HOARE LEA

Beinn Ghlas Wind Farm Repowering.
Appendix 11.1 Environmental Noise Assessment

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Executive Summary

Hoare Lea (HL) have been commissioned by RSK to undertake a noise assessment for the construction and operation of the proposed Beinn Ghlas Wind Farm Repowering (the Proposed Development). Noise will be emitted by equipment and vehicles used during construction and decommissioning of the wind farm and by the turbines during operation. The level of noise emitted by the sources and the distance from those sources to the receiver locations are the main factors determining levels of noise at receptor locations.

Construction Noise

Construction noise has been assessed by a desk-based study of a potential construction programme (including the decommission of the existing wind turbines) and by assuming the Proposed Development is constructed using standard and common methods. Noise levels have been calculated for receiver locations closest to the areas of work and compared with guideline and baseline values. Construction noise, by its very nature, tends to be temporary and highly variable and therefore much less likely to cause adverse effects. Factors including in particular the restrictions of hours of working have been taken into consideration. It is concluded that noise generated through construction activities would have a minor impact, provided that some activities are restricted during weekend periods.

Construction traffic associated with the Proposed Development is considered to be potentially associated with negligible increases in noise for properties along the construction route. Cumulative traffic could however, under worst-case assumptions, be associated with minor (A83 and A85) to moderate (A819) impacts in the absence of further mitigation.

Operational Noise

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 those locations around the site most likely to be affected by noise. Noise limits have been derived following the simplified assessment method stipulated in national planning guidance. The Cruach Clenamacrie and Corr Chnoc Wind Farms were included in the cumulative assessment. Other more distant wind farms were not considered as they do not make an acoustically relevant contribution to cumulative noise levels. The Barachander Wind Farm is currently at scoping stage and was therefore not included in the cumulative assessment.

Predicted operational noise levels, in isolation and cumulatively, have been compared to the limit values to demonstrate that turbines of the type and size which would be installed can operate within the simplified limit. It is concluded therefore that operational noise levels from the wind farm will be within levels recommended in national guidance for wind energy schemes.

Operational noise from the proposed substation was not assessed due to the large separation distance of more than 2 km to any noise-sensitive receptors, which is likely to be result in negligible levels of noise based on professional judgement.

This Executive Summary contains an overview of the noise assessment and its conclusions. No reliance should be placed on the content of this Executive Summary until this report has been read in its entirety.

1. Introduction

1.1 This report presents an assessment of the potential construction and operational noise impacts of the Beinn Ghlas Wind Farm Repowering (the Proposed Development) on the residents of nearby dwellings. The assessment considers both the construction and operation of the Proposed Development and also the likely impacts of its decommissioning. The assessment also considers cumulative effects from the nearby Corr Chnoc and Cruach Clenamacrie Wind Farms, other more distant wind farms were not considered because their potential noise contribution was considered acoustically negligible.

1.2 Noise and vibration which arises from the construction of a wind farm is a factor which should be taken into account when considering the Proposed Development. However, in assessing the impacts of construction noise, it is accepted that the associated works are of a temporary nature. The main work locations for construction of the turbines are distant from nearest noise sensitive residences and are unlikely to cause notable impacts. The construction and use of access tracks will, however, occur at lesser separation distances. Assessment of the temporary impacts of construction noise is primarily aimed at understanding the need for dedicated management measures and, if so, the types of measures that are required. Further details of relevant working practices, traffic routes, and proposed working hours are described in the Chapter 10 (Traffic and Transport) of the Environmental Impact Assessment Report (EIAR).

1.3 Once constructed and operating, 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 lying around the Proposed Development will therefore generally form the basis of the assessment of the levels of noise against accepted standards.

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

2. Policy and Guidance Documents

2.1 Planning Policy and Advice Relating to Noise

2.1.1 The Scottish National Planning Framework 4 (NPF)[1] provides advice on how the planning system should manage the process of encouraging, approving and implementing renewable energy proposals including onshore wind farms. NPF4 Policy 11 suggests noise impacts on communities and dwellings are one of the aspects that will need to be considered; however, it provides no specific advice. Planning Advice Note PAN1/2011[2] 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

1 Scottish National Planning Framework 4, Scottish Government. Adopted 13 February 2023.
2 Planning Advice Note 1/2011: Planning & Noise, Scottish Government, March 2011.

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[3] provides further advice on noise and confirms that the recommendations of 'The Assessment and Rating of Noise from Wind Farms' (ETSU-R-97)[4] "*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 development 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 With regard to infrasound and low-frequency noise, the above-referenced online planning advice note, Onshore wind turbines refer 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'*.

2.1.4 The Scottish Government Onshore Wind Policy Statement 2022[5] mentions the potential for the advice in ETSU-R-97 to be modified in future based on a review from the UK Government, but continues to support its use in the meantime, confirming the advice from the Online Renewables Planning Advice set out above. Although a report on this topic commissioned by the UK Government has been published (WSP BEIS Report)[6], its recommendations for updates to some aspects of the ETSU-R-97 methodology will need to be considered by the national governments. The WSP BEIS report does not provide a replacement or update to ETSU-R-97 and until it is replaced or updated, the Scottish Government has confirmed in the Onshore Wind Policy Statement 2022 that the ETSU-R-97 methodology continues to be applicable.

2.1.5 The recommendations contained in ETSU-R-97 therefore 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)[7]. This was subsequently endorsed by the

3 Scottish Government, Online Renewables Planning Advice, Onshore Wind Turbines (https://www.gov.scot/publications/onshore-wind-turbines-planning-advice). Updated 28 May 2014.

4 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.

5 Scottish Government (2021) - Onshore wind - policy statement 2022, December 2022.

6 WSP, A Review of Noise Guidance for Onshore Wind Turbines, report for the UK Department for Business, Energy & Industrial Strategy, October 2022 (published 10 February 2023).

7 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.

Scottish Government[8] which advised in the Online Renewables Planning Advice on Onshore wind turbines that this *'should be used by all IOA members and those undertaking assessments to ETSU-R-97'*, The methodology of ETSU-R-97 and the IOA GPG has therefore been adopted for the present assessment and is described in greater detail below.

2.1.6 For assessing noise from non-wind turbines sources associated with the Proposed Development, such as fixed plant associated with the substation and battery storage elements, PAN1/2011 advises the use of the BS 4142 standard. Although PAN1/2011 references the 1997 version of the standard, the more recent 2019 version[9] is now applicable.

2.1.7 PAN1/2011 and the Technical Advice Note[10] accompanying PAN1/2011 note that construction noise control can be achieved through planning conditions that limit noise from temporary construction-sites, or by means of the Control of Pollution Act (CoPA) 1974[11]. The CoPA provides two means of controlling construction noise and vibration. Section 60 provides the Local Authority with the power to impose at any time operating conditions on the development site. Section 61 allows the developer to negotiate a prior consent for a set of operating procedures with the Local Authority before commencement of site works.

2.1.8 For detailed guidance on construction noise and its control, the Technical Advice Note refers to British Standard BS 5228[12] 'Noise control on construction and open sites', Parts 1 to 4 but confirms that the updated version of this standard, published in January 2009 is relevant when used within the planning process. The 2009 version consolidates all previous parts of the standard into BS 5228-1: 2009 (amended 2014)[13] (BS 5228-1) for airborne noise and BS 5228-2: 2009 (amended 2014)[14] (BS 5228-2) for ground-borne vibration. These updated versions have therefore been adopted as the relevant versions upon which to base this assessment.

2.1.9 BS 5228-1 provides guidance on a range of considerations relating to construction noise including the legislative framework, general control measures, example methods for estimating construction noise levels and example criteria which may be considered when assessing impact magnitude. Similarly, BS 5228-2 provides general guidance on legislation, prediction, control and assessment criteria for construction vibration.

2.1.10 Planning Advice Note PAN50[15] "Controlling the Environmental Effects of Surface Mineral Workings" gives guidance on the environmental effects of mineral working. The main document summarises the key issues with regard to various environmental effects relating to surface mineral extraction and processing such as road traffic, blasting, noise, dust, visual intrusion etc. In addition, several annexes to the main document have been published which consider specific aspects in more detail: Annex A, "The Control of Noise at Surface Mineral Workings" and Annex D "The Control of Blasting at Surface Mineral Workings". BS 5228-1 and BS 5228-2 also provide guidance relating to surface mineral extraction including the assessment of noise and vibration impacts associated with quarry blasting. BS 6472-2 2008[16] gives similar guidance on assessing vibration from blasting associated with mineral extraction.

8 Letter from John Swinney MSP, Scottish Government, 29/05/2013
9 British Standard 4142: 2014+A1 2019 Method for rating and assessing industrial and commercial sound. British Standards Institution. 2019.
10 PAN1/2011 Technical Advice Note – Assessment of Noise, Scottish Government, March 2011.
11 Control of Pollution Act, Part III, HMSO, 1974.
12 BS 5228 Noise and Vibration Control on Construction and Open Sites, Parts 1 to 4.
13 BS 5228-1:2009-A:2014 'Code of practice for noise and vibration control on construction and open sites – Part 1: Noise'.
14 BS 5228-2:2009-A:2014 'Code of practice for noise and vibration control on construction and open sites – Part 2: Vibration'.
15 Planning Advice Note 50: Controlling The Environmental Effects of Surface Mineral Workings, 1996.
16 BS 6472-2:2008:Guide to evaluation of human exposure to vibration in buildings - Part 2: Blast-induced vibration.

3. Scope and Methodology

3.1 Methodology for Assessing Construction Noise

3.1.1 Construction works include both moving sources and static sources. The moving sources normally comprise mobile construction plant and Heavy Goods Vehicles (HGVs). The static sources include construction plant temporarily placed at fixed locations and in some instances, noise arising from blasting activities where rock is to be worked through.

3.1.2 The analysis of construction noise has been undertaken in accordance with BS 5228-1 which provides methods for predicting construction noise levels on the basis of reference data for the emissions of typical construction plant and activities. These methods include for the calculation of construction traffic along access tracks and haul routes and also for construction activities at fixed locations such as the bases of turbines, site compounds or sub stations.

3.1.3 The BS 5228 calculated levels are then compared with absolute noise limits for temporary construction activities which are commonly regarded as providing an acceptable level of protection from the short-term noise levels associated with construction activities.

3.1.4 Separate consideration is also given to the possible noise impacts of construction related traffic passing to and from the site along local surrounding roads. In considering potential noise levels associated with construction traffic movement on public roads, reference is made to the accepted UK prediction methodology provided by 'Calculation of Road Traffic Noise'[17] (CRTN).

3.1.5 Decommissioning is likely to result in less noise than during construction of the Proposed Development and was therefore scoped out of the assessment.

3.1.6 The nature of works and distances involved in the construction of a wind farm are such that the risk of non-negligible impacts relating to ground borne vibration are very low (excluding blasting). Occasional momentary vibration can arise when heavy vehicles pass dwellings at very short separation distances, but again this is not sufficient to constitute a risk of moderate/major impacts in this instance. Accordingly, vibration impacts (excluding blasting) do not warrant detailed assessment and are therefore not discussed further in this assessment.

3.1.7 As a worst-case, some rock extraction by means of blasting operations could be required in some instances for construction of the turbine base and the access track. The analysis of the related potential impacts has been made in accordance with PAN50, BS 6472-2 2008 and BS 5228.

3.2 Methodology for Assessing Wind Farm Operational Noise

3.2.1 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 a standardised[18] wind speed of 12 m/s (43.2 km/h). ETSU-R-97 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*

17 Calculation of Road Traffic Noise, HMSO Department of Transport, 1988.

18 Standardised wind speeds are based on wind speeds at the hub (or nacelle) height of the turbines, which are then corrected using a fixed correction factor. Equation 1 of IOA GPG Supplementary Guidance Note 4 (Wind Shear, July 2014) should be used with a notional height of 10 metres and a reference roughness length of 0.05 metres.

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.'

3.2.2 In the case of the Proposed Development, separation distances between the wind turbines and nearest residential dwellings are relatively large (more than 1.5 km), such that at all locations noise levels will fulfil this simplified criterion, therefore background noise surveys are not required. Additionally, the 35 dB L_{A90} criterion would form the basis for noise limits which would be used to control noise from the Proposed Development during operation.

3.2.3 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 also need to consider the combined operational noise of the Proposed Development with the other wind farms (operational, consented, or in planning) in the area. However, where the noise level from any other identified neighbouring wind farm at a receptor location is predicted to be at least 10 dB below the contribution from the Proposed Development wind turbines (and below the criterion), the proposed wind farm can be assumed to have a negligible impact at that receptor location. Therefore, in line with paragraph 5.1.5 of the IOA GPG, the noise immission level from this wind farm would be excluded from assessment at this location. Where this difference is less than 10 dB, a detailed cumulative assessment will be undertaken in line with the guidance, recommendations and discussion given in Section 5 of the IOA's GPG.

3.2.4 To undertake the assessment of operational noise in accordance with the foregoing methodology the following steps are required:

- specify the number and locations of the wind turbines on all wind farms;
- identify the locations of the nearest, or most noise sensitive, neighbours;
- specify the type and noise emission characteristics of the wind turbines;
- calculate the noise immission levels due to the operation of the wind turbines as a function of site wind speed at the nearest neighbours;
- compare the calculated wind farm noise immission levels with the simplified assessment criterion and assess in the light of planning requirements.

3.2.5 The foregoing steps, as applied to the Proposed Development, are set out subsequently in this assessment.

3.2.6 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 on the Proposed Development.

3.3 Methodology for Assessing Operational Noise from the Substation

3.3.1 Noise from non-wind turbines sources associated with the Proposed Development, such as fixed plant associated with the substation, can be assessed using the BS 4142 standard, which is referenced in the Technical Advice Note accompanying PAN1/2011. However, in this instance, as the proposed substation is more than 2 km from the nearest noise-sensitive receptor, the associated noise levels are likely to be negligible, based on professional experience of similar developments, and is therefore not considered further in any detail in the present assessment.

3.4 Construction Noise Criteria

3.4.1 BS 5228-1 indicates a number of factors are likely to affect the acceptability of construction noise including site location, existing ambient noise levels, duration of site operations, hours of work, attitude of the site operator and noise characteristics of the work being undertaken.

3.4.2 BS 5228-1 informative Annex E provides example criteria that may be used to consider the magnitude of any construction noise impacts. The criteria do not represent mandatory limits but rather a set of example approaches intended to reflect the type of methods commonly applied to construction noise. The example methods are presented as a range of possible approaches (both facade and free field noise levels, hourly and day-time averaged noise levels) according to the ambient noise characteristics of the area in question, the type of development under consideration, and the expected hours of construction activity. In broad terms, the example criteria are based on a set of fixed limit values which, if exceeded, may result in a large impact unless ambient noise levels (i.e. regularly occurring levels without construction) are sufficiently high to provide a degree of masking of construction noise.

3.4.3 Based on the range of guidance values set out in BS 5228 Annex E, and other reference criteria provided by the World Health Organization (WHO) and PAN50 Annex A: The Control of Noise at Surface Mineral Workings (1996), the following impact assessment scale has been derived. The values have been chosen in recognition of the relatively low ambient noise typically observed in rural environments. The presented criteria have been normalised to free-field day-time noise levels occurring over a time period, T, equal to the duration of a working day on-site. BS 5228-1 Annex E provides varied definitions for the range of day-time working hours which can be grouped for equal consideration. The values presented in Table 1 have been chosen to relate to daytime hours from 07:00 to 19:00 on weekdays, and 07:00 to 13:00 on Saturdays.

Table 1 - Construction Noise Impact Assessment

Impact	Noise Level dB $L_{Aeq,T}$		Description
	4 weeks or more	1 to 4 weeks	
Major	> 75	> 85	Trigger level for noise insulation works, or costs thereof, as set out in E.4 of BS 5228-1.
Moderate	> 65 ≤ 75	> 75 ≤ 85	Most stringent threshold values for potential significant effects given in Annex E of BS 5228-1 for example methods relevant to proposed development is exceeded.
Minor	> 55 ≤ 65	> 65 ≤ 75	Noise is likely to be audible, but unlikely to change behaviour. of BS 5228-1 thresholds not exceeded.
Negligible	≤ 55	≤ 65	At least 10 dB below the most stringent criteria provided in of BS 5228-1.
The values presented above relate to noise impacts that occur during working hours from 07:00 to 19:00 on weekdays, and 07:00 to 13:00 on Saturdays. Alternate criteria would apply to noise impacts outside of these hours. For noise impacts 13:00 to 19:00 on Saturdays and 07:00 to 19:00 on Sundays the above thresholds would reduce by 10 dB(A) in each category. For noise impacts 19:00 to 07:00 on any day the above thresholds would reduce by 20 dB(A) in each category.			

3.4.4 When considering the impact of short-term changes in traffic, associated with the construction activities, on existing roads in the vicinity of the Project, reference can be made to the criteria set out in the Design Manual for Roads and Bridges (DMRB[19]). A classification of magnitudes of changes in the predicted traffic noise level calculated using the CRTN methodology is set out: for short-term changes such as those associated with construction activities, changes of less than 1 dB(A) are considered

19 The Highways Agency, Transport Scotland, Transport Wales and The Department for Regional Development (Northern Ireland) (2020). 'Design Manual for Roads and Bridges, LA 111 Noise and vibration', revision 2.

negligible, 1 to 3 dB(A) is minor, 3 to 5 dB(A) moderate and changes of more than 5 dB(A) constitute a major impact. This classification can be considered in addition to the criteria of Table 1.

3.4.5 Blasting operations can generate airborne pressure waves or "air overpressure". This covers both those pressure waves generated which are in the frequency range of human audibility (approximately 20 Hz to 20 kHz) as well as infrasonic pressure waves (those with a frequency of below 20 Hz), which, although outside the range of human hearing, can sometimes be felt.

3.4.6 Noise from blasting (i.e. pressure waves in the human audible range) is not considered in the same way as noise from other construction activities due to the fact that a large proportion of the energy contained within pressure waves generated by a blast is at frequencies that are below the lower frequency threshold of human hearing, and that the portion of energy contained within the audible range is generally of low frequency and of smaller magnitude than the infrasonic pressure variations.

3.4.7 The relevant guidance documents advise controlling air overpressure (and hence noise from blasting) through the use of good practices during the setting and detonation of charges as opposed to absolute limits on the levels produced, therefore no absolute limits for air overpressure or noise from blasting will be presented in this assessment.

3.4.8 In accordance with the guidance in BS 6472-2: 2008 and PAN50 Annex D, ground vibration caused by blasting operations will be considered acceptable if peak particle velocity (PPV) levels, at the nearest sensitive locations, do not exceed 6 mm/s for 95% of all blasts measured over any 6-month period, and no individual blast exceeds a PPV of 12 mm/s.

3.5 Operational Noise Criteria

3.5.1 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 Proposed Development will still be within levels considered acceptable under the ETSU-R-97 assessment method.

3.6 Consultation

3.6.1 A summary of the proposed approach to the assessment was discussed in the scoping report and in subsequent correspondence (sent in December 2023) to Argyll and Bute Council Environmental Health Department. No substantive response was received.

4. Baseline

4.1 General Description

4.1.1 The Proposed Development is located in an area of relatively low population density. The noise environment in the surrounding area is generally characterised by 'natural' sources, such as wind disturbed vegetation, birds and farm animals. Other sources of noise include intermittent local road and agricultural vehicle movements in the area.

4.2 Noise assessment locations

4.2.1 The assessment has considered operational noise from the Proposed Development at the assessment locations listed in Table 2. The list of receptor locations is not intended to be exhaustive but sufficient to be representative of noise levels typical of those receptors closest to the Proposed Development.

Other noise-sensitive receptors are not considered further as they are sufficiently dino impact on assessstant from the Proposed Development.

Table 2 - Assessment properties in the vicinity of the Proposed Development

ID	Property	Easting	Northing	Approximate Distance to Closest Turbine (m)	Closest Turbine (ID)
2	Duntanachan	196710	728227	1890	T07
1	Clachadubh	194756	727375	2979	T06
5	Barguillean Farm	198045	728811	2270	T07
6	Sithean / Bunanta	198330	728610	2148	T07
3	Bar Glas	197764	728716	2141	T07
4	Am Barrr	197857	728777	2210	T07

4.2.2 The receptors in Table 2 are annotated in **Figure 11.1** which shows their locations respective to the Proposed Turbines.

5. Noise Impact Assessment

5.1 Predicted Construction Noise Levels

5.1.1 The level of construction noise that occurs at the surrounding properties will be highly dependent on a number of factors such as the final site programme, equipment types used for each process, and the operating conditions that prevail during construction. It is not practically feasible to specify each and every element of the factors that may affect noise levels, therefore it is necessary to make reasonable allowance for the level of noise emissions that may be associated with key phases of the construction.

5.1.2 In order to determine representative emission levels for this study, reference has been made to the scheduled sound power data provided by BS 5228. Based on experience of the types and number of equipment usually associated with the key phases of constructing a wind farm, the scheduled sound power data has been used to deduce the upper sound emission level over the course of a working day. In determining the rating applicable to the working day, it has generally been assumed that the plant will operate for between 75 % and 100 % of the working day. In many instances, the plant would actually be expected to operate for a reduced percentage, thus resulting in noise levels lower than predicted in this assessment.

5.1.3 To relate the sound power emissions to predicted noise levels at surrounding properties, the prediction methodology outlined in BS 5228 has been adopted. The prediction method accounts for factors including screening and soft ground attenuation. The size of the Site and resulting separation distances to surrounding properties allows the calculations to be reliably based on positioning all the equipment at a single point within a particular working area (for example, in the case of turbine erection, it is reasonable to assume all associated construction plant is positioned at the base of the turbine under consideration). In applying the BS 5228 methodology, it has been conservatively assumed that there are no screening effects, and that the ground cover is characterised as 50% hard / 50% soft.

5.1.4 Table 3 lists the key construction activities, the associated types of plant normally involved, the expected worst-case sound power level over a working day for most of the key activities occurring in potential proximity of the dwellings, the property which would be closest to the activity for a portion of construction, and the predicted noise level. It must be emphasised that these predictions only relate the noise level occurring during the time when the activity is closest to the referenced property. In many cases such as access track construction and turbine erection, the separating distances will be considerably greater for the majority of the construction period and the predictions are therefore the worst-case periods of the construction phase.

Table 3 - Predicted construction noise levels

Task Name	Plant/Equipment	Upper Collective Sound Emission Over Working Day $L_{WA,T}$ dB(A)	Nearest Receiver	Minimum Distance to Nearest Receiver	Predicted Upper Daytime L_{Aeq}
Upgrade Access Track	excavator / dump trucks / tippers / dozers / vibrating rollers	120	Am Barr	25	84 (very short period)
Access Road – Rock Breaking Section to the south of Glen Lonan Road	Semi-mobile Crushers / hydraulic excavators / rock breaker / Lorry	125	Sithean/Bunanta	240	67 (short period <4 weeks)
Forestry felling around access track	Harvesters and forwarders, characterised by saw noise diesel engine noise emissions commonly associated with tractors and excavation noise	115	Am Barr	25	79 (very short period)
Construct site tracks	excavators / dump trucks / tippers / dozers / vibrating rollers	120	Sithean/Bunanta	200	64
Rock Extraction (southern access road section construction)	Primary and secondary stone Crushers / excavators / screening systems / pneumatic breakers / conveyors	125	Sithean/Bunanta	350	64

5.1.5 Comparing the above predicted noise levels to the range of background noise levels measured around the Proposed Development suggests that the noisier construction activities would be audible at various times throughout the construction phase. However, comparing the levels to the significance criteria presented previously (Table 1) indicates that the majority of construction activities considered in Table 3, including rock breaking along the access road off Glen Lonan Road, would have impacts of minor magnitude. For the track upgrade activity (and associated felling) which is closest to Am Barr, predicted noise levels are likely to represent those for a very short-term period when activity is closest to the receptor. Noise levels will quickly diminish as the work progresses, moving the activity further from the property. The short-term nature of this activity consequently categorises the impact to be of minor magnitude.

5.1.6 All other construction activities at and around the turbine locations, including decommissioning of the existing turbines, erection of the new ones and most of the other infrastructure (such as the substation) or temporary construction compounds, would occur at distances of more than 1.8 km from the nearest dwellings, and associated with predicted levels not exceeding 43 dB $L_{Aeq,}$, and would therefore be associated with negligible impacts.

5.1.7 An existing open storage compound, located c.200 m north of Barguillean Farm and Am Barr, is proposed to be used as a vehicle and material storage area on a temporary basis until the Proposed

Development temporary construction compound is constructed. No construction activity is proposed in this area and therefore **negligible** impacts are anticipated when considering the separation distance of c.200 m to sensitive receptors and temporary nature of activity in the compound.

5.1.8 Some construction activities could occur during Saturday afternoons and Sundays day-time periods, which is outside the hours assumed when determining the criteria of Table 1 (see 3.4.3). This would represent an increase in the impact magnitude to moderate at worst for the activities considered in Table 3, even taking into account the duration of the works. However, all other works occurring closer to the turbine locations would remain associated with a negligible impact magnitude. It is therefore proposed to avoid work on Saturday afternoon and Sundays for upgrade/construction works for the access track within 500 m of residential properties. This would reduce associated impacts to **minor** at most.

5.1.9 In addition to on-site activities, construction traffic passing to and from the site will also represent a potential source of noise to surrounding properties. The transport assessment for the proposal presented in **EIAR Chapter 10: Traffic & Transport** has identified that the most intensive traffic will likely occur in the 15th month of construction. with a maximum generation of 170 construction vehicles movements per day (including 70 HGV), on the basis of a worst-case scenario. This represents an average maximum of around 6 HGV vehicle movements each hour, based on a 12-hour working day.

5.1.10 The construction site access track carrying heavy vehicles which leads from the A85 to the site entrance of the Proposed Development will pass closest to properties such as Am Barr, approximately 25 m away from the midsection of the relevant access track. Once vehicles are travelling on this haul road this will give rise to a maximum predicted noise level of 54 dB(A) $L_{eq,1hr}$ based on 6 vehicles per hour travelling at 30 km/hr[20], using the prediction methodology of BS 5228-1. At this location, this represents an impact of **negligible** magnitude based on Table 1.

Table 4 - Projected traffic flows (worst-case scenario)

Road	Without Development		With Development	
	Annual Average Weekday Traffic (AAWT) Flow	% Heavy Goods Vehicles	Annual Average Weekday Traffic (AAWT) Flow	% Heavy Goods Vehicles
A816 to A85 merge (Oban)	16992	1.4%	17077	1.6%
A85 between A816 and A828	9219	3.2%	9269	3.1%
A828 between A85 and B845 (On Connel Bridge)	5800	4.6%	5855	5.1%
A85 between A828 and A819 (Taynuilt)	5136	6.9%	5201	7.5%
A85 east of Dalmally	3120	8.6%	3185	9.6%
Glen Lonan Road	68	16.8%	238	34.2%

20 A speed of 30 km/hr (close to 20 miles per hour) is estimated based on our experience of this type of activity and considered reasonably representative.

Table 5 - CRTN predicted increase in daytime average traffic noise levels ($L_{A10,18hour}$)

Road	Maximum Change in Traffic Noise Level, dB(A)
A816 to A85 merge (Oban)	0.1
A85 between A816 and A828	0.0
A828 between A85 and B845 (On Connel Bridge)	0.2
A85 between A828 and A819 (Taynuilt)	0.2
A85 east of Dalmally	0.3

5.1.11 The assessment presented in Table 10.13 in Chapter 10 has been used to ascertain the 2032 daily projected traffic flows for scenarios with and without the Proposed Development. These total daily vehicle counts are summarised in Table 4 above. The methodology set out in CRTN was then used to determine the associated maximum total change in the average day time traffic noise level at any given location due to construction of the Proposed Development: see Table 5.

5.1.12 Table 5 indicates a maximum potential increase of no more than 0.3 dB(A) in the day-time average noise level during particular phases of the construction programme at some locations adjoining the A85. For the other routes, noise increases of 0.2 dB or less are predicted. Based on the criteria set out in the DMRB, the associated change in traffic noise level along these routes would correspond to a negligible impact during the construction period for the Proposed Development construction traffic in isolation. No cumulative traffic effects are anticipated for the future year of 2032.

5.1.13 In conclusion, noise from construction activities has been assessed and is predicted to result in a temporary negligible to minor impact.

5.1.14 This conclusion is based on construction activities generally being limited to working hours from 07:00 to 19:00. Upgrade/construction works for the access track within 500 m of residential properties would be further restricted on Saturday afternoons and Sundays. However, activities that are unlikely to give rise to noise audible at the site boundary may continue outside of the stated hours. Furthermore, turbine deliveries may take place outside these times with the prior consent of the relevant authorities. In addition, good practice measures recommended in BS 5228-1 should be used to minimise construction noise levels.

5.1.15 Chapter 10 also presents an assessment of potential cumulative traffic increases along certain routes, on the basis of worst-case assumptions over overlapping construction programmes for other development at further distances, as outlined in Chapter 10. The resulting worst-case cumulative traffic increases along relevant links are also set out in Table 4, with associated noise increases calculated using the CRTN methodology in Table 5. Cumulative traffic increases are associated with predicted increases above 1 dB and below 3 dB on the A85, representing a minor impact based on the criteria of paragraph 3.4.4.

5.2 Construction Noise & Vibration Levels – Blasting

5.2.1 Because of the difficulties in predicting noise and air overpressure resulting from blasting operations at on-site borrow pits, these activities are best controlled following the use of good practice during the setting and detonation of charges, as set out earlier in this report.

5.2.2 Given the separation distances between the location of the wind turbines and the nearest noise sensitive receptors (approximately 1.9 km as a minimum) it is very unlikely that any blasting associated with construction of the turbines and their foundations would cause non-negligible adverse impacts, and therefore no further mitigation is required there.

5.2.3 However, blasting may be used for rock extraction as part of the construction of the site access, which may occur in closer proximity (although no closer than approximately 350 m) to some noise-sensitive receptors and therefore will require further management. The transmission and magnitude of ground vibrations associated with blasting operations at borrow pits are subject to many complex influences including charge type and position, and importantly, the precise nature of the ground conditions (material composition, compaction, discontinuities) at the source, receiver, and at every point along all potential ground transmission paths. Clearly any estimation of such conditions is subject to considerable uncertainty, thus limiting the utility of predictive exercises. Mitigation of the impacts of these activities is best achieved through on-site testing processes carried out in consultation with the Local Authorities, as described earlier in this report. Blasting within 1 km of the noise-sensitive receptors should also be avoided during Saturday afternoons and Sundays.

5.3 Operational Wind Turbine Emissions Data

5.3.1 The exact model of turbine to be used at the site will be the result of a future tendering process and therefore a representative turbine model has been assumed for this noise assessment. This operational noise assessment is based upon the noise specification of the Vestas V136 4.5 MW wind turbine. This turbine model was retained as a precautionary assumption, resulting in marginally higher noise levels than other turbine models of similar dimensions such as the Nordex N133-4.8 MW or the Siemens-Gamesa SG 5.0-132.

5.3.2 Seven turbines have been modelled using the layout as set out in Annex B. The candidate turbine is a variable speed, pitch regulated machine with a rotor diameter of 136 metres and a hub height of 82 metres. Due to its variable speed operation, the sound power output of the Vestas V136 turbine varies considerably with wind speed, being quieter at the lower wind speeds when the blades are rotating more slowly. The candidate turbine also incorporates as standard the use of Serrated Trailing Edges (or STE), which reduce noise emissions, as standard. However, to represent a worst-case scenario, the turbines were assumed to be installed without STEs, which increased the noise emissions by 2.9 dB(A).

5.3.3 Vestas have supplied specified noise emission data for the Vestas V136 turbine. In the absence of specific information about uncertainty allowances in the data, a further correction factor of +2 dB was added to the specification data in line with advice in the IOA GPG. The sound power data has been made available for standardised reference wind speeds of 3 m/s to 12 m/s inclusive. In addition to the overall sound power data, reference has been made to manufacturer documents for the unit to derive a representative sound spectrum for the turbine, based on an energetic average of the available information at each octave band. The overall sound power and spectral data are presented in Table B3 and B4 in Annex B.

5.3.4 Assessment of the cumulative noise from operating the Cruach Clenmacrie and Corr Chnoc Wind Farms together with the Proposed Development also requires source information for the turbine types. Annex B outlines the turbine data for these wind farms which have been taken from their respective Environmental Statements, the noise emission data for the turbines running unconstrained, including suitable uncertainty allowances as well as a further uplifts where appropriate, were applied and presented in line with current good practice. Sound spectrum for the turbines was also derived using relevant manufacturer data and presented in Tables B3, B7 and B11 of Annex B. This is therefore consistent with the guidance of the IOA GPG.

5.4 Choice of Wind Farm Operational Noise Propagation Model

5.4.1 The ISO 9613-2 model[21] 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.

5.4.2 For the purposes of the present assessment, all noise level predictions have been undertaken using a receiver height of four metres above local ground level, mixed ground (G=0.5) and an air absorption based on a temperature of 10°C and 70 % relative humidity. A receiver height of four metres will be typical of first floor windows and result in slightly higher predicted noise levels than if a 1.2 to 1.5 metre receiver height were chosen in the ISO 9613 algorithm. The attenuation due to terrain screening accounted for in the calculations has been limited to a maximum of 2 dB(A). In situations of propagation above concave ground, a correction of +3 dB was added. These propagation factors are shown in Annex B.

5.4.3 This method is consistent with the recommendations of the above-referenced Institute of Acoustics Good Practice Guide which provides recommendations on the appropriate approach when predicting wind turbine noise levels. The IOA GPG also allows for directional effects to be taken into account within the noise modelling: under upwind propagation conditions between a given receiver and the wind farm the noise immission level at that receiver can be as much as 10 dB(A) to 15 dB(A) lower than the level predicted using the ISO 9613-2 model. However, predictions have been made assuming downwind propagation from every turbine to every receptor at the same time as a worst-case.

5.5 Predicted Wind Farm Operational Noise Immission Levels

5.5.1 Table 6 shows predicted noise immission levels at each of the selected assessment locations for each wind speed over the range of wind speeds where source noise emission level data are available. All wind farm noise immission levels in this report are presented in terms of the L_{A90} noise indicator in accordance with the recommendations of the ETSU-R-97 report, obtained by subtracting 2 dB(A) from the calculated L_{Aeq} noise levels based on the turbine sound power levels presented in Annex B.

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

Property	Predicted levels L_{A90}, (dB) at Standardised 10 m Wind Speeds (m/s)									
	3	4	5	6	7	8	9	10	11	12
Duntanachan	17.7	22.1	26.7	29.8	30.4	30.4	30.4	30.4	30.4	30.4
Clachadubh	14.3	18.7	23.3	26.4	27.0	27.0	27.0	27.0	27.0	27.0
Barguillean Farm	17.4	21.8	26.4	29.5	30.1	30.1	30.1	30.1	30.1	30.1
Sithean/Bunanta	18.1	22.5	27.1	30.2	30.8	30.8	30.8	30.8	30.8	30.8
Bar Glas	19.4	23.8	28.4	31.5	32.1	32.1	32.1	32.1	32.1	32.1
Am Barr	17.9	22.3	26.9	30.0	30.6	30.6	30.6	30.6	30.6	30.6

21 ISO 9613-2:2024 'Acoustics – Attenuation of sound during propagation outdoors – Part 2: General method of calculation', International Standards Organisation, 1996 (updated 2024).

5.5.2 It is apparent from Table 6 that predicted levels do not exceed 34 dB L_{A90} at any of the properties at all wind speeds.

5.6 ETSU-R-97 assessment

5.6.1 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.

5.6.2 The assessment (shown in tabular form in Table 6) shows that the predicted wind farm noise immission levels meet the simplified ETSU-R-97 noise criterion of 35 dB(A) under all wind speeds and at all locations. Therefore, the Proposed Development (in isolation) complies with the requirements of ETSU-R-97.

5.7 ETSU-R-97 Cumulative Assessment

5.7.1 Other wind development, operational, consented or in planning, have been identified within 5 km of the Proposed Development to be included in a cumulative assessment in accordance with ETSU-R-97 and IOA GPG. The cumulative developments assessed are the Cruach Clenamacrie Wind Farm (Energy Consents Unit reference ECU00004841) to the north-west of the Proposed Site, and Corr Chnoc Wind Farm (Energy Consents Unit reference ECU00006023) to the west. Another wind development (Barachander Wind Farm), to the southwest of the Proposed Development, is currently in scoping stage and therefore, has not been included in this cumulative assessment.

5.7.2 Figure B1 illustrates the map of the Site with the Proposed wind turbines, locations of the other wind developments in the area, it illustrates the cumulative noise level contours, and shaded area illustrating noise difference between other wind farms and the Proposed Development. Receptors located within the 35 dB(A) contour and areas where Proposed Development noise is within 10 dB (yellow shaded) or above 10 dB (green shaded) other wind farm noise levels have been included in the assessment, receptors located within area where Proposed Development noise is 10 dB below other wind farm noise levels (grey shaded) have been excluded from the assessment.

5.7.3 Figure B1 shows most receptors to be outside the 35 dB(A) predicted cumulative noise contour except for the Clachadubh property, which is located between Corr Chnoc Wind Farm and the Proposed Development. The assessment (shown in tabular form in Table 7) shows the predicted cumulative wind farm noise immission levels (L_{A90}) at each of the assessed receptors. These predictions are cumulative; assuming all other wind farms are operating with the proposed turbines in operation as described in Annex B and that all receptors are downwind of all wind turbines at the same time. These cumulative noise levels are unlikely to occur in practice.

Table 7 – Cumulative Predicted L_{A90} (dB) wind farm noise immission levels at each of the noise assessment locations as a function of standardised wind speed for the Proposed Development, Cruach Clenamacrie, and Corr Chnoc.

Property	Predicted levels L_{A90}, (dB) at Standardised 10 m Wind Speeds (m/s)									
	3	4	5	6	7	8	9	10	11	12
Duntanachan	22.3	24.8	29.3	33.0	33.8	33.9	34.0	34.2	34.3	34.3
Clachadubh	24.4	25.8	30.3	34.3	35.2	35.4	35.6	35.9	36.0	36.0
Barguillean Farm	20.1	23.2	27.8	31.2	31.9	32.0	32.1	32.2	32.3	32.3

Property	Predicted levels L_{A90}, (dB) at Standardised 10 m Wind Speeds (m/s)									
	3	4	5	6	7	8	9	10	11	12
Sithean/Bunanta	20.7	23.8	28.4	31.8	32.5	32.6	32.7	32.8	32.9	32.9
Bar Glas	20.9	24.5	29.1	32.4	33.1	33.1	33.2	33.2	33.3	33.3
Am Barr	20.1	23.5	28.0	31.4	32.1	32.2	32.3	32.4	32.4	32.4

5.7.4 Table 7 shows that predicted cumulative noise levels do not exceed 35 dB(A) at all receptors at all wind speeds except for Clachadubh which shows cumulative levels of just under 36 dB(A) at wind speeds of 10 m/s and above only. The difference of 1 dB with the 35 dB(A) criterion would not be expected to be perceptible to the human ear (see Annex A).

5.7.5 Furthermore it should be noted that this predicted level is based on downwind predictions from all wind turbines as a worst-case; however, it is not possible for this to occur in practice for this receptor as it is located between the Proposed Development and the other wind farms considered and, as such, it can either be upwind of one and downwind of the other or vice versa and cannot be downwind of both. Therefore, Annex C sets out further calculations which have been carried out in relation to Clachadubh using directional propagation methods as discussed in Paragraph 5.5.3 of the IOA GPG guidance. Figure C1 illustrates predicted noise levels from the total cumulative and individual wind developments across all wind directions at 10 m/s. This shows that total cumulative predicted levels to be at maximum 35.4 dB(A). Based on the IOA GPG guidance, a predicted theoretical cumulative excess of the noise limit by less than 0.5 dB is not considered acoustically relevant[22]. Therefore, the predicted excess at the Clachadubh property is considered negligible.

5.7.6 It is therefore concluded that predicted cumulative noise immission levels from the Proposed Development, when operating together with the Cruach Clenamacrie and Corr Chnoc Wind Farms, can remain compliant with the ETSU-R-97 simplified noise limit of 35 dB(A) (with negligible exceptions).

5.8 Low Frequency Noise, Vibration and Amplitude Modulation

5.8.1 Low frequency noise and vibration resulting from the operation of wind farms are issues that have been attracting a certain amount of attention over recent years. Consequently, Annex A includes a detailed discussion of these topics. In summary of the information provided therein, the current recommendation is that ETSU-R-97 should continue to be used for the assessment and rating of operational noise from wind farms.

5.8.2 Annex A also discusses the published research on the subject of wind turbine blade swish Amplitude Modulation (or AM). As a consequence of the combined results of this research, and in particular the development by the IOA of an objective technique for identifying and quantifying AM noise, as well as a review of the subjective response to AM noise by a Government-commissioned research group, a penalty-type approach to account for instances of increased AM outside what is expected from 'normal' blade swish has been proposed. Some uncertainty remains at this stage over the application of such a penalty (as discussed in Annex A) but current Scottish planning guidance still considers that ETSU-R-97 continues to be applicable.

[22] 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 0.4 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 0.4 dB or less is not considered acoustically relevant.

6. Summary of Key Findings and Conclusions

6.1.1 This report has presented an assessment of the impacts of construction and operational noise from the Proposed Development on the residents of nearby dwellings.

6.1.2 Several residential properties lying around the wind farm have been selected as being representative of the closest located properties to the wind farm. Noise assessments have been undertaken at these properties by comparing predicted construction and operational noise levels with relevant assessment criteria. In the case of construction noise, relevant assessment criteria are in the form of absolute limit values derived from a range of environmental noise guidance. In relation to operational noise, the limits have been derived from the simplified and most stringent noise limits applicable under ETSU-R-97.

6.1.3 The construction noise assessment has determined that associated levels are expected to be audible at various times throughout the construction programme but remain with acceptable limits such that their temporary impacts are considered of minor magnitude, provided that some activities are restricted during weekend periods.

6.1.4 Construction traffic associated with the Proposed Development in isolation is considered to be associated with negligible increases in noise for properties along the construction route. No Cumulative traffic effects are anticipated for the future year of 2032.

6.1.5 Operational noise from the wind farm has been assessed in accordance with the methodology set out in ETSU-R-97, 'The Assessment and Rating of Noise from Wind farms'. This document provides a robust basis for assessing the operational noise of a wind farm as recommended by The Scottish Government's Online Renewables Planning Advice on Onshore wind turbines.

6.1.6 It has been demonstrated that the relevant ETSU-R-97 noise limit can be satisfied at all assessment properties across all wind speeds for the Proposed Development in isolation and cumulatively. This assessment has been based on the use of the robust manufacturer sound power data for the Vestas V136 wind turbine which is typical of the type and size of turbine which may be considered for this site, and assuming worst case downwind propagation. At some locations under some wind conditions and for a certain proportion of the time, the wind farm noise may be audible; however, operational noise immission levels comply with the criteria of the guidance recommended by planning policy for the assessment of wind farm noise.

Annex A - General Approach to Noise Assessment & Glossary

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

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

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

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

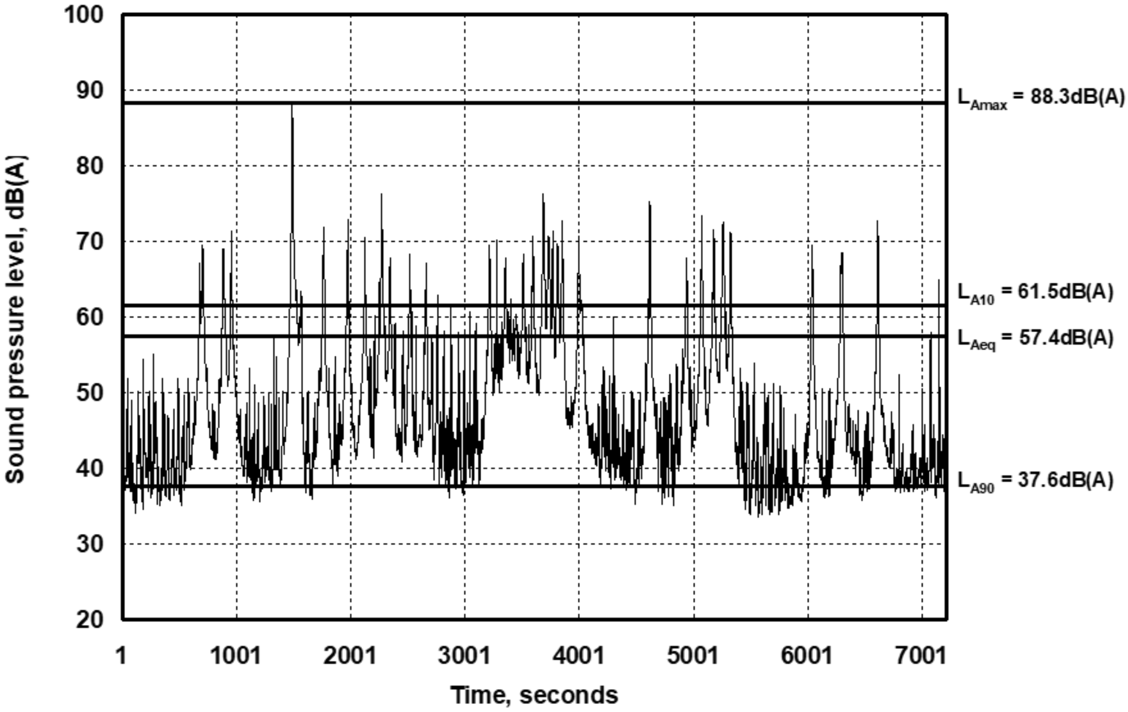
A.5. Before reviewing the potential effects of environmental sound on people, it is useful first to consider the means by which physical sound can be quantified.

Indicators of physical sound levels

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

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

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



Objective measures of noise

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

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

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

Sound levels and decibels

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

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

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

Frequency selectivity of human hearing and A-weighting

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

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

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

Temporal variation of noise and noise indices

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Effects of sound on people

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

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

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

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

Speech interference

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

Sleep disturbance

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

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

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

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

Noise annoyance

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

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

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

A.41. Whether or not an exposed individual has a personal interest in a given sound often has a significant bearing on their acceptance of it. For example, if recipients gain benefit from an association with the sound producer, or if they accept that the sound is necessary and largely unavoidable, then they are likely to be more tolerant of it. This is often the case even if they don't necessarily consider it desirable. A good example of this is road traffic noise which is the dominant noise heard by over 90% of the population but results in relatively few complaints.

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

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

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

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

Specific Environment	Critical Health Effects	$L_{Aeq,T}$	Time base (hrs)	L_{Amax} (dB)
Outdoor living area	Serious annoyance, day time and evening	55	16	-
	Moderate annoyance, day time and evening	50	16	-
Dwelling, 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 not appropriate for assessing the acceptability of noise produced by any specific development. Furthermore, these guidelines do not provide recommendations for indoor noise levels and the 2000 WHO Guidelines for Community Noise remain applicable in this regard. For these reasons, the 2018 guidelines will not be referenced any further.

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

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

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

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

Low frequency noise and vibration – wind farms

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

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

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

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

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

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

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

A-weighting

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

Alternative frequency weightings

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

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

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

Wind-farm infrasound and vibration

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

A.62. As early as 1997 a report by Snow[23] gave details of a comprehensive study of infrasound and low frequency sound (up to around 100 Hz) and vibration measurements made in the vicinity of a wind farm. Measurements were made both on the wind farm site, and at distances of up to 1 kilometre. During the experiments a wide range of wind speeds and directions were recorded. It was found that the vibration levels at 100 metres from the nearest turbine itself were a factor of 10 lower than those recommended for human exposure in the most critical buildings (i.e. laboratories for precision measurements), and lower again than the limits specified for residential premises. A similar comparison with recognised limits for assessing structural damage showed that the measured vibrations were a factor of 100 below the recommended guidelines at 100 metres from the turbines.

A.63. Noise and vibration levels were found to comply with recommended residential criteria even on the wind turbine site itself. Although low level infrasonic (i.e. below 20 Hz) periodic noise from the wind farm was detected by instrumentation at distances up to 1 kilometre, the measuring instruments used were much more sensitive than human hearing. Based on his measurements Snow concluded that subjective detection of the wind turbines may be apparent at this distance, but if this is the case it will be due to higher frequency components (which are more readily masked by general ambient environmental noise) and not the low frequency components which lie below the threshold of audibility.

A.64. In 2003, findings on both low frequency sound and infrasound have been compiled into the previously referenced extensive review report commissioned by DEFRA and prepared by Dr G Leventhall[24]. Dr Leventhall notes that despite the numerous published studies there is little or no agreement about the biological effects of infrasound or low frequency sound on human health. Leventhall notes that direct evidence of adverse effects of exposure to low-intensity levels of infrasound (less than 90 dB) is lacking.

23 'Low frequency noise and vibration measurements at a modern wind farm', D. Snow, ETSU Report ETSU W/13/00392/REP, 1997
24 'A review of published research on low frequency noise and its effects', G. Leventhall, report for DEFRA, 2003

He goes on to describe the low frequency hearing threshold i.e. the lowest levels which are audible to an average person with normal hearing. He notes the threshold at 4 Hz is about 107 dB, at 10 Hz it is about 97 dB and at 20 Hz it is 79 dB. As such, high levels of infrasound are required to exceed the hearing thresholds at such low frequencies. Leventhall therefore concluded that most people can be reassured that there will be no serious consequences to peoples' health from infrasound exposure.

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

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

A.66. In 2004/2005 researchers from Keele University investigated the effects of the extremely low levels of vibration resulting from wind farms on the operation of a seismic array installed at Eskdalemuir in Scotland. This is one of the most sensitive ground-borne vibration detection stations in the world. The results of this study were initially misinterpreted, as just discussed for the DEFRA/Leventhall report, in that if infrasonic vibrations from wind farms can be measured, then they must consequentially have some potential effect on humans. In order to clarify their position, the authors subsequently explained[25] that:

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

A.67. They then continue:

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

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

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

A.69. In 2006, the results of a study specifically commissioned by the UK Department of Trade and industry (DTI) to look at the effects of infrasound and low frequency noise (LFN) arising from the operation of wind farms have been published in what is commonly referred to as the DTI LFN Report[26]. This Report is quite categorical in its findings: infrasound is not the perceived health threat suggested by some

25 'Wind farm noise', P. Styles, letter by Prof P Styles and S Toon printed in The Scotsman, August 2005.
26 'The measurement of low frequency noise at three UK wind farms', M. Hayes, DTI Report W/45/00656/00, 2006

observers, nor should it even be considered a potential source of disturbance. Quoting from the Executive Summary to the DTI LFN Report:

'Infrasound noise emissions from wind turbines are significantly below the recognised threshold of perception for acoustic energy within this frequency range. Even assuming that the most sensitive members of the population have a hearing threshold which is 12 dB lower than the median hearing threshold, measured infrasound levels are well below this criterion.

The document "Community Noise" prepared for the World Health Organisation, states that "there is no reliable evidence that infrasound below the hearing threshold produce physiological or psychological effects". Other detection mechanisms of infrasound only occur at levels well above the threshold of audibility.

It may therefore be concluded that infrasound associated with modern wind turbines is not a source which will result in noise levels which may be injurious to the health of a wind farm neighbour'.

A.70. This has been subsequently confirmed by many international studies and reviews. For example, a study for the National Institute for Public Health and the Environment (RIVM) in the Netherlands[27] published in 2020 concluded in this regard that:

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

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

Low frequency sound

A.72. A report prepared for DEFRA by Casella Stanger[28] lists wind farms as a possible source of audible low frequency sound (20 Hz to 200 Hz). However, this is one possible source in a list of many commonly encountered sources such as pumps, boilers, fans, road, sea and rail traffic, the wind, thunder, the sea, etc. The report only considers the general issues associated with low frequency sound and makes no attempt to quantify the potential problem associated with each of these sources. This is in contrast to other reports which have considered the specific situation associated with wind farms.

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

A.74. Based on the findings of the DTI LFN Report, low frequency sound in the greater than 20 Hz frequency range may, under some circumstances, be measured to be of a comparable or higher level than the

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

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

threshold of audibility. On such occasions this low frequency sound may become audible to low frequency sensitive persons who may already be awake inside nearby properties, but not to the degree that it will cause awakenings. However, such noise should still be assessed for its potential subjective effects in the conventional manner in which environmental noise is generally assessed. In particular, the subjective effects of this audible low frequency sound should not be confused with the claimed adverse health effect arguments concerning infrasound which, in any event, have now been shown from the results of the DTI LFN Report to be wholly unsubstantiated.

A.75. In November 2006, the UK Government released a statement[29] concerning low frequency sound, reiterating the conclusion of the DTI LFN report that:

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

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

Blade swish (amplitude modulation)

A.77. The noise assessment methodology presented in ETSU-R-97, sets out noise limits which already account for typically encountered levels of blade swish. Notwithstanding the conclusions and advice presented in the preceding paragraphs concerning both infrasound and low frequency sound, the DTI LFN Report went on to suggest that, where complaints of noise at night had occurred, these had most likely resulted from an increased amplitude modulation of the blade passing noise, making the 'swish, swish, swish' sound (often referred to as 'blade swish') more prominent than normal. Whilst it was therefore acknowledged that this effect of enhanced amplitude modulation of blade aerodynamic noise may occur, it was also concluded that there were a number of factors that should be borne in mind when considering the importance to be placed on the issue when considering present and proposed wind farm installations:

- it appeared that the effect had only been reported as a problem at a very limited number of sites (the DTI report looked at the 3 out of 5 U.K. sites where it has been reported to be an issue out of the 126 onshore wind farms reported to be operational at the time in 2006);
- the effect occurred only under certain conditions at these sites (the DTI LFN Report was significantly delayed while those involved in taking the measurements waited for the situation to occur at each location);
- at one of the sites concerned it had been demonstrated that the effect can be reduced to an acceptable level by the introduction of a Noise Reduction Management System (NRMS) which controls the operation of the necessary turbines under the relevant wind conditions (this NRMS had to be switched off in order to gain the data necessary to inform the DTI LFN Report);
- whilst still under review, it appeared that the most likely cause of the increased amplitude modulation was related to an increase in the stability of the atmosphere during evening and night time periods, hence the increased occurrence of such an effect at these times, but this effect had been shown by measurement of wind speed profiles to be extremely site specific;
- internal noise levels were below all accepted night time criteria limits and insufficient to wake residents, it was only when woken by other sources of a higher level (such as local road traffic) that there were self-reported difficulties in returning to sleep.

A.78. The Government then commissioned an independent research project to further investigate the prevalence of the impact of enhanced levels of amplitude modulation across UK wind farms. This

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

research work was awarded to the University of Salford who reported on their findings in July 2007[30]. The Salford study concluded that that the occurrence of increased levels of 'blade swish' was infrequent, but suggested it would be useful to undertake further work to understand and assess this feature of wind turbine noise.

A.79. As a consequence of the findings of the report by the University of Salford, the UK Department for Business, Enterprise and Regulatory Reform (BERR formerly the DTI) issued a statement in August 2007[31] which concluded:-

> *'A comprehensive study by Salford University has concluded that the noise phenomenon known as aerodynamic modulation (AM) is not an issue for the UK's wind farm fleet.*
>
> *AM indicates aerodynamic noise from wind turbines that is greater than the normal degree of regular fluctuation of blade swoosh. It is sometimes described as sounding like a distant train or distant piling operation.*
>
> *The Government commissioned work assessed 133 operational wind projects across Britain and found that although the occurrence of AM cannot be fully predicted, the incidence of it from operational turbines is low'.*

A.80. The statement then concludes with the advice:

> *'Government continues to support the approach set out in Planning Policy Statement (PPS) 22 – Renewable Energy. This approach is for local planning authorities to "ensure that renewable energy developments have been located and designed in such a way to minimise increases in ambient noise levels", through the use of the 1997 report by ETSU to assess and rate noise from wind energy development'.*

A.81. This represents an aspect of wind turbine noise which has become the subject of considerable research in the UK and abroad in the past years and the state of knowledge on the subject is rapidly evolving. An extensive research programme entitled 'Wind Turbine Amplitude Modulation: Research to Improve Understanding as to its Cause and Effect' was published in 2013[32]. This research, commissioned by RenewableUK (ReUK) was specifically aimed at identifying and explaining some of the key features of wind turbine AM noise.

A.82. Claims have emerged from different researchers that wind turbines were capable of generating noise with characteristics out with that expected of them. This characteristic was an enhanced level of modulated aerodynamic noise that resulted in the blade swish becoming more impulsive in character, such that those exposed to it would describe it more as a 'whoomp' or 'thump' than a 'swish'. It could also become audible at distances from the wind turbines that were considerably greater than the distances at which blade swish could ordinarily be perceived. It has since emerged that this may be similar to the character of the noise identified in the DTI LFN study. Hence for the purposes of the ReUK project, any such AM phenomena with characteristics falling outside those expected of this "normal" AM (NAM) were therefore termed 'Other AM' (OAM).

A.83. The research identified the most likely cause of OAM noise is transient stall on the wind turbine blade (i.e. stall which occurs over a small area of each turbine blade in one part of the blade's rotation only). The occurrence of transient stall will be dependent on a combination of factors, including the air inflow conditions onto the individual blades, how these inflow conditions may vary across the rotor disc, the design of the wind turbine blades and the manner in which the wind turbine is operated. Variable inflow conditions may arise, for example, from any combination of wind shear, wind veer, yaw errors, turbine

30 'Research into Aerodynamic Modulation of Wind Turbine Noise', Report by University of Salford, URN 07/1235 (July 2007)

31 'Government statement regarding the findings of the Salford University report into Aerodynamic Modulation of Wind Turbine Noise', BERR, Ref: 2007/033 (1st August 2007)

32 Wind Turbine Amplitude Modulation: Research to Improve Understanding as to its Cause and Effect, Renewable UK, December 2013.

wake effects, topographic effects, large scale turbulence, etc. However, the occurrence of OAM on any particular site cannot be predicted at this stage.

A.84. As a consequence of the combined results of the ReUK research, and most notably the development of objective techniques for identifying and quantifying AM noise and the ability to relate such an objective measure to the subjective response to AM noise, ReUK has proposed an AM test[33] for implementation as a planning condition, although this was subject to discussion.

A.85. The Institute of Acoustics (IOA) published in 2016 a standardised methodology[34] for the assessment and rating of AM magnitude. The method provides a decibel level each 10 minute which represents the magnitude of the modulation in the noise, and minimises the influence of sources not related to wind turbines. The proposed method, unlike other methods that have previously been proposed, utilises as the core of its detection capability the fact that AM noise from wind turbines, by definition, exhibits periodicity at a rate that is directly related to the rotational speed of the source wind turbine. The IOA document does not however provide any thresholds or criteria methodology for using the resulting AM values.

A.86. The UK Government (DECC or Department of Energy and Climate Change, now obsolete) commissioned a review focused on the subjective response to AM with a view to recommend how this feature may be controlled. The outcome of this research has been published[35] in October 2016 by the Department for Business, Energy & Industrial Strategy (DBEIS). This report recommends the use of a “character penalty” approach, in which a correction is applied to the overall A-weighted noise level to account for AM in the noise in a manner similar to that used to assess tonality in the noise according to ETSU-R-97. This penalty is based on the above IOA methodology for detecting AM. The researchers make a number of recommendations for local authorities to consider and qualifications for the use of such controls, and note that the current state of knowledge on the subject and the implications of their proposed control is limited and that a period of testing and review over the next few years would be beneficial. The authors were however unable to provide clarity on how exactly the recommendations would operate in practice for any particular wind farm. On publication of the report, DBEIS encouraged local authorities in England to consider the research but provided limited guidance on how the outcomes were to be accounted for within the planning system.

A.87. A Scottish Government onshore wind policy statement[36] published in late 2022 mentions the potential for the advice in ETSU-R-97 to be modified in future based on a review from the UK Government but continues to support its use “*until such time as new guidance is produced*”. Subsequently, a report commissioned by the UK Department for Business, Energy & Industrial Strategy was published[37] in February 2023 and concludes that the noise limits in ETSU-R-97 should be reviewed and that updated guidance on amplitude modulation should be included but makes no firm recommendations with regards to any update. Therefore, until the UK or national governments conclude such a review, the ETSU-R-97 methodology continues to be applicable. The UK Government has also confirmed[38] that ETSU-R-97 should continue to apply until the review recommendations are considered in further detail.

33 Template Planning Condition on Amplitude Modulation (guidance notes), RenewableUK, December 2013.

34 Institute of Acoustics (IOA) Amplitude Modulation Working Group, Final Report, A Method for Rating Amplitude Modulation in Wind Turbine Noise, June 2016.

35 Review of the evidence on the response to amplitude modulation from wind turbines, WSP for Department for Business, Energy & Industrial Strategy. https://www.gov.uk/government/publications/review-of-the-evidence-on-the-response-to-amplitude-modulation-from-wind-turbines

36 Scottish Government (2021) - Onshore wind - policy statement 2022, December 2022.

37 WSP, A Review of Noise Guidance for Onshore Wind Turbines, report for the UK Department for Business, Energy & Industrial Strategy, October 2022 (published 10 February 2023).

38 Government Response to the House of Lords Science and Technology Committee Report: The neglected pollutants: the effects of artificial light and noise on human health, December 2023. https://committees.parliament.uk/publications/42401/documents/210714/default/ [accessed January 2023]

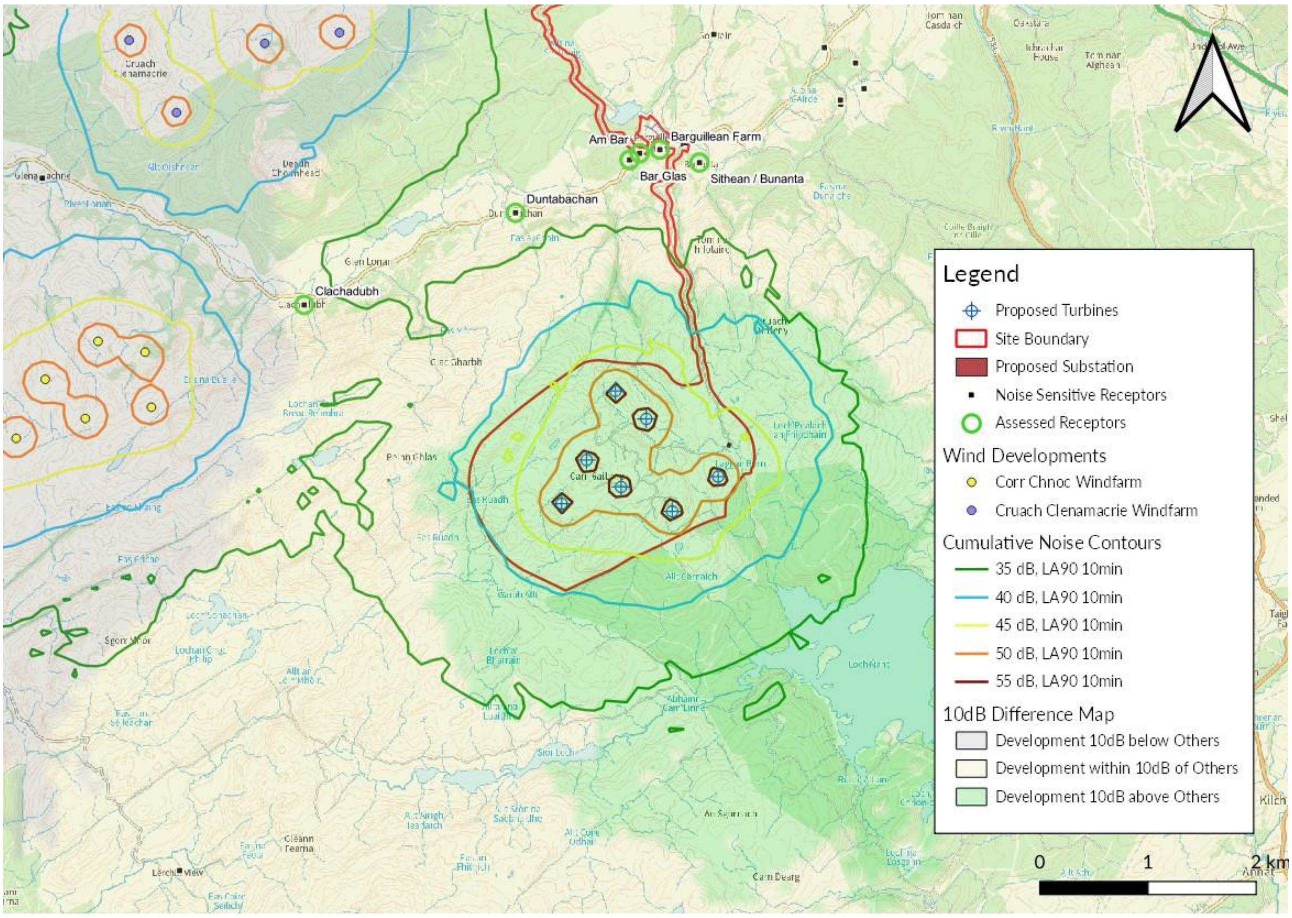
Glossary of Acoustics Terminology

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

Annex B – Location Maps and Turbine Coordinates

Figure B1 - Map showing site boundary, the layout of the proposed turbines, other wind farms, Noise Sensitive Receptors, Cumulative noise contours, 10dB difference shaded area, and the noise assessment locations (green circles).



Turbine & Propogation Details: The Proposed Development

Table B1 – Turbine coordinates

Turbine	Easting	Northing
T01	198584	725789
T02	198159	725467
T03	197686	725693
T04	197136	725538
T05	197919	726322
T06	197367	725942
T07	197633	726580
All turbines modelled at 81.9 m hub height and operating in unconstrained Mode PO4-0S.		

Table B2-Propagation attenuation effects due to terrain (dB) – positive numbers are due to terrain shielding barrier effects (e.g. 2), representing a decrease in noise levels, and negative numbers (e.g. -3) represent an increase in predicted noise levels due to concave ground effects. Where there is a zero shown, neither terrain shielding nor concave ground were found.

Property	Turbine number						
	T01	T02	T03	T04	T05	T06	T07
Duntanachan	2	2	2	2	2	2	2
Clachadubh	2	2	2	2	2	2	2
Barguillean Farm	2	2	2	2	0	0	0
Sithean/Bunanta	2	2	2	2	0	0	0
Bar Glas	2	2	0	0	0	0	-3
Am Barr	2	2	0	0	0	0	0

Table B3 - Wind turbine sound power levels (dB L_{Aeq}) used in the noise assessment - the proposed Development.

Turbine make / model	Standardised 10 m Wind Speed (m/s)											
	1	2	3	4	5	6	7	8	9	10	11	12
V136-4.5MW - Mode PO4-0S	-	-	96.1	100.5	105.1	108.2	108.8	108.8	108.8	108.8	108.8	108.8
Derived from: Vestas Performance Specification V136-4.5 MW 50/60 Hz (Low HH), Document no.: 0067-7056.V02, Date: 09/03/2021. +2dB included in levels above for uncertainties in absence of specific test data.												

Table B4 - Octave band sound power spectrum (dB L_{Aeq}) for reference wind speed conditions (v_{10} = 8 m/s) - the proposed Development

Turbine make / model	Octave Band Centre Frequency (Hz)								
	63	125	250	500	1000	2000	4000	8000	A
V136-4.5MW - Mode PO4-0S	89.9	97.5	102.1	103.9	102.8	98.7	91.9	82.0	108.8
Derived from: Vestas Document DMS 00067-4732 V02, 20/03/2018 for V136 4/4.2MW variant. Normalised to 108.8 dB(A).									

Turbine & Propogation Details: Cruach Clenmacrie Wind Farm

B.1. Cruach Clenamacrie Wind Farm was submitted in planning to the Scottish Energy Consents Unit in January 2025 (Ref: ECU00004841). The development consists of six turbines based on the Vestas V162 7.2MW (STE) candidate turbines at a hub height of 119 m above ground. The development is located approximately 4.1 km northwest of the closest Proposed Development turbine. Cruach Clenamacrie Wind Farm Environmental Impact Assessment Report (EIAR) Chapter 8 – Noise[39] shows that the development was assessed and complied with the simplified ETSU-R-97 criterion of 35 dB(A), using the V162 7.2 MW candidate turbine. The emission levels for Cruach Clenamacrie Wind Farm used in this cumulative assessment are therefore set such that that the Cruach Cleanmacrie Wind Farm predicted levels do not exceed this limit at the nearest controlling property Glenamachrie (Table 2).

B.2. Sound power levels for the Cruach Clenamacrie turbines are taken from documents available publicly for the Vestas V162 7.2 MW wind turbine as referenced in the tables below and include an allowance of +2 dB for uncertainties in line with IOA GPG guidance. These overall sound power levels are approximately the same as sound power levels submitted in the EIAR. The sound power levels in Table B6 are further uplifted as required by the IOA GPG when considering cumulative effects: in this instance, an uplift of +1 dB was applied as this resulted in predicted noise levels from Cruach Clenamacrie Wind Farm to just reach the simplified limit of 35 dB(A) at its nearest noise sensitive receptors, Glenamachrie.

Table B5 – Turbine coordinates

Turbine	Easting	Northing
CR1	193137	729822
CR2	193575	729153
CR3	194247	730351
CR4	194392	729793
CR5	194873	730439
CR6	195082	729892
All turbines modelled at 119 m hub height and operating in unconstrained Mode PO7200 with STE		

Table B6 - Propagation attenuation effects due to terrain (dB) – positive numbers are due to terrain shielding barrier effects (e.g. 2), representing a decrease in noise levels, and negative numbers (e.g. -3) represent an increase in predicted noise levels due to concave ground effects. Where there is a zero shown, neither terrain shielding nor concave ground were found.

Property	Turbine number					
	CR1	CR2	CR3	CR4	CR5	CR6
Duntanachan	2	2	0	0	0	0
Clachadubh	0	0	2	2	2	2
Barguillean Farm	0	0	0	0	0	0
Sithean/Bunanta	0	0	0	0	0	-3
Bar Glas	2	2	2	2	2	2
Am Barr	2	2	2	2	0	0

[39] The Scottish Government Energy Consents Unit ECU00004841 – EIAR Volume 1 - Chapter 8 – Noise

Table B7 - Wind turbine sound power levels (dB L_{Aeq}) used in the noise assessment – Cruach Clenamacrie Wind Farm.

Turbine make / model	Standardised 10 m Wind Speed (m/s)											
	1	2	3	4	5	6	7	8	9	10	11	12
V162 7.2MW STE – Mode PO7200	-	-	96.0	96.9	101.4	105.6	106.6	106.8	107.1	107.4	107.5	107.5
Derived from: Vestas Performance Specification, EnVentus V162-7.2 MW 50/60 Hz' Vestas document ref. 0114-3777 V03, 01/07/2022. +2 dB included in levels above for uncertainties in absence of specific test data. (Further uplift of +1 dB added in model)												

Table B8 - Octave band sound power spectrum (dB L_{Aeq}) for reference wind speed conditions (v_{10} = 8 m/s) – Cruach Clenamacrie Wind Farm

Turbine make / model	Octave Band Centre Frequency (Hz)								
	63	125	250	500	1000	2000	4000	8000	A
V162 7.2MW STE – Mode PO7200	89.2	97.1	100.4	100.8	99.3	94.8	87.2	76.6	106.8
Derived from: Vestas V162-7.2MV Third Octave Noise Emission, document ref. 0116-1715_02, 05/10/2022. Normalised to 106.8 dB(A).									

Turbine & Propogation Details: Corr Chnoc Wind Farm

B.3. Corr Chnoc Wind Farm was submitted in planning to the Scottish Energy Consents Unit in January 2025 (Ref: ECU00006023). The development consists of twelve turbines based on the Vestas V162 7.2MW (STE) candidate turbines at a hub height of 119 m above ground. The development is located approximately 3.8 km west of the closest proposed turbine. Corr Chnoc Wind Farm EIAR Chapter 14 – Noise[40] shows that the development was assessed in isolation and cumulatively with the operational Beinn Ghlas Wind Farm using the V162 7.2 MW candidate turbine.

B.4. Sound power levels for the Corr Chnoc turbines are taken from documents available publicly for the Vestas V162 7.2 MW wind turbine as referenced in the tables below and include an allowance of +2 dB for uncertainties in line with IOA GPG guidance. These overall sound power levels are approximately 1.5 dB above the sound power levels presented in the EIAR. The sound power levels in Table B10 were not further uplifted in the cumulative assessment in this instance, as the predicted noise levels from Corr Chnoc Wind Farm reach 35 dB(A) at its nearest noise sensitive receptors, Kilbride (Easting / Northing 191591/724491).

Table B9 – Turbine coordinates

Turbine	Easting	Northing
C1	193343	726430
C2	193285	726939
C3	192732	726325
C4	192850	727039
C5	192362	726688
C6	192093	726142
C7	191605	726466
C8	191453	725895
C9	191012	726261
C10	190866	725664
C11	190398	725729
C12	189971	725997
All turbines modelled at 119 m hub height and operating in unconstrained Mode PO7200		

Table B10 - Propagation attenuation effects due to terrain (dB) – positive numbers are due to terrain shielding barrier effects (e.g. 2), representing a decrease in noise levels, and negative numbers (e.g. -3) represent an increase in predicted noise levels due to concave ground effects. Where there is a zero shown, neither terrain shielding nor concave ground were found.

Property	Turbine number											
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
Duntanachan	-3	-3	0	-3	0	0	0	0	0	0	2	0
Clachadubh	0	0	2	0	2	2	2	2	2	2	2	2

[40] The Scottish Government Energy Consents Unit ECU00006023 – ES Volume 1 – Chapter 14 – Noise

Property	Turbine number											
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
Barguillean Farm	-3	2	-3	2	2	2	2	2	2	2	2	2
Sithean/Bunanta	0	-3	0	-3	-3	0	0	0	0	0	0	-3
Bar Glas	2	2	2	2	2	2	2	2	2	2	2	2
Am Barr	2	2	2	2	2	2	2	2	2	2	2	2

Table B11 - Wind turbine sound power levels (dB L_{Aeq}) used in the noise assessment – Corr Chnoc Wind Farm

Turbine make / model	Standardised 10 m Wind Speed (m/s)											
	1	2	3	4	5	6	7	8	9	10	11	12
V162 7.2MW STE – Mode PO7200	-	-	96.0	96.9	101.4	105.6	106.6	106.8	107.1	107.4	107.5	107.5
Derived from: Vestas Performance Specification, EnVentus V162-7.2 MW 50/60 Hz' Vestas document ref. 0114-3777 V03, 01/07/2022. +2 dB included in levels above for uncertainties in absence of specific test data.												

Table B12 - Octave band sound power spectrum (dB L_{Aeq}) for reference wind speed conditions (v_{10} = 8 m/s) – Corr Chnoc Wind Farm

Turbine make / model	Octave Band Centre Frequency (Hz)								
	63	125	250	500	1000	2000	4000	8000	A
V162 7.2MW STE – Mode PO7200	89.2	97.1	100.4	100.8	99.3	94.8	87.2	76.6	106.8
Derived from: Vestas V162-7.2MV Third Octave Noise Emission, document ref. 0116-1715_02, 05/10/2022. Normalised to 106.8 dB(A).									

Annex C – Directional Predictions

Figure C1 - Chart of ETSU-R-97 based noise limits (day and night) appropriate for the assessment location of Clachadubh, as well as predicted noise immission levels shown by wind direction for the Proposed Development, the other wind farms considered, and the cumulative total, for a wind speed of 10 m/s.

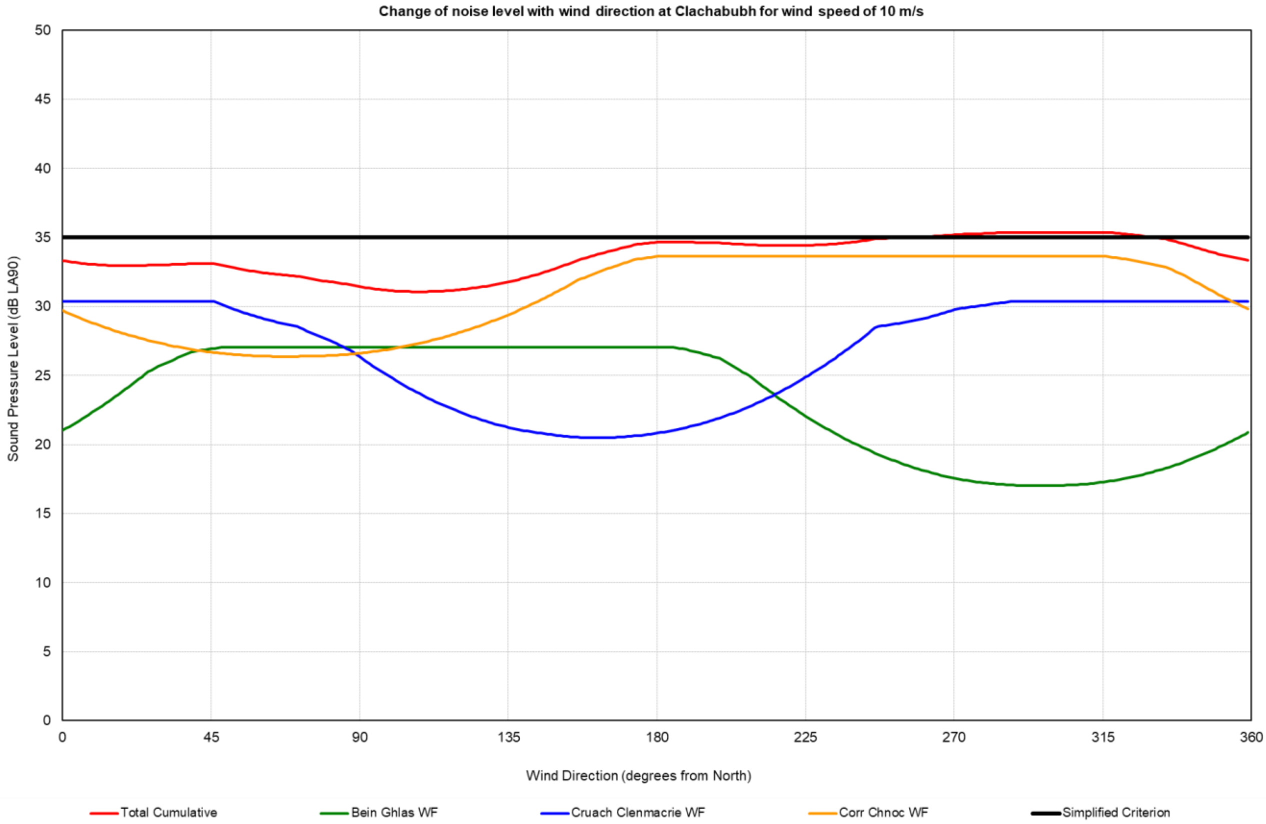


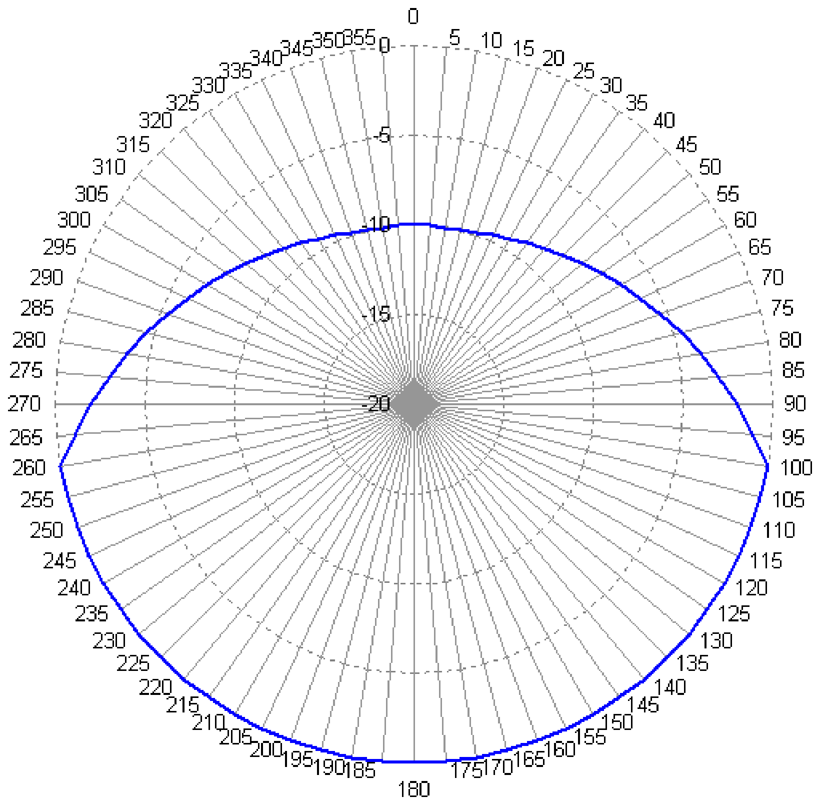
Figure C2 below illustrates the relationship assumed between the reduction in turbine noise levels and wind heading that may occur, because of propagation effects. This relationship is based on the conservative assumption that: for a range of headings directly downwind (0°) to crosswind (90°) there may be no reduction in noise levels; once in cross wind directions (90°), then the reduction may be 2.0 dB(A); and when upwind, the reduction would be 10 dB(A). The values assumed for the wind heading related attenuation are derived from the JOULE project (Bass et. al., 1998) in conjunction with advice in PPG24 and ISO 9613-2. The JOULE project indicated that upwind propagation could result in levels 10 dB(A) to 15 dB(A) below those predicted by ISO 9613 (under favourable downwind conditions). ISO 9613-2 suggests that predictions made using the model are applicable with a range of wind headings 'wind direction within an angle of ±45° of the direction connecting the centre of the dominant sound source and the centre of the specified area, with the wind blowing from the source to the receiver'.

Although now out of commission, advice contained within PPG24 was used to inform the methodology of directional assessment. PPG24 relates the amount of attenuation to the presence of a positive vector component of wind speed: 'The noise level measured at a monitoring point will be affected by wind speed and direction, and temperature gradients, particularly when the monitoring point is remote (>30m) from the source. The size of these effects is hard to predict, and so measurements (or predictions) should be made under reasonably stable conditions. A suitable condition is a light wind with a vector component up to 2 m/s from source to receiver; this will increase the noise level by about 2 dB(A) compared with the no wind case.'

It has been assumed therefore that the values of propagation in favourable downwind conditions should be valid for angles up to ±45 degrees as recommended by ISO 9613-2. Following the advice in PPG24, once a positive vector component of wind is equal to 2 m/s then this gives rise to a +2 dB(A) increase in noise levels compared to a cross wind (at 90 and 270 degrees) case when the level of attenuation is set at 0 dB. Given that the propagation model could be used in wind speeds up to 12 m/s then a positive vector component wind speed of 2 m/s could exist at an angle of 10 degrees of downwind propagation (i.e. at 100 and 260 degrees in Figure C2). Once the receptor is upwind then the level of attenuation is 10 dB compared to favourable propagation, the minimum reported from the JOULE project. The attenuation factors have been normalised zero for favourable downwind propagation and are therefore applied as a correction to the values predicted using the model given in ISO 9613-2.

Furthermore, these propagation directivity corrections were only applied for receptors located at a sufficient distance from the turbines (assuming a distance of 5 to 10 tip heights on a precautionary basis). The correction applied is consistent with advice provided in the IOA GPG.

Figure C2 - Relationship of the change of noise levels with wind direction, 180° is where the receptor is directly downwind of the turbine and 0° where the receptor is directly upwind of the turbine.



Direction	Attenuation
0	-10.0
15	-9.9
30	-9.3
45	-8.3
60	-6.7
75	-4.6
90	-2.0
105	0.0
120	0.0
135	0.0
150	0.0
165	0.0
180	0.0
195	0.0
210	0.0
225	0.0
240	0.0
255	0.0
270	-2.0
285	-4.6
300	-6.7
315	-8.3
330	-9.3
345	-9.9
360	-10.0

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