Pentland floating offshore wind farm

Volume 3: Appendix A.5.1

Operational Turbine Noise Assessment

PENTLAND FLOATING OFFSHORE WIND FARM

OFFSHORE EIAR (VOLUME 3): TECHNICAL APPENDICES

APPENDIX 5.1: OPERATIONAL TURBINE NOISE ASSESSMENT

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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 Pentland Floating Offshore Wind Farm (PFOWF) Array. The report specifically considers the impact of airborne noise from the offshore turbines on onshore noise-sensitive residential receptors, including cumulative considerations. 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 the largest turbine layout at the closest point to the shore, with relatively high noise emissions. Account was taken of the potential for enhanced noise propagation which can occur over water in certain conditions. The potential combination of the noise from the PFOWF Array along with the following wind farms was considered: Limekiln Wind Farm and extension, Drum Hollistan 2 Wind Farm, Ackron Wind Farm, Baillie Wind Farm and Forss 1, 2 and 3 Wind Farms. The impacts of other wind farm projects located further away is considered negligible.

Noise limits have been derived, either based on the simplified assessment method stipulated in national planning guidance or based on the assessment undertaken for other wind farm sites considered. Predicted operational noise levels, based on estimates of emission levels for the turbines of the type and size which would be installed, have been compared to these limit values.

It can be demonstrated that the proposed turbines can operate within the limits derived at onshore locations, or that the cumulative impact on receptors in proximity to the other wind farm sites considered would be negligible. No substantial increase in duration or level of exposure was identified on this basis for any of the properties neighbouring other wind farms in the area. Therefore, it is concluded that operational noise levels from the wind farm are likely to be within levels recommended in national guidance for wind energy schemes.

A finalised desktop assessment of predicted noise levels could be undertaken when the selection of the proposed turbine layout and model has been finalised, although this is likely to result in lower noise levels than those set out in this report. 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 This report presents an assessment of the potential operational noise impacts of the offshore turbines of the Pentland Floating Offshore Wind Farm (PFOWF) Array on the residents of onshore dwellings. Noise will be emitted by equipment and vehicles used during construction and decommissioning of the PFOWF Onshore Transmission Infrastructure (the Onshore Development) and by the PFOWF Array turbines during operation: this report considers the latter operational assessment in detail, but not operational noise from the Onshore Development components or construction/decommissioning effects as these are not part of the scope of the Offshore Development EIA.

1.2 Assessment of operational noise accounts for the potential cumulative total of the PFOWF Array as well as other wind farms nearby, following consultation with the Highland Council (THC, see section 3.3 below). To identify the scope of this study, a representative selection of residential receptors at or close to the shore area which is closest to the proposed turbines were identified, up to around 3 km from the shoreline, and approximately 8 to 10 km from the proposed turbines. Wind farm developments, either consented or operational, which were potentially likely to affect these receptors cumulatively with the PFOWF Array were then identified based on information provided by THC: these were located within up to 5 km from the receptors identified. Based on the experience of similar projects, this study area is considered representative of the potential impacts and other, more distant wind farms were not considered because their potential noise contribution was considered negligible[1].

1.3 Specifically, the other onshore wind farms considered were the Limekiln Wind Farm and extension, Drum Hollistan 2 Wind Farm, Ackron Wind Farm, Baillie Wind Farm and Forss 1, 2 and 3 Wind Farms. It is understood that the Cairnmore Hill Wind Farm was refused consent and a new application for a reduced number of turbines is being considered. No further details are available, but it is in any case located more than 3 km further away from the PFOWF Array than the other wind farms considered.

1.4 Wind turbines may emit two types of noise. Firstly, aerodynamic noise is a 'broad band' noise, sometimes described as having a characteristic modulation, or 'swish', which is produced by the movement of the rotating blades through the air. Secondly, mechanical noise may emanate from components within the nacelle of a wind turbine. This is a less natural sounding noise which is generally characterised by its tonal content. Traditional sources of mechanical noise comprise gearboxes or generators. Due to the acknowledged lower acceptability of tonal noise in otherwise 'natural' noise settings such as rural areas, modern turbine designs have evolved to minimise mechanical noise radiation from wind turbines. Aerodynamic noise tends to be perceived when the wind speeds are low, although at very low wind speeds the blades do not rotate or rotate very slowly and so, at these wind speeds, negligible aerodynamic noise is generated. In higher winds, aerodynamic noise is generally masked by the normal sound of wind blowing through trees and around buildings. The level of this natural 'masking' noise relative to the level of wind turbine noise determines the subjective audibility of the wind farm. The relationship between wind turbine noise and the naturally occurring masking noise, at residential dwellings situated onshore closest to the PFOWF Array will, therefore, generally form the basis of the assessment of the levels of noise against accepted standards.

1.5 An overview of environmental noise assessment and a glossary of noise terms are provided in Annex A.

1 The IOA GPG suggests that cumulative noise effects need not be considered where differences between existing and proposed wind farm noise levels are 10 dB(A) or more.

2. Policy and Guidance Documents

2.1 Planning Policy and Advice Relating to operational Noise

2.1.1 Scottish Planning Policy (SPP)[2] provides advice on how the planning system should manage the process of encouraging, approving and implementing renewable energy proposals including onshore wind farms. Whilst SPP suggests noise impacts are one of the aspects that will need to be considered it provides no specific advice. Planning Advice Note PAN1/2011[3] provides general advice on the role of the planning system in preventing and limiting the adverse effects of noise without prejudicing investment in enterprise, development and transport. PAN1/2011 provides general advice on a range of noise related planning matters, including references to noise associated with both construction activities and operational wind farms. In relation to operational noise from wind farms, Paragraph 29 states that:

> *'There are two sources of noise from wind turbines - the mechanical noise from the turbines and the aerodynamic noise from the blades. Mechanical noise is related to engineering design. Aerodynamic noise varies with rotor design and wind speed, and is generally greatest at low speeds. Good acoustical design and siting of turbines is essential to minimise the potential to generate noise. Web based planning advice on renewable technologies for Onshore wind turbines provides advice on 'The Assessment and Rating of Noise from Wind Farms' (ETSU-R-97) published by the former Department of Trade and Industry [DTI] and the findings of the Salford University report into Aerodynamic Modulation of Wind Turbine Noise.'*

2.1.2 The Scottish Government's Online Renewables Planning Advice on Onshore wind turbines[4] provides further advice on noise, and confirms that the recommendations of 'The Assessment and Rating of Noise from Wind Farms' (ETSU-R-97)[5] "*should be followed by applicants and consultees, and used by planning authorities to assess and rate noise from wind energy developments*". The aim of ETSU-R-97 is:

> *'This document describes a framework for the measurement of wind farm noise and gives 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. The suggested noise limits and their reasonableness have been evaluated with regard to regulating the Project of wind energy in the public interest. They have been presented in a manner that makes them a suitable basis for noise-related planning conditions or covenants within an agreement between a developer of a wind farm and the local authority.'*

2.1.3 The recommendations contained in ETSU-R-97 provide a robust basis for assessing the noise implications of a wind farm. ETSU-R-97 has become the accepted standard for such developments within the UK. 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)[6]. This was subsequently endorsed by the Scottish Government[7] which advised in the web based planning advice note that this *'should be used by all IOA members and those undertaking assessments to ETSU-R-97'*, The methodology of ETSU-R-97 and

2 Scottish Planning Policy (SPP), Scottish Government, 2014.
3 Planning Advice Note 1/2011: Planning & Noise, Scottish Government, March 2011.
4 Scottish Government, Online Renewables Planning Advice, Onshore Wind Turbines (https://www.gov.scot/publications/onshore-wind-turbines-planning-advice). Updated 28 May 2014.
5 ETSU-R-97, the Assessment and Rating of Noise from Wind Farms, Final ETSU-R-97 Report for the Department of Trade & Industry. The Working Group on Noise from Wind Turbines, 1997.
6 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.
7 Letter from John Swinney MSP, Scottish Government, 29/05/2013

the IOA GPG has therefore been adopted for the present assessment and is described in greater detail below.

2.1.4 With regard to infrasound and low-frequency noise, the above-referenced online planning advice note, Onshore wind turbines refers to a report for the UK Government which concluded that *'there is no evidence of health effects arising from infrasound or low frequency noise generated by the wind turbines that were tested'*. On this basis, this aspect of wind turbine noise will not be considered further in the present report.

3. Scope and Methodology

3.1 Methodology for Assessing Wind Farm Operational Noise

3.1.1 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 using a standard correction.

3.1.2 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).

3.1.3 The day-time noise limit is derived from background noise data measured during the 'quiet periods of the day' defined in ETSU-R-97: 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 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). The precise choice of the fixed lower limit within the range 35 dB(A) to 40 dB(A) depends on a number of 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.

3.1.4 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 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 in ETSU-R-97 on the basis of World Health Organization (WHO) guidance[8] for the noise inside a bedroom and an assumed difference between outdoor and indoor noise levels with windows open. In the time since ETSU-R-97 was released, the WHO guidelines were revised to suggest a lower internal noise level, but conversely, a higher assumed difference between outdoor and indoor noise levels. Notwithstanding the WHO

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

guideline revisions, the ETSU-R-97 limit remains consistent with current national planning policy guidance with respect to night-time noise levels. In addition, following revision of the night-time WHO criteria, ETSU-R-97 has been incorporated into planning guidance for Wales, England and Scotland and at no point during this process was it felt necessary to revise the guidance within ETSU-R-97 to reflect the change in the WHO guideline internal levels. The advice contained within ETSU-R-97 remains a valid reference on which to continue to base the fixed limit at night.

3.1.5 The exception to the setting of both the 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.

3.1.6 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.'*

3.1.7 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. The assessment will therefore need to consider the combined operational noise of the PFOWF Array with other wind farms in the area to be satisfied that the combined cumulative noise levels are within the relevant ETSU-R-97 criteria. The IOA GPG however suggests that cumulative noise effects need not be considered where differences between existing and proposed wind farm noise levels are 10 dB or more, as this represents an acoustically negligible effect.

3.1.8 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.

3.1.9 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 within the PFOWF Array.

3.2 Operational Noise Criteria

3.2.1 The acceptable limits for wind turbine operational noise are clearly defined in the ETSU-R-97 document and these limits should not be breached. 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 the noise limits derived in accordance with ETSU-R-97. Depending on the levels of background noise the satisfaction of the ETSU-R-97 derived 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 PFOWF Array will still be within levels considered acceptable under the ETSU-R-97 assessment method.

3.3 Consultation

3.3.1 It was initially proposed in the scoping request for the Project to assess airborne operational noise impacting onshore noise-sensitive receptors, but scope out potential cumulative impacts due to the interaction with other onshore or offshore components, as these were considered either too distant or unlikely to be associated with an acoustically important increase in noise.

3.3.2 In their scoping response, The Highland Council (THC) acknowledged there was limited likelihood of operational noise being an issue at onshore noise-sensitive receptors. However, THC recommended that an operational noise assessment in line with ETSU-R-97 and applicable good practice guidance from the IOA GPG was undertaken in detail: this could require in some cases background noise measurements in accordance with ETSU-R-97.

3.3.3 A cumulative assessment may be required in relation to existing or consented or, in some cases, proposed wind turbine developments, unless predicted noise levels are negligible (more than 10 dB below that of the PFOWF Array), taking into account, where relevant, consented levels for these schemes. The potential increase in noise exposure associated with a property becoming affected by wind turbine noise from more than one direction should specifically be considered.

3.3.4 It was proposed in consultation with the Environmental Health Department of (THC) in September 2021 to undertake a desktop predictive assessment without the need for additional background noise monitoring. This was because it was considered likely that predicted operational noise levels from the PFOWF Array would be below 35 dB L_{A90} at all closest onshore locations on the basis of preliminary modelling results. This consultation was based on similar assumptions for the PFOWF Array layout as that currently proposed. This was accepted by the THC representative (email response dated 28/09/2021).

3.3.5 The scoping response from THC also noted that: "any complaints linked to amplitude modulation would be investigated in terms of the Statutory Nuisance provisions of the Environmental Protection Act 1990." This will therefore not be considered in further detail in this report.

4. Baseline

4.1 General Description

4.1.1 The noise sensitive receptors considered in this study are located in an area of relatively low population density. The noise environment in the surrounding area is expected to be typical of the rural location, and generally characterised by 'natural' sources, such as wind disturbed vegetation, birds, farm animals and to the north of the site, coastal water movements. Other sources of noise likely include intermittent local road and agricultural vehicle movements in the area. In proximity to the Dounreay Site (former nuclear facility), industrial noise may be perceptible at times. Some of the properties considered in relative proximity to operational wind farm sites are also likely to be exposed to existing wind turbine noise.

4.2 Noise-sensitive properties considered

4.2.1 The assessment has considered operational noise from the PFOWF Array at a selection of representative residential properties: these assessment locations are listed in Table 1. The list of receptor locations is not intended to be exhaustive but sufficient to be representative of noise levels typical of those receptors requiring consideration. These were selected into different groups, as detailed in Table 1: first of all, the locations considered as part of the assessment of the Onshore Development were considered in the first instance. The properties along the shoreline closest to the proposed PFOWF Array were also considered. Finally, properties neighbouring the different cumulative wind farms (WF) which may potentially be affected by the PFOWF Array were also considered. All of the properties considered are located approximately 8 km to 10 km from the closest potential location of the offshore turbines of the PFOWF Array. The properties are also shown on Figure B1 in Annex B.

Table 1 - Assessment properties in the vicinity of the proposed development

Property	Easting	Northing	Property group	Approximate Distance to Closest PFOWF Array Turbine (m)
Isauld House	297442	965774	Onshore Development elements	9,420
Isauld Lodge	297563	965505	Onshore Development elements	9,720
Farm house A836	299014	966181	Onshore Development elements	10,000
Fresgoe	295702	966097	Shoreline properties	8,360
Portskerra shore	287910	966348	Shoreline properties	8,160
Portskerra	287774	965855	Shoreline properties	8,660
Bighouse	289116	964910	Shoreline properties	9,180
Sandside House	295170	965309	Shoreline properties	8,930
Reay	296073	964909	Shoreline properties	9,600
Achins	295877	964090	Limekiln WF and extension	10,310
Borlum House	297199	964065	Limekiln WF and extension	10,820
Loanscorribest	298508	964010	Limekiln WF and extension	11,480
Achiebraeskiall	301667	965128	Baillie WF	12,580
Buolfreuoch	301799	966448	Baillie WF	11,810
Stemster	303827	965661	Baillie WF	13,890
House west of Halladale Bridge	289385	963121	Ackron / Drum Hollistan 2 WF	10,890
Ackron Farm	289980	962514	Ackron / Drum Hollistan 2 WF	11,420
Hill of Lybster	302659	969164	Forss Wind Farm and extensions	11,090
Crosskirk	303080	969885	Forss Wind Farm and extensions	11,200

4.2.2 Relevant noise limits are considered below in further detail in relation to the ETSU-R-97 individual or cumulative noise assessment where relevant.

4.3 Operational Wind Turbine Emissions Data

4.3.1 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 18 MW, with a rotor diameter of up 260 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.

4.3.2 To assist with this assessment, indicative worst-case noise emissions levels from a wind turbine manufacturer were provided by Highland Wind Limited (HWL), for a 10 MW and 18 MW turbine. 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 be at prototype stage. However, this is considered robustly representative of the turbines of up to 260 m rotor diameter which may be used for the PFOWF Array. A further +2 dB was added to the manufacturer data provided to obtain robust emission levels, for both the 10 MW and 18 MW models: 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 wind speeds reference using the standard procedure of IEC 61400-11 based on a hub height of 165 m. The noise modelling in this report is based on the minimum hub height 165 m for the PFOWF Array as this represents the worst-case for noise propagation.

4.3.3 In addition to the overall sound power data, it is necessary to consider a representative sound spectrum for the turbine. In the absence of available test data for turbines of this type, reference was made to a representative spectrum[9] considered for the Dounreay Trì Floating Wind Demonstration Project (The Dounreay Trì Project). The spectrum was then scaled to match the A-weighted sound power levels indicated. The overall sound power and spectral data are presented in Table 2 and Table 3.

4.3.4 The assumed sound power levels are more than 10 dB higher than those of typical onshore turbine models and 7 to 8 dB higher than those assumed for the Dounreay Trì Project. This is substantial considering that a 10 dB increase would require the acoustic energy to be 10 times higher, which is considered unlikely, even accounting for the turbine power capacity and dimensions considered. Therefore, the assessment is undertaken on a very conservative basis, in the absence of more definitive data at this stage.

4.3.5 An indicative layout considered to represent a worst-case assumption for the purpose of the noise assessment was also provided, with turbines located as far south and east as was realistic within the proposed PFOWF Array Area (the area where the turbines will be located): as shown in Annex B. All modelling presented in this report is based on the assumed layout of 7 turbines of 18 MW capacity, as a worst-case.

Table 2 - Wind turbine sound power levels used in the noise assessment – 165 m hub height

Standardised 10 m Wind Speed (m/s)	Sound Power Level (dB L_{Aeq})	
	10 MW turbine	18 MW turbine
3	104.7	105.5
4	107.3	108.1
5	112.7	113.5
6	117.2	118.1
7	118.9	119.8
8	119.1	120.0
9	119.1	120.0
10	119.1	120.0
11	119.1	120.0
12	119.1	120.0

[9] Dounreay Trì Offshore Wind Farm Environmental Statement, Appendix 29.1, Noise Assessment, September 2016.

Standardised 10 m Wind Speed (m/s)	Sound Power Level (dB L_{Aeq})	
	10 MW turbine	18 MW turbine
Derived from:	*Indicative manufacturer data, with addition of +2 dB penalty to account for potential uncertainties.*	

Table 3 – Representative Octave band sound power spectrum (dB L_{Aeq}) assumed for reference wind speed conditions (v_{10} = 8 m/s)

Octave Band Centre Frequency (Hz)	A-Weighted Sound Power Level (dB(A))
	18 MW turbine
63	101.7
125	110.4
250	113.5
500	114.0
1000	113.5
2000	111.7
4000	105.1
8000	87.2
Derived from:	*Based on data assumed for the Dounreay Trì Project.*

4.4 Choice of Wind Farm Operational Noise Propagation Model

4.4.1 The ISO 9613-2 model[10] 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.

4.4.2 All wind farm noise immission levels in this report are presented in terms of the $L_{A90,T}$ noise indicator, in accordance with the recommendations of the ETSU-R-97 report, obtained by subtracting 2 dB(A) from the calculated $L_{Aeq,T}$ noise levels, based on the sound power levels presented in Table 2 and Table 3.

4.4.3 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

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

the hemispherical spreading of sound. Several references[11,12,13] propose an additional factor of *+10log (d/d₀)* is added beyond a reference distance d_0: this represents the enhanced propagation corresponding to cylindrical rather than spherical spreading. The reference distance d_0 would vary in reality, based on a range of factors, and 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 frequencies of sound. It was considered, due to the height of the proposed source (with a typical hub height of 165 m), that a transition distance of d_0 = 3000 m would be more representative. This is supported by additional modelling undertaken using the Danish BEK 135 prediction method[14], 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[15], but is only stated to apply at certain wind speeds (8 or 10 m/s). Nevertheless, the comparison at 8 m/s shows that the assumptions made are robust and would allow for a variation in the final turbine dimensions (rotor diameter and hub height) from the assumptions made above.

4.4.4 In addition, a previous measurement study[12] 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 deducted at the sea-shore boundary. For onshore propagation, the propagation reverts to normal hemispherical propagation (without the $+10\log(d/d_0)$ factor) but still assuming G=0 instead of the G=0.5 (50% hard ground), which would normally be assumed in line with the IOA GPG guidance. Overall, the propagation method is considered relatively conservative for locations situated away from the shoreline.

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

4.5 Predicted Wind Farm Operational Noise Immission Levels

4.5.1 Table 4 shows predicted noise immission levels from the PFOWF Array 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 shown in Table 2. A prediction is also shown for 8 m/s, using the propagation correction factors set out in the Danish BEK 135 method instead of the $10\log(d/d_0)$ factor, to further support the assumptions made: a comparison shows that lower levels are obtained with the latter method than for the main predictions of Table 4: this supports the approach taken.

11 Institute of Acoustics Good Practice Guide, Supplementary Guidance Note 6, Noise Propagation Over Water for On-Shore Wind Turbines, July 2014.
12 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.
13 Swedish Environmental Protection Agency, Measuring and Calculating Sound from Wind Turbines, Guidance Document, June 2013.
14 BEK 135, 07/02/2019, Bekendtgørelse om Støj Fra Vindmøller (Executive Order on noise from wind turbines), Ministry of the Environment and Food, Denmark.
15 L.S. Søndergaard, et. al., "Long distance noise propagation over water for an elevated height-adjustable sound source", 9th International Conference on Wind Turbine Noise, 18-21 May 2021.

Table 4 - Predicted L_{A90} wind farm noise immission levels at each of the noise assessment locations as a function of standardised wind speed for the PFOWF Array turbines alone.

Property	Standardised 10 m Wind Speed (m/s)										BEK 135 Method
	3	4	5	6	7	8	9	10	11	12	(8m/s)
Project onshore elements and shoreline properties											
Isauld House	15.9	18.5	23.9	28.5	30.2	30.4	30.4	30.4	30.4	30.4	28.4
Isauld Lodge	15.5	18.1	23.5	28.1	29.8	30.0	30.0	30.0	30.0	30.0	28.0
Farm house A836	15.2	17.8	23.2	27.8	29.5	29.7	29.7	29.7	29.7	29.7	27.6
Fresgoe	17.1	19.7	25.1	29.7	31.4	31.6	31.6	31.6	31.6	31.6	29.9
Portskerra shore	17.5	20.1	25.5	30.1	31.8	32.0	32.0	32.0	32.0	32.0	30.4
Portskerra	16.8	19.4	24.8	29.4	31.1	31.3	31.3	31.3	31.3	31.3	29.6
Bighouse	16.2	18.8	24.2	28.8	30.5	30.7	30.7	30.7	30.7	30.7	29.0
Sandside House	16.3	18.9	24.3	28.9	30.6	30.8	30.8	30.8	30.8	30.8	29.2
Reay	15.4	18.0	23.4	28.0	29.7	29.9	29.9	29.9	29.9	29.9	28.3
Limekiln WF and extension (and Drum Hollistan 2 WF)											
Achins	14.6	17.2	22.6	27.2	28.9	29.1	29.1	29.1	29.1	29.1	27.4
Borlum House	14.6	17.2	22.6	27.2	28.9	29.1	29.1	29.1	29.1	29.1	26.8
Loanscorribest	13.4	16.0	21.4	26.0	27.7	27.9	27.9	27.9	27.9	27.9	26.0
Baillie WF											
Achiebraeskiall	12.3	14.9	20.3	24.9	26.6	26.8	26.8	26.8	26.8	26.8	24.7
Buolfreuoch	13.1	15.7	21.1	25.7	27.4	27.6	27.6	27.6	27.6	27.6	25.5
Stemster	11.0	13.6	19.0	23.6	25.3	25.5	25.5	25.5	25.5	25.5	23.4
Ackron / Drum Hollistan 2 WF											
House west of Halladale Bridge	14.0	16.6	22.0	26.6	28.3	28.5	28.5	28.5	28.5	28.5	26.9
Ackron Farm	13.4	16.0	21.4	26.0	27.7	27.9	27.9	27.9	27.9	27.9	26.4
Forss Wind Farm and extensions											
Hill of Lybster	14.3	16.9	22.3	26.9	28.6	28.8	28.8	28.8	28.8	28.8	26.3
Crosskirk	14.4	17.0	22.4	27.0	28.7	28.9	28.9	28.9	28.9	28.9	26.2

4.5.2 The Predictions of Table 4 are considered separately for each of the property groups identified (Table 1).

4.6 ETSU-R-97 assessment (including cumulative)

4.6.1 The ETSU-R-97 assessment will consider separately each of the groups of properties identified in Tables 1 or 4. For the properties close to the shoreline or to the Onshore Development components, consideration of the PFOWF Array in isolation is sufficient as these properties are relatively distant from the other wind farms considered. For the other groups of properties, located closer to the cumulative wind farms identified, the predicted worst-case contribution from the PFOWF Array is compared to the relevant noise limit applicable for the other wind farm at these properties.

4.6.2 For some locations, there is no realistic prospect of the site being downwind from both sets of turbines, and so it is sufficient to consider predictions from the PFOWF Array in isolation. If there are cases for which the property could be downwind from both sets of turbines, the cumulative noise levels from both sites are considered in relation to the applicable noise limit. In line with current good practice (see IOA GPG), this is considered on the basis that the applicable noise limits for each of the wind farms considered would be just met at the nearest neighbouring properties. If the noise limit was determined in relation to background noise measurements, these would have been referenced to wind speeds measured at a certain height: it is therefore necessary to apply a correction to predictions for the PFOWF Array, to account for the increased height of the proposed turbines (to account for wind shear effects). If the noise limit is based on a fixed threshold at all wind speeds, then no wind shear adjustment is required.

4.6.3 In addition to compliance of cumulative levels with relevant criteria, THC requested consideration of the increased potential duration of exposure for these residents. This is a relevant consideration in ETSU-R-97 when setting the minimum day-time limits in the range of 35 to 40 dB (A) but is less relevant, given the noise limits that apply to these receptors are already at the lowest within the 35 dB(A) to 40 dB(A) range suggested in ETSU-R-97. This will however be considered in each cumulative situation.

PFOWF Array in isolation

4.6.4 We can first note that all predicted worst-case noise levels of Table 4 meet the simplified ETSU-R-97 noise criterion of 35 dB(A) under all wind speeds and at all locations. They are therefore considered acceptable in isolation without the need for a specific baseline noise survey.

4.6.5 The ETSU-R-97 noise limits assume that the wind turbine noise contains no audible tones. Where tones are present a correction is added to the measured or predicted noise level before comparison with the recommended limits. The audibility of any tones can be assessed by comparing the narrow band level of such tones with the masking level contained in a band of frequencies around the tone called the critical band. The ETSU-R-97 recommendations suggest a tone correction which depends on the amount by which the tone exceeds the audibility threshold and should be included as part of the consent conditions. The turbines to be used for this site will be chosen to ensure that the noise emitted will comply with the requirements of ETSU-R-97 including any relevant tonality corrections.

4.6.6 For the first group of properties considered in Table 4, "Project onshore elements and shoreline properties", consideration of the PFOWF Array in isolation is considered sufficient as these are relatively distant from other wind farm projects in the area. The potential for cumulative impacts is considered in further detail for the other properties in the area which are located closest to the different cumulative schemes considered. This is considered in turn for each of the wind farms considered below.

Limekiln Wind Farm and extensions and Drum Hollistan 2 Wind Farm

4.6.7 For the properties closest to Limekiln Wind Farm and its proposed Extension, which are located south of the A836, such as Borlum House and Loanscorribest, predicted levels from the PFOWF Array are 29 dB L_{A90} or less. As explained in section 4.4, this is likely to represent an overestimate for such properties which are 1 to 3 km or more from the shore. These properties are also relevant to the assessment of the Drum Hollistan 2 Wind Farm.

4.6.8 Given the relative locations of these additional wind farm projects (Limekiln Wind Farm and its proposed Extension, and Drum Hollistan 2 Wind Farm) and the PFWOF Array, the relevant properties which are located between these schemes could not realistically be located downwind of both developments and therefore cumulative levels would not in practice increase beyond the individual contribution of each site for the properties concerned.

4.6.9 Both the June 2019 consent for the Limekiln Wind Farm and the latest information[16] for the Limekiln Wind Farm Extension consider a noise limit of 35 dB L_{A90} for day-time periods and 38 dB L_{A90} for the night-time. The Drum Hollistan 2 Wind Farm was also assessed on the basis that cumulative predictions at the nearest property (Loanscorribest) would not exceed 35 dB L_{A90}. The predictions for the PFOWF Array would therefore clearly be compliant with these derived noise limits. It is therefore concluded that cumulative noise levels would in practice remain below the applicable noise limits should these wind farm schemes all be consented.

4.6.10 Although the residents considered would in theory be exposed to wind farm noise in an additional range of wind conditions, northerly winds, this would be at a lower level (29 dB(A) at most) and for conditions which occur for a minority of the time on average, given the prevailing south-westerly wind direction in the UK. Therefore, the potential increase in exposure duration is considered marginal in this case.

Baillie Wind Farm

4.6.11 The consent[17] for the Baillie Wind Farm defines noise limits based on the ETSU-R-97 guidance set out in section 3.1 above, set at the greater of either 5 dB above background or lower limits of 35 and 43 dB for day-time and night-time respectively (for non-involved properties). Background noise levels were determined based on measurements[18] at representative locations in 2013.

4.6.12 The predictions for the PFOWF Array at the closest properties of Achiebraeskiall and Buolfreuoch do not exceed 28 dB L_{A90}. These properties would not be downwind of both wind farms simultaneously, and therefore the noise levels would not add up cumulatively in practice (as discussed above). This means that predictions are compliant with the applicable noise limits for this scheme. As the properties are around 3 km or more inland, and onshore propagation has assumed hard ground conditions, actual noise levels will be lower in practice. For the same reason as for the properties nearest the Limekiln Wind Farm, the increased duration of exposure would be marginal at most.

4.6.13 For the property Stemster, the locations of both wind farms relative to this property are broadly comparable and a more detailed assessment is therefore undertaken. The applicable ETSU-R-97 noise limits at this property are considered below in Table 5. The predicted noise levels for the PFOWF Array are also shown with a conservative shift of 2 m/s applied to represent potential wind shear effects between the 65 m hub height for the Baillie Wind Farm turbines and those of the PFOWF Array: this means that predictions at 6 m/s in Table 4 are shown in Table 5 at 4 m/s, etc. Noise levels at the highest wind speeds of 11 and 12 m/s were kept at a constant noise level.

Table 5 - Assessment of PFOWF Array predicted noise levels at Stemster

Description	Standardised 10 m Wind Speed (m/s) (referenced to Baillie Wind Farm)								
	4	5	6	7	8	9	10	11	12
Day-time limit	35	35	37	41	44	47	51	54	57
Night-time limit	43	43	43	43	43	46	50	53	55
Predictions for PFOWF Array (Table 4) with wind shift	24	25	25	25	25	25	25	25	25

[16] Limekiln Wind Farm Extension Additional Information, March 2021, https://www.limekilnwindfarm.co.uk/
[17] Scottish Government, Consent Under S36 of the Electricity Act 1989, Baillie Wind Powered Electricity Generating Station, 2010.
[18] Hoare Lea Report reference "REP-1004589-MJ-201300507-03 Baillie WF Baseline Assessment" dated 07/05/2013.

Description	Standardised 10 m Wind Speed (m/s) (referenced to Baillie Wind Farm)								
	4	5	6	7	8	9	10	11	12
Difference with day-time limit	-11	-10	-12	-15	-19	-22	-25	-28	-31
Difference with night-time limit	-19	-18	-18	-18	-18	-21	-24	-27	-29

4.6.14 The assessment of Table 5 demonstrates that the predictions of noise from the PFOWF Array are clearly below the applicable noise limits, by 10 dB or more in all cases, which represents a negligible impact (see 3.1.7) at Stemster.

Ackron and Drum Hollistan 2 WF

4.6.15 The assessment[19] for the Ackron Wind Farm considered both this development and the cumulative noise from the Drum Hollistan 2 Wind Farm. The nearest noise-sensitive receptors to these developments are located to the west, with properties such as Ackron Farm which are involved with the Ackron Wind Farm (and therefore where a minimum limit of 45 dB applies in accordance with ETSU-R-97), and non-involved properties such as the House West of Halladale Bridge, where a limit of 35 dB L_{A90} was applied. For the involved properties such as Ackron Farm, the predictions of Table 4 are below 28 dB L_{A90} and therefore more than 10 dB below the applicable 45 dB noise limit, resulting in a negligible contribution.

4.6.16 The non-involved property West of Halladale Bridge could be exposed to levels of 35 dB from the combination of the Ackron Wind Farm and the Drum Hollistan 2 Wind Farm in downwind conditions which correspond to easterly winds. Although a contribution of up to 29 dB L_{A90} is predicted from the PFOWF Array, this would be under northerly winds such that actual cumulative levels would not increase substantially in practice. As the property is more than 2 km inland, the predictions are likely over-stated as they assume hard ground propagation (see above). The contribution of the PFOWF Array (and therefore any increased exposure) would therefore also be negligible overall for this property in practice.

Forss Wind Farm and extensions

4.6.17 The assessment[20] for the Forss Wind Farm Extension (or Forss III) considers the operational Forss 1 and 2 Wind Farms (which operate under a single combined consented noise limit) and the proposed extension which comprises two additional turbines. The assessment properties considered, Hill of Lybster and Crosskirk, are representative for the purpose of the assessment of cumulative impacts with the PFOWF Array.

4.6.18 The Hill of Lybster property is financially involved (see paragraph 3.1.5) with the proposed Forss Wind Farm Extension and therefore an increased noise limit of at least 45 dB applies: the predictions for the PFOWF Array of around 30 dB are therefore acoustically negligible. For Crosskirk, Table 6 presents the noise limits derived in the assessment for the Forss Wind Farm Extension, based on previous survey data. Predicted noise levels are also shown for the combined noise from the existing turbines and the proposed extension: this was based on the information presented, with noise from the Forss wind turbines set at a level not to exceed the lowest of the day-time or night-time noise limits where predicted noise levels from the Forss turbines would potentially be above the Forss noise limits.

[19] Ackron Wind Farm EIA report, December 2020, planning reference 20/05080/FUL.
[20] Forss Wind Farm Extension, EIA Report, October 2020, Planning reference 20/04455/FUL.

Table 6 - Assessment of derived noise limits for the Forss Wind Farm Extension, PFOWF Array predicted and cumulative noise levels at Crosskirk

Description	Standardised 10 m Wind Speed (m/s) (referenced to Baillie Wind Farm)								
	4	5	6	7	8	9	10	11	12
Daytime limit	35.0	35.3	37.1	39.0	40.8	42.6	44.4	46.3	48.1
Night-time limit	38.0	38.0	38.0	38.0	38.7	40.8	43.2	45.7	48.2
Forss I+II+III prediction	32.0	34.4	36.8	38.0	38.7	40.8	42.0	42.0	42.4
Predictions for PFOWF Array (Table 4) with wind shift	26.9	28.6	28.8	28.8	28.8	28.8	28.8	28.8	28.8
Cumulative level	33.2	35.4	37.4	38.5	39.1	41.1	42.2	42.2	42.6
Max difference with noise limit	-1.8	0.1	0.3	0.5	0.4	0.3	-1.0	-3.5	-5.5

4.6.19 Table 6 also shows predicted noise levels for the PFOWF Array, based on those of Table 4 but, as set out above at 4.6.13, with a wind speed adjustment of 2 m/s applied to account for the differences in the heights of the wind speed references considered, which provides a robust assessment. The resulting cumulative noise levels are then set out, based on adding both predictions, given the property Crosskirk could in some conditions be broadly downwind of both the PFOWF Array and the Forss I+II+III turbines. The cumulative noise levels are only marginally above the applicable noise limit (by 0.5 dB or less) and such differences can be considered negligible[21], taking into consideration the conservative nature of the propagation predictions.

4.6.20 The increased exposure to noise at these properties would be negligible given the relative levels of the noise and the direction of worst-case exposure being comparable.

4.7 Finalised turbine layout and specification

4.7.1 As discussed in section 4.3, the noise emission data assumed for the proposed PFOWF Array turbines 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. This would include consideration of potential tonality from the turbines as required in ETSU-R-97. At this 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.

4.7.2 However, section 4.3 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. Therefore, an updated assessment is likely to conclude in noise levels lower than those assessed within this report.

[21] The IOA GPG suggests that cumulative noise effects need not be considered where differences between existing and proposed wind farm noise levels are 10 dB or more. The addition of a noise source 10 dB(A) below that of another theoretically adds less than 0.5 dB to the total but is not considered to require assessment according to the IOA GPG. Therefore, any increase of cumulative total noise levels by less than 0.5 dB is not considered acoustically relevant.

4.7.3 Any updated analysis should be undertaken on a predictive basis using either the same prediction method as used in the current report, or an updated version, using the most up-to-date evidence on offshore noise propagation.

4.7.4 Please note that post-construction operational noise from the PFOWF Array would be very difficult to measure in practice, because of the low levels of noise predicted (assuming precautionary and pessimistic predictive modelling, with lower levels likely in practice), the likelihood of elevated background noise levels for receptors closest to the shore, and low probability of occurrence of favourable propagation conditions. It is therefore not recommended to consider post-construction noise monitoring to verify the 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 ETSU-R-97 guidelines, either based on the simplified assessment method described therein. or those determined for the other wind farm sites considered (at relevant receptors). These predictions were made based on conservative estimates of emission levels for the turbines of the type and size which would be installed offshore. The potential combination of the noise from the PFOWF Array along with the following wind farms was considered: Limekiln Wind Farm and extension, Drum Hollistan 2 Wind Farm, Ackron Wind Farm, Baillie Wind Farm and Forss 1, 2 and 3 Wind Farms.

5.1.2 The assessment demonstrates that the proposed turbines can operate within the limits derived at onshore locations, or that the cumulative impact on receptors in proximity to the other wind farm sites considered would be negligible. Properties neighbouring other wind farms in the area, and which are already experiencing existing wind turbine noise, would not be expected to experience a substantial increase in duration or level of exposure on this basis. It is concluded therefore that operational noise levels from the PFOWF Array are likely to be within levels recommended in national guidance for wind energy schemes.

Annex A - General Approach to Noise Assessment

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.

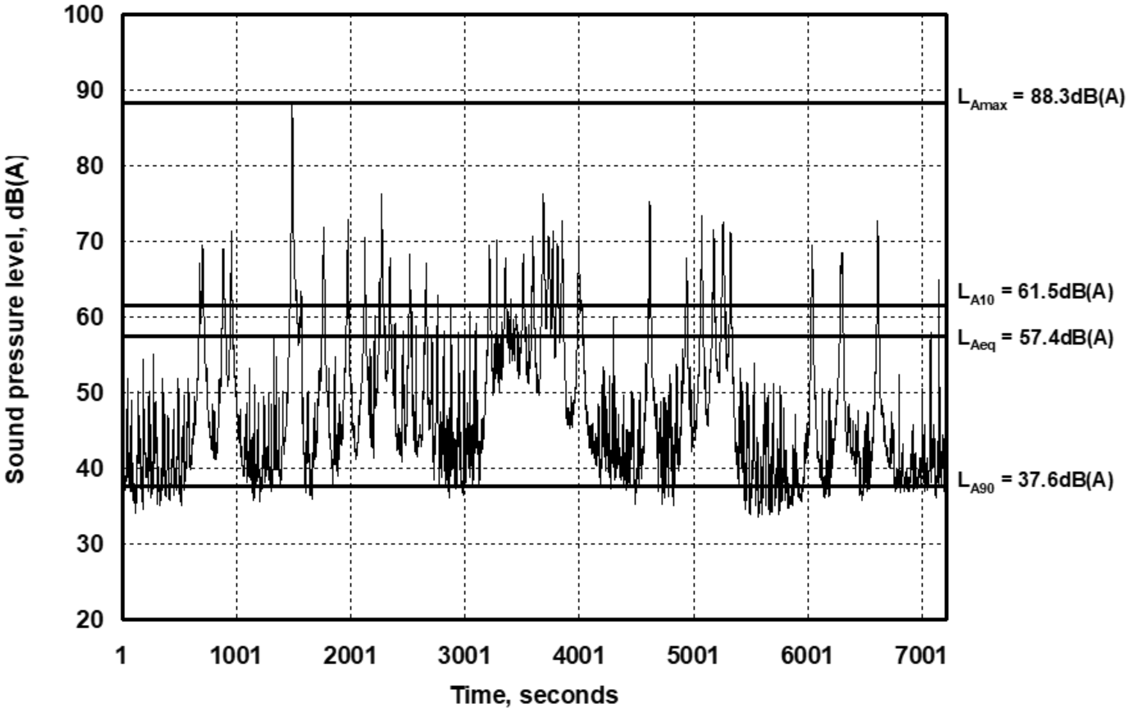
A.5. Before reviewing the potential effects of environmental sound on people, it is useful first to consider the means by which physical sound can be quantified.

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, indoors	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)	Speech intelligibility, disturbance of information extraction, message communication	35	-	-

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 is 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.

A-weighting

A.51. 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.

Annex B – Location Maps and Turbine Coordinates

Figure B1	Map showing the assumed worst case layout (for noise receptors) of the PFOWF Array turbines (red circles) within the PFOWF Array Area, as well as the noise assessment locations considered (green). Location and layouts of the cumulative wind farms considered are also shown on the map.

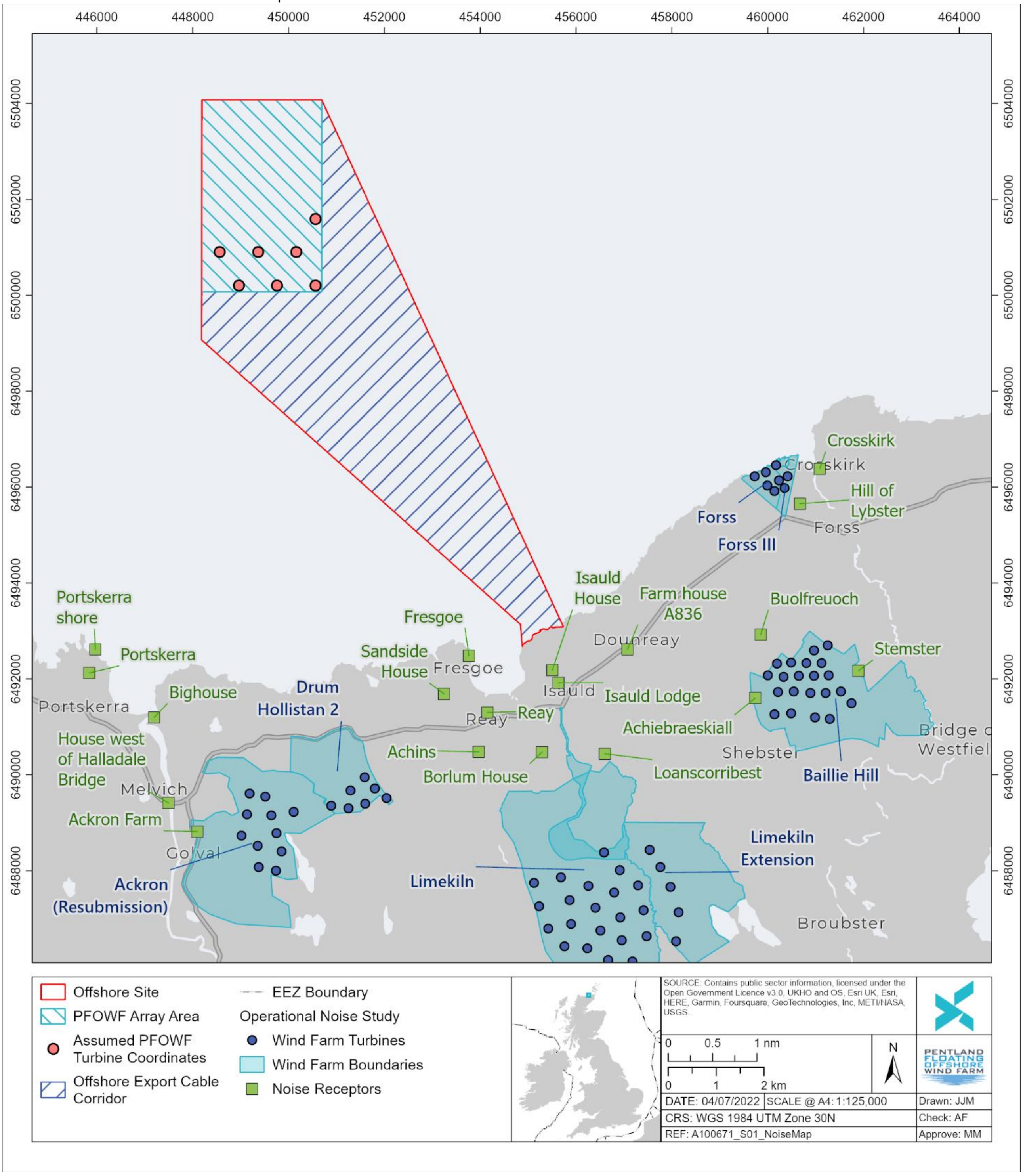


Table B1 – Assumed turbine coordinates – 7-turbine – layout modelled in operational study as worst-case (for the purpose of the noise study. UTM grid coordinates (zone 30N)

Turbine	Easting	Northing
1	448962	6500204
2	449762	6500204
3	450562	6500204
4	448562	6500897
5	449362	6500897
6	450162	6500897
7	450562	6501590

Annex C – 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
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.

Terminology	Description
	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

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