.1.19 This is the attenuation of sound, in decibels, due to other miscellaneous effects, such as propagation through foliage, industrial sites or built-up regions of housing. No such miscellaneous attenuations have been included in the completed calculations.

### **Concave Ground Profiles (Valley corrections)**

- 4.1.1.20 The IOA GPG advises that a correction of +3 dB (or +1.5 dB if using  $G=0.0$ ) should be added to the calculated receiver noise level for situations where there is propagation across a valley, i.e. a concave ground profile, or where the ground falls away significantly between the source and receiver location. This is to account for the possible effect of ground reflections focussing at the receiver.
- 4.1.1.21 The +3 dB correction is applied where the mean height above ground of the direct line of sight from the receiver to the source is greater than, or equal to, half of the absolute height difference between the source and receiver.
- 4.1.1.22 In this case, because the topography between the BaT and Horshader wind turbines and the closest NSRs is generally flat, no valley corrections have been applied.

## 4.2 OFFSHORE WIND TURBINE NOISE CALCULATION METHOD

4.2.1.1 Offshore wind turbine noise level predictions have adopted the same method as applied for onshore wind turbines (i.e. ISO 9613-2: 1996), see Section 4.1, but with parameter selections and adaptations applied as appropriate for propagation over water.

### Noise Prediction Parameters

4.2.1.2 The following parameters/settings have been made for offshore turbine noise propagation calculations:

- Ground absorption: sea (G)=0, land (G)=0.5;
- NSR calculation height: 4 m;
- Topography: none;
- A correction from  $L_{Aeq,T}$  to  $L_{A90,T}$  of -2 decibel (dB) was applied;
- Temperature: 10°C;
- Humidity: 70%.

4.2.1.3 No topographic or barrier screening corrections are included in the calculations because propagation is over water. For the same reason, no corrections for propagation across concave ground profiles (valleys) have been included either.

4.2.1.4 Described below are the details of the prediction calculation terms as applied in the offshore wind turbine noise calculations.

### $L_w$ – Sound Power Level

4.2.1.5 The same as for onshore wind turbine noise calculation, except that all source data has included a +2 dB uncertainty correction. Sound Power level data specific to the candidate turbines has been applied.

### $D_c$ – Directivity

4.2.1.6 Calculations have been undertaken for Downwind conditions, Upwind conditions and Crosswind conditions. The applied directivity corrections have been calculated based on 'Figure 6a' from the IOA GPG (directional corrections for flat landscapes).

### $A_{div}$ – Geometric Divergence Attenuation

4.2.1.7 As sound propagates from the source, the energy disperses resulting in sound levels reducing relative to distance. Over land, sound from point sources, such as wind turbines, propagates under the inverse square law (spherical spreading), reducing by 6 dB per doubling of distance. For sound propagation over large bodies of water, this can overestimate the noise attenuation that arises, so an adaptation is required to account for this.

4.2.1.8 The adaption applied for propagation over water has followed the principle applied in IOA GPG Supplementary Guidance Note (SGN) 6: Noise propagation over water for on-shore wind turbines. Whilst the title of this SGN suggests that it is applicable to onshore wind turbine noise propagating, paragraph 2.2.3 states:

*“GPG Para 4.3.5 requires a  $G=0$  Hard Ground Correction to be used for the calculation of noise propagation over large bodies of water which cover at least 50% of the distance. Where the body of water is at least 700 m in extent (**or the turbine is offshore**) [our emphasis], the following formula should be used: ...”*

$$L=L_s -20\log(r) +3 -\Delta L_a +10\log(r/700)$$

4.2.1.9 The presented formula includes an adaption factor ( $+10\log(d/d_0)$ ) to reduce distance attenuation from spherical radiation (6 dB loss per double of distance) to cylindrical radiation (3 dB loss per doubling of distance) beyond a reference distance ( $d_0$ ) for the remainder of the total propagation distance to the NSR ( $d$ ).

4.2.1.10 The value of  $d_0$  stated in the SGN 6 is 700 m, which is consistent with: Long-Range Sound Propagation Over the Sea with Application to Wind Turbine Noise, Final report for the Swedish Energy Agency project 21597-3 (M. Boué), as current at the time of publication of the IOA GPG, but this was then updated in the Swedish prediction method to  $d_0 = 1000$  m accounting for more recent research contained in *Measuring and Calculating Sound from Wind Turbines: Guidance Document* (Swedish Environmental Protection Agency 2013).

4.2.1.11 Conference paper: *Assessment of noise prediction methods for long range sound propagation of wind turbines over water* (Mylonas and Uzunoglu, 2015) confirms: *“Initially the Swedish method of 2002 suggested that the phenomena of multiple reflections on water already started at 200 m distance. This was later corrected to 700 m and finally set to 1000 m. Hence, after 1000 m sound attenuation will be 3 dB and not 6 dB per doubling of distance”.*

4.2.1.12 The loss of distance attenuation during propagation over sea/water (compared to over land) is due to a multiple reflection/refraction effects, which are a) less prevalent when there is a negative temperature gradient (temperature decreasing with height) because atmospheric reflections/refractions are lessened under these conditions, and b) dependant on the source height above water.

4.2.1.13 With respect of source height, the higher the source, the lower the loss of distance attenuation. The research on which the Swedish method ( $d_0 = 1,000$  m) is based, was for source heights substantially lower height than the 175.8 m and 198.4 m hub heights associated with Option 1 and Option 2 respectively.

4.2.1.14 Conference paper: *Long distance noise propagation over water for an elevated height-adjustable sound source* (Sondergaard et al), from the 9<sup>th</sup> international conference on Wind Turbine Noise (18-21 May 2021) confirms:

*"1.2 Multiple reflections. Multiple reflections (sometimes also called "cylindrical spreading") is an effect that can happen when sound propagates over relatively large distances, especially over acoustically hard reflecting surfaces such as water....*

*It is caused by downward refraction up to a sufficiently high altitude that causes the sound field to bend towards and be reflected by the terrain (water) surface. Over longer distances the sound field can bend down and be reflected multiple times. Unlike a situation without downward refraction, the sound cannot "escape".*

*The acoustically hard surface contributes a minimum of phase change in the reflection making the sound field more coherent than for reflections from acoustically softer surfaces. The longer the propagation occurs with downward refraction towards the ground, the less is the effect of spherical spreading (hence the name "cylindrical spreading").*

4.2.1.15 It goes on to discuss different contributing factors, confirming that the higher the source is, the lower the loss of distance attenuation, because the noise has travelled further under spherical conditions before any refraction/reflection effects can occur:

*"The higher a sound source is located, the greater distance is required, before the sound field is refracted to the ground. Since multiple reflections occur a long distance from the source, less energy can build up resulting in lower noise levels".*

4.2.1.16 Similarly, the Danish BEK 135 prediction method, which is specifically for offshore wind turbine noise prediction, also applies an adaption factor to account for the transition from spherical radiation to cylindrical radiation, but with a more complex application accounting for source height. More distance attenuation is afforded as the source height increases.

4.2.1.17 Consistent with this, conference paper: *Assessment of noise prediction methods for long range sound propagation of wind turbines over water* (Mylonas and Uzunoglu, 2015) concluded the following:

*"The calculations with the CNPE method over a totally reflecting water surface indicated that the transition from spherical (6 dB per doubling of distance) to cylindrical spreading (3 dB reduction of doubling of distance) of sound is related to the height of the source and for an average height of 100 m does not occur before 3000-4000 m distance for a receiver height of 1.5 m for frequencies 63 Hz to 125 Hz. In addition for a source of 65 m the transition to cylindrical spreading seems to occur after 1000 - 2000 m. The Swedish method assuming a transition at 1000 m seems unrealistic".*

4.2.1.18 Accounting for the proposed hub heights, and drawing on the most recent research, a reference distance ( $d_0$ ) of 3,000 m has been applied. The same approach ( $d_0 = 3,000$  m) was also applied in the noise assessment as reported for the *Pentland Floating Offshore Wind Farm: Pentland floating offshore wind farm Volume 3: Appendix A.5.1: Operational Turbine Noise Assessment*. The typical hub height for that development was stated to be 165 m, i.e. lower than that proposed for both Options 1 and 2 as being considered here (see **Table 2-1**). This further supports the approach as duly conservative for the Offshore Project.

### **$A_{atm}$ – Atmospheric Attenuation**

4.2.1.19 The same as for onshore wind turbine noise calculation.

### **$A_{gr}$ – Ground Attenuation**

4.2.1.20 The same as for onshore wind turbine calculation, except that  $G=0$  has been applied in accordance with the IOA GPG SGN6.

### **$A_{bar}$ – Barrier Attenuation**

4.2.1.21 The same as for onshore wind turbine noise calculation. All barrier attenuations have been reduced to 0 given that there would be no barriers between the turbines and the coastline.

### **$A_{misc}$ – Miscellaneous Attenuations**

4.2.1.22 The same as for onshore wind turbine noise calculation. No miscellaneous attenuations have been included in the completed calculations.

### **Concave Ground Profiles (Valley corrections)**

4.2.1.23 The same as for onshore wind turbine noise calculation. No valley corrections have been applied because propagation is over the sea.

## 5 GLOSSARY OF TERMS AND ABBREVIATIONS

5.1.1.1 A list of key terms and acronyms used in this Appendix are provided in **Table 5-1** and **Table 5-2**.

Table 5-1 Acronyms and abbreviations

Term	Definition
°C	Degrees centigrade
BaT	Baile an Truiseil (an existing wind farm)
BEK	Bekendtgørelse (English Translation from Danish: 'Regulation')
dB	Decibel
dB(A)	A-weighted decibel
EIAR	Environmental Impact Assessment Report
kJ	Kilojoule
IOA GPG	The Institute of Acoustics' guidance document: <i>A Good practice guide to the application of ETSU-R-97 for the assessment and rating of wind turbine noise</i>
Hz	Hertz
NSR	Noise sensitive receptor
m	metres
m/s	Metres per second
MHWS	Mean High Water Springs
MW	Megawatt
OCAS	Offshore Cable Area of Search
OSP	Offshore Substation Platform
OWF	Offshore Wind Farm
pW	Picowatt
SGN	Supplementary Guidance Note
WTG	Wind turbine generator

Table 5-2 Glossary

Term	Meaning
$A_{atm}$	Atmospheric Attenuation
$A_{bar}$	Barrier Attenuation
$A_{div}$	Geometric Divergence Attenuation
$A_{gr}$	Ground Attenuation
$A_{misc}$	Miscellaneous Attenuations
A-weighting	Frequency weighted sound level, weighted according to the A-scale, which takes into account the increased sensitivity of the human ear at some frequencies.
d (or r)	Distance between source/turbine hub and the observer/NSR
$d_0$	Distance beyond which spherical spreading is assumed
$D_c$	Directivity
G	Ground absorption coefficient
K	kilo

Term	Meaning
$L_{A90,T}$	A statistical noise index defined as the level that is exceeded for 90% of the time over the measurement time period T. The 'A' denotes that the level is determined with 'A-weighting' applied.
$L_{Aeq,T}$	The 'continuous equivalent sound level' noise index. A single-figure noise index that represents the constant sound level that would contain the same sound energy as the fluctuating noise experienced over the time-period 'T'. The 'A' denotes that the level is determined with 'A-weighting' applied.
L	Sound pressure level at the observer/NSR
$\Delta L_a$	The integrated frequency dependent absorption coefficient, a function of r
$L_s$	The turbine sound power
$L_W$	Linear sound power level
$L_{WA}$	A-weighted sound power level

## 6 REFERENCES

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