# Chleansaid Wind Farm.
# Environmental noise assessment.

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# Audit sheet.

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# Contents.

# Executive Summary

Hoare Lea (HL) have been commissioned by RSK Environment Limited, on behalf of ESB Asset Development UK Limited, to undertake a noise assessment for the construction and operation of the proposed Chleansaid Wind Farm (the Proposed Development). Noise will be emitted by equipment and vehicles used during construction and decommissioning of the Proposed Development 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 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. Various mitigation methods have been suggested to reduce the effects of construction noise, the most important of these being suggested restrictions of hours of working. It is concluded that noise generated through construction activities will have a minor effect.

De-commissioning is likely to result in less noise than during construction of the Proposed Development. The construction phase has been considered to have minor noise effects, therefore decommissioning will, in the worst case, also have minor noise effects.

## 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 at one noise-sensitive location (Dalnessie) neighbouring the Proposed Development site (with other properties located further away and with negligible noise effects). A survey has been performed to establish existing baseline noise levels at Dalnessie. Noise limits have been derived from this data following the method stipulated in national planning guidance.

Predicted operational noise levels have been compared to these limit values to demonstrate that turbines of the type and size which would be installed can operate within the limits so derived. It is concluded therefore that operational noise levels from the Proposed Development will be within levels deemed, by national guidance, to be acceptable for wind energy schemes.

Cumulative effects with the proposed Strath Tirry Wind Farm were also considered but were determined to be negligible. Other, more distant wind farms were not considered as they do not make an acoustically relevant contribution to cumulative noise levels.

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

# 1. Introduction

1.1.1 This report presents an assessment of the potential construction and operational noise effects of the Chleansaid Wind Farm (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 effects of its decommissioning. Assessment of the operational noise effects accounts for the cumulative effect of the Proposed Development as well as the proposed Strath Tirry Wind Farm nearby. Other, more distant wind farms were not considered because as their potential noise contribution was considered negligible.

1.1.2 Noise and vibration which arises from the construction of the Proposed Development should be taken into account. However, in assessing the effects 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 significant effects. The construction and use of access tracks may, however, occur at lesser separation distances. Assessment of the temporary effects 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 2 Proposed Development and Chapter 12 Transport of the EIA Report.

1.1.3 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 around the Proposed Development will therefore generally form the basis of the assessment of the levels of noise against accepted standards.

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

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

2.1.2 The Scottish Government's online guidance ("Onshore wind turbines: planning advice" [iii]) confirms that the recommendations of 'The Assessment and Rating of Noise from Wind Farms' (ETSU-R-97)[iv] "*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 The recommendations contained in ETSU-R-97 provide a robust basis for assessing the noise implications of a wind farm. ETSU-R-97 has become the accepted standard for such developments within the UK. Guidance on good practice on the application of ETSU-R-97 has been provided by the Institute of Acoustics (IOA Good Practice Guide or GPG)[v]. This was subsequently endorsed by the Scottish Government[vi] which advised in the web based planning advice note that this *'should be used by all IOA members and those undertaking assessments to ETSU-R-97',* The methodology of ETSU-R-97 and the IOA GPG has therefore been adopted for the present assessment and is described in greater detail below.

2.1.4 With regard to infrasound and low-frequency noise, the above-referenced online planning advice note, Onshore wind turbines refers to a report for the UK Government which concluded that *'there is no evidence of health effects arising from infrasound or low frequency noise generated by the wind turbines that were tested'.*

2.1.5 PAN1/2011 and the Technical Advice Note[vii] 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[viii]. 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.

2.1.6 For detailed guidance on construction noise and its control, the Technical Advice Note refers to British Standard BS 5228[ix] '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)[x] (BS 5228-1) for airborne noise and BS 5228-2: 2009 (amended 2014)[xi] (BS 5228-2) for ground-borne vibration. These updated versions have therefore been adopted as the relevant versions upon which to base this assessment.

2.1.7 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 effect significance.

Similarly, BS 5228-2 provides general guidance on legislation, prediction, control and assessment criteria for construction vibration.

2.1.8 Planning Advice Note PAN50[xii] "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 effects associated with quarry blasting. BS 6472-2 2008[xiii] gives similar guidance on assessing vibration from blasting associated with mineral extraction.

# 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'[xiv] (CRTN).

3.1.5 The nature of works and distances involved in the construction of a wind farm are such that the risk of significant effects 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 significant impacts in this instance. Accordingly, vibration impacts do not warrant detailed assessment and are therefore not discussed further in this assessment.

3.1.6 It is anticipated that some rock extraction from borrow pits by means of blasting operations would be required in some instances. 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 12 m/s (43.2 km/h), where all wind speeds are referenced to a ten metre measurement height (refer to Annex F for a discussion of how wind speeds are referenced to ten metre height).

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

3.2.3 The day-time noise limit is derived from background noise data measured during the 'quiet periods of the day' defined in ETSU-R-97: these comprise weekday evenings (18:00 to 23:00), Saturday afternoons and evenings (13:00 to 23:00) and all day and evening on Sundays (07:00 to 23:00). Multiple samples of ten-minute background noise levels using the $L_{A90,10min}$ measurement index are measured contiguously over a wide range of wind speed conditions (a definition of the $L_{A90,10min}$ index is given in Annex A). The measured noise levels are then plotted against the simultaneously measured wind speed data and a 'best-fit' curve is fitted to the data to establish the background noise level as a function of wind speed. The ETSU-R-97 day-time noise limit is then set to the greater of either: a level 5 dB(A) above the best-fit curve to the background noise data over a 0-12 m/s wind speed range or a fixed level in the range 35 dB(A) to 40 dB(A). The precise choice of the fixed lower limit within the range 35 dB(A) to 40 dB(A) depends on a number of factors: the number of noise affected properties, the likely duration and level of exposure and the consequences of the choice on the potential power generating capability of the wind farm.

3.2.4 ETSU-R-97 clearly indicates that the day-time limit is intended to lie within the range from 35 dB(A) to 40 dB(A). Therefore one can conclude that there must be projects where 35 dB(A) is appropriate and conversely, projects where 40 dB(A) is appropriate. Within ETSU-R-97 there is a specific example: *"A single wind turbine causing noise levels of 40 dB(A) at several nearby residences would have less planning merit (…) than 30 wind turbines also causing the same amount of noise at several nearby residences"*. Therefore, where a project offers relatively low power generating potential, the day-time limit should naturally tend towards the lower end of the range, unless the number of noise affected properties and the extent to which those properties would be affected by the higher noise levels is sufficiently low to justify noise limits tending towards the upper end of the range. Conversely, sites with relatively large power generating capacity should naturally justify limits towards the upper end of the range. The relatively large energy generating potential of the Proposed Development as well as the very low number of surrounding properties in the immediate vicinity of the scheme, would suggest a limit tending towards the upper end of the 35 dB(A) to 40 dB(A) range. However, given that the choice of limit has little impact on generation capacity, this will tend to justify a limit at the lower end of that range, in line with the preferences of the Local Planning Authority (see below). The appropriate choice of value is considered subsequently in Section 5.7 in this Report.

3.2.5 The night-time noise limit is derived from background noise data measured during the night-time periods (23:00 to 07:00) with no differentiation being made between weekdays and weekends. The ten minute $L_{A90,10min}$ noise levels measured over these night-time periods are again plotted against the concurrent wind speed data and a 'best-fit' correlation is established. As with the day-time limit, the night-time noise limit is also set as the greater of: a level 5 dB(A) above the best-fit background curve, or a fixed level of 43 dB(A). This fixed lower night-time limit of 43 dB(A) was set in ETSU-R-97 on the basis of World Health Organization (WHO) guidance[xv] for the noise inside a bedroom and an assumed difference between outdoor and indoor noise levels with windows open. In the time since ETSU-R-97 was released, the WHO guidelines were revised to suggest a lower internal noise level, but conversely, a higher assumed difference between outdoor and indoor noise levels. Notwithstanding the WHO guideline revisions, the ETSU-R-97 limit remains consistent with current national planning policy guidance with respect to night-time noise levels. In addition, following revision of the night-time WHO criteria, ETSU-R-97 has been incorporated into planning guidance for Wales, England and Scotland and at no point during this process was it felt necessary to revise the guidance within ETSU-R-97 to reflect the change in the WHO guideline internal levels. The advice contained within ETSU-R-97 remains a valid reference on which to continue to base the fixed limit at night.

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

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

> *'For single turbines or wind farms with very large separation distances between the turbines and the nearest properties a simplified noise condition may be suitable. We are of the opinion that, if the noise is limited to an $L_{A90,10min}$ of 35dB(A) up to wind speeds of 10m/s at 10m height, then this condition alone would offer sufficient protection of amenity, and background noise surveys would be unnecessary. We feel that, even in sheltered areas when the wind speed exceeds 10m/s on the wind farm site, some additional background noise will be generated which will increase background levels at the property.'*

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

3.2.9 To undertake the assessment of noise effects 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;
- measure the background noise levels as a function of site wind speed at the nearest neighbours, or at least at a representative sample of the nearest neighbours;
- determine the day-time and night-time noise limits from the measured background noise levels at the nearest 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; and
- compare the calculated wind farm noise immission levels with the derived noise limits and assess in the light of planning requirements.

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

3.2.11 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 Construction Noise Criteria

3.3.1 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.

3.3.2 BS 5228-1 informative Annex E provides example criteria that may be used to consider the significance of any construction noise effects. 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 significant effect unless ambient noise levels (i.e. regularly occurring levels without construction) are sufficiently high to provide a degree of masking of construction noise.

3.3.3 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 significance criteria have 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 day-time hours from 07:00 to 19:00 on weekdays, and 07:00 to 13:00 on Saturdays. For noise impacts occurring 13:00 to 19:00 on Saturdays and 07:00 to 19:00 on Sundays the thresholds of Table 1 would reduce by 10 dB(A) in each category.

**Table 1 - Free-field Noise Criteria against which Construction Noise Effects are Assessed**

| Significance | Noise Level dB $L_{Aeq,T}$ | | Description |
|---|---|---|---|
| | 4 weeks or more | up 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<br>≤ 75 | > 75<br>≤ 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<br>≤ 65 | > 65<br>≤ 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. |

3.3.4 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[xvi]). 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 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.

3.3.5 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.

3.3.6 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.

3.3.7 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.

3.3.8 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.

### 3.4 Operational Noise Criteria

3.4.1 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.

### 3.5 Consultation

3.5.1 Prior to undertaking the background survey, a summary of the proposed monitoring survey at one location was forwarded to the Environmental Health Department of The Highland Council's (THC) for comment, and was subsequently agreed to be representative for the purpose of an ETSU-R-97 assessment. This consultation was based on a preliminary project layout which was of a similar form to the layout currently proposed. The agreed noise monitoring location is shown on the plan in Annex B. Further information about the equipment used and pictures of the survey locations are presented in Annex C. This information was also provided to THC following installation of the monitoring equipment and no adverse comments received.

3.5.2 In response to the initial scoping request, THC also expressed a general preference for the following alternative, more stringent noise limits, similar to those of ETSU-R-97 described above in section 3.2 but with:

- the lower day-time limit set to a level of 35 dB(A), at the lowest end of the range of 35 dB(A) to 40 dB(A) set out in ETSU-R-97, regardless of the site-specific factors which ETSU-R-97 recommends as needing consideration when setting a value within this range; and
- the lower limit at night-time set at a level of 38 dB(A) instead of 43 dB(A) as prescribed in ETSU-R-97; or
- the simplified limit of 35 dB(A) set out in ETSU-R-97 (for day and night-time).

3.5.3 These preferred THC limits would apply for a wind farm scheme in isolation or for cumulative levels.

# 4. Baseline

## 4.1 General Description

4.1.1 The Proposed Development will cover an area extending approximately 3 km north to south and 2 km west to east and is located in a rural area of very low population density, with only two properties (Dalnessie Lodge and Estate Manager's Cottage) located within a 3 km radius from the proposed turbines. The noise environment in the surrounding area is generally characterised by 'natural' sources, such as wind disturbed vegetation, and birds or water courses.

## 4.2 Details of the Baseline Background Noise Survey

4.3 It was agreed with THC that monitoring at the nearest property at Dalnessie as being representative of the background noise environment for the nearest residences to the Proposed Development. The location is shown on the plan in Annex B and listed in Table 2, and is located approximately 1.5 km from the nearest turbine. The assessment has considered the effects of the Proposed Development at that location: in the rest of this assessment, "Dalnessie" represents both properties identified at that location.

Table 2 - Background noise monitoring and assessment location (approximate Easting / Northing)

| Property | Easting | Northing |
|---|---|---|
| Dalnessie | 263026 | 915249 |

4.3.1 The cumulative analysis (presented later in this report) also considers potential effects at other properties located closer to the proposed Strath Tirry Wind Farm, as discussed further in section 5.7.

4.3.2 The background noise monitoring exercise was conducted over a period of 4 weeks. The equipment used for the survey comprised a Rion NL-52 logging sound level meter, which was enclosed in an environmental case with battery power to enable at least 14 days continuous logging at the required ten minute averaging periods. An outdoor enhanced windshield system was used to reduce wind induced noise on the microphone and provide protection from rain. This windshield system was supplied by the sound level meter manufacturer and maintains the required performance of the whole measurement system when fitted. The environmental enclosure provided an installed microphone height of approximately 1.2 to 1.5 metres above ground level, consistent with the requirements of ETSU-R-97.

4.3.3 The sound level meter was located on the side of the property closest to the Proposed Development, never closer than 3.5 metres from the façade of the property and as far away as was practical from obvious atypical localised sources of noise such as running water, trees or boiler flues. Details and photographs of the measurement location are presented in Annex C.

4.3.4 The measurement system was calibrated on its deployment on 16/04/2021, during an interim visit on 02/05/2021 and upon collection of the equipment on 14/05/2021. No acoustically important (>0.5 dB(A)) drifts in calibration were found to have occurred on any of the systems. This equates to a total ETSU-R-97 analysis period of at 28 days, which is in excess of the minimum of one week suggested by ETSU-R-97 and is compliant with the IOA GPG requirements.

4.3.5 The measurement system was set to log the $L_{A90,10min}$ and $L_{Aeq,10min}$ noise levels continuously over the deployment period. The system's internal clock was synchronized with Greenwich Mean Time (GMT) by the use of a Global Positioning System (GPS) receiver. The clock on the met mast from which wind data was subsequently collected for the analysis of the measured background noise as function of wind speed was also set to GMT.

## 4.4 Measured Background Noise Levels

4.4.1 The ETSU-R-97 assessment method requires noise data to be related to wind speed data at a standardised height of ten metres, with wind speeds either directly measured at a height of ten metres or by calculation from measurement at other heights, the appropriate choice being determined by practitioner judgement and the available data sources. Since the publication of ETSU-R-97, the change in wind speed with increasing height above ground level has been identified as a potential source of variability when carrying out wind farm noise assessments. The effect of site specific wind shear can be appropriately addressed by implementing the ETSU-R-97 option of deriving ten metre height reference data from measurements made at taller heights. It is this method that has been used in the noise assessment for the Proposed Development to account for the potential effect of site-specific wind shear. This method is consistent with the preferred method described in the IOA GPG. Wind speeds were measured on a 91 metre high meteorological mast located within the boundary of the development site (approximate easting and northing 260975, 918660). Values of wind speed at a standardised height of ten metres were calculated from those measured on the tall mast (“standardised wind speed”). Full details of the calculation method are given in Annex F. This analysis was based on a hub height of 125 m, which is slightly larger than the hub height of up to 118.5 m which would be used for the candidate turbine assumed: this results in slightly more stringent noise limit values and therefore represents a conservative analysis.

4.4.2 Figures D1 and D2 reproduced at Annex D show the range of wind conditions experienced during the noise survey period. During the quiet day-time and night-time periods wind speeds were typically less than 10 m/s. although some periods with wind speeds up to 11 m/s were experienced. The wind was observed to be directed from the west for the majority of the survey period, including strong winds from the south-west consistent with the typical prevailing wind direction for the UK. These conditions and the range of wind speeds obtained are consistent with the requirements of the IOA GPG.

4.4.3 Figures E1 and E2 of Annex E show the results of the background noise measurements at the monitoring location. The background noise data are presented in terms of $L_{A90,10min}$ background noise levels plotted as a function of ten metre height wind speed. Two plots are shown, one for quiet day-time periods and the other for night-time periods, both derived in accordance with ETSU-R-97.

4.4.4 Data from the survey location were inspected to identify periods which may have been influenced by extraneous noise sources, giving rise to atypical and elevated levels. ETSU-R-97 requires that any data affected by rainfall be excluded from the analysis. A rain gauge was also installed at Dalnessie during the noise survey period; data from this gauge were therefore used to exclude those periods where rain was indicated.

4.4.5 In addition to the impact noise on surrounding vegetation and the sound level meter itself, in some environments rainfall can result in appreciable changes in background sound levels, for example as a result of wet roads which increase tyre noise emissions or dissipating flow noise in water courses and drainage systems. Observations whilst on-site indicated traffic noise to be a negligible influence on background sound levels, and thus the possible effect of increased tyre noise from wet roads is not considered relevant to this site. In terms of water flow noise, this was not observed to be a strong contributor at the chosen monitoring location. Based on the above, rainfall is considered to have a limited effect on background sound levels. Inspection of the data generally tends to support this, given the absence of any identifiable clear data trends that are normally characteristic of a site affected by rain related background sound levels (such as flat clusters of data on the noise versus wind plot, or sharp increases in noise followed by a progressive decrease with time).

4.4.6 The measured background noise data may also have been increased by other extraneous sources or atypical events. The Time-history of the noise levels at the survey location was therefore inspected to look for any atypical relationships when compared to the wind speeds present during that time. Any elevated levels found in this way were excluded. The trend of the data when plotted against wind speed was also inspected to look for atypical relationships or outliers within the dataset (particularly at low wind speeds) which were excluded. Any data removed from the analysis in this way is indicated on the charts as red circles. The analysis and filtering of the data was therefore undertaken in accordance with current good practice as set out in the IOA GPG.

4.4.7 Following removal of those data points, best-fit lines were generated using a polynomial fit of a maximum of 2nd order. These lines of best-fit were then used to derive the noise limits required by ETSU-R-97 that apply during the day-time and night-time periods up to 12 m/s. The corresponding ETSU-R-97 noise limits are summarised in Table 3 and Table 4. The noise limits have been set either at the prevailing measured background level plus 5 dB, or at the relevant fixed lower limit, whichever is the greater. The derivation of the relevant fixed lower limit value used for day-time periods (35 dB(A)) is described in section 5.7 below. For night-time periods, a noise limit is shown both using the fixed limit of 43 dB(A) prescribed in ETSU-R-97 as well as the 38 dB(A) lower limit preferred by THC.

Table 3 - Day time $L_{A90,T}$ Noise Limits Derived from the Baseline Noise Survey According to ETSU-R-97

| Property | Standardised 10 m Wind Speed (m/s) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Dalnessie | 35.0 | 35.0 | 35.9 | 37.8 | 40.0 | 42.3 | 44.8 | 47.5 | 47.5 |

Table 4 - Night time $L_{A90,T}$ Noise Limits Derived from the Baseline Noise Survey According to ETSU-R-97 (and THC preference)

| Property | Standardised 10 m Wind Speed (m/s) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Dalnessie (ETSU-R-97) | 43.0 | 43.0 | 43.0 | 43.0 | 43.0 | 43.0 | 45.3 | 48.6 | 48.6 |
| Dalnessie (THC preference) | 38.0 | 38.0 | 38.0 | 38.0 | 39.5 | 42.2 | 45.3 | 48.6 | 48.6 |

# 5. Predicted Noise Effects

## 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 5 lists the key construction activities, the associated types of plant normally involved, the expected worst-case sound power level over a working day for each activity, the closest separation distance from the assessment location (Dalnessie) during any 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 property considered. 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 5 - Predicted Construction Noise Levels – predicted levels at Dalnessie**

| Task Name | Plant/Equipment | Upper Collective Sound Emission Over Working Day $L_{WA,T}$ dB(A) | Minimum Distance to Dalnessie | Predicted Upper Day-Time $L_{Aeq}$ |
|---|---|---|---|---|
| Upgrade Access Track | excavator / dump trucks / tippers / dozers / vibrating rollers | 120 | 160 | 66 |
| Construct temporary construction/mobilisation compounds | excavator / dump truck / tippers / rollers/ delivery trucks | 120 | 110 | 71 |
| Construct site tracks | excavators / dump trucks / tippers / dozers / vibrating rollers | 120 | 1400 | 45 |
| Construct Sub-Station | excavator / concrete truck / delivery truck | 110 | 1200 | 37 |
| Construct crane hardstandings | excavators / dump trucks | 120 | 1500 | 45 |
| Construct turbine foundations | Piling Rigs / excavators / tippers / concrete trucks / mobile cranes / water pumps / pneumatic hammers / compressors / vibratory pokers | 120 | 1500 | 45 |

| Task Name | Plant/Equipment | Upper Collective Sound Emission Over Working Day $L_{WA,T}$ dB(A) | Minimum Distance to Dalnessie | Predicted Upper Day-Time $L_{Aeq}$ |
|---|---|---|---|---|
| Excavate and lay site cables | excavators / dump trucks / tractors & cable drum trailers / wacker plates | 110 | 1200 | 37 |
| Erect turbines | cranes / turbine delivery vehicles / artics for crane movement / generators / torque guns | 120 | 1500 | 45 |
| Reinstate crane bases | excavator / dump truck | 115 | 1500 | 40 |
| Reinstate road verges | excavator / dump truck | 115 | 1400 | 40 |
| Lay cable to sub-stations | JCB / saws / hydraulic breaker / dump truck/ tipper / wacker plate / tandem roller / tractor & cable drum trailer / delivery truck | 115 | 1200 | 42 |
| Borrow Pit Quarrying | Primary and secondary stone Crushers / excavators / screening systems / pneumatic breakers / conveyors | 125 | 1000 | 53 |
| Construct Battery Storage Area | Harvesters and forwarders, characterised by saw noise diesel engine noise emissions commonly associated with tractors and excavation noise | 110 | 1300 | 36 |

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 indicates that the majority of construction activities will result in negligible impacts, based on Table 1.

5.1.6 For the track upgrade activity closest to Dalnessie, predicted noise levels of up to 66 dB are likely to represent those for a very short term period when activity is closest to the receptor. Noise levels will quickly diminish as track upgrade works progresses, moving the activity further from the property. Similarly, construction of the mobilisation compounds could generate worst-case noise levels of around 71 dB, but this would be for a short period of much less than 4 weeks. The short-term nature of these activities consequently categorises the associated effects to be of minor significance (see Table 1).

5.1.7 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 assessment in Chapter 12: Traffic and Transportation of the EIA Report for the Proposed Development has predicted the volume of traffic likely to be generated during the construction. This concluded that the importation of construction materials (worst-case scenario) would result in up to 336 HGV two-way movements, or an average of 34 two-way HGV movements each hour on some of the identified roads. Table 12.15 of Chapter 12 was used to ascertain the projected traffic flows for scenarios with and without the Proposed Development.

5.1.8 The most sensitive receiver location in respect of vehicle movements is at Dalnessie which lies relatively close to the proposed site access track, at a distance of approximately 160 metres, and which is a relatively isolated property. Large vehicles can generate noise levels in the order of 108 dB (sound power level) when in motion. However, these types of plant usually pass a receiver location quite quickly. When stationary the same vehicles will be operating in idle which considerably lowers the noise output to the environment. Based on the prediction methodology in BS 5288 and accounting for large vehicles moving at an estimated 20 miles per hour, the predicted noise level at this dwellings is of 53 dB $L_{Aeq,T}$, which represents a negligible impact.

5.1.9 Construction traffic movements on existing local surrounding roads also represent a potential source of noise effects to surrounding properties. The above-referenced projected changes in traffic flow are summarised in Table 6. On this basis, the methodology set out in CRTN has been 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 7.

**Table 6 - Projected Traffic Flows – maximum predicted traffic**

| Road | Without Development | | With Development | |
|---|---|---|---|---|
| | Annual Average Daily Traffic Flow | % Heavy Goods Vehicles | Annual Average Daily Traffic Flow | % Heavy Goods Vehicles |
| A836 North of Lairg Lodge | 329 | 10.0% | 700 | 52.7% |
| A836 Lairg Village | 2077 | 7.0% | 2262 | 13.8% |
| A839 Pittentrail | 896 | 3.0% | 1081 | 18.0% |
| A836 Bonar Bridge | 1861 | 5.8% | 2047 | 13.5% |
| A836 Ardgay Village | 1910 | 7.0% | 2095 | 14.4% |
| A9 the Mound | 4445 | 6.4% | 4630 | 9.8% |
| A9 Glenmorangie Distillery | 8196 | 6.2% | 8567 | 9.9% |
| A9 South of Clashmore | 7381 | 5.1% | 7567 | 7.1% |
| A836 North of Edderton | 735 | 23.1% | 920 | 36.7% |
| A836 Achinduich | 1110 | 8.3% | 1295 | 20.1% |

**Table 7 - CRTN Predicted Increase in day-time Average Traffic Noise Levels ($L_{A10,18hour}$)**

| Road | Maximum Change in Traffic Noise Level, dB(A) |
|---|---|
| A836 North of Lairg Lodge | n/a* |
| A836 Lairg Village | 1.7 |
| A839 Pittentrail | 4.4** |
| A836 Bonar Bridge | 2.0 |
| A836 Ardgay Village | 1.8 |
| A9 the Mound | 0.7 |

| Road | Maximum Change in Traffic Noise Level, dB(A) |
|---|---|
| A9 Glenmorangie Distillery | 0.8 |
| A9 South of Clashmore | 0.5 |
| A836 North of Edderton | n/a* |
| A836 Achinduich | 3.2** |
| ** Traffic volume too low for reliable CRTN predictions.*<br>***Traffic volume relatively low (less than 2000 vehicles per day).* | |

5.1.10 In some cases, highlighted in Table 7, the total flow on the roads was below or close to the minimum flow volume of 1000 vehicles per day that is required by the CRTN methodology to enable reliable predictions. Based on the predicted noise levels that CRTN suggests for the lowest flow value, it can be deduced that the associated $L_{Aeq,T}$ for the working day would be below 65 dB $L_{Aeq}$. Although the relative increase associated with the construction traffic either cannot be calculated using CRTN or would be above 3 dB, this is considered as representing an effect of minor magnitude given the low overall levels of noise and the temporary nature of the impact. This is particularly the case as the worst-case traffic increases predicted would represent short periods associated with aggregate import to site.

5.1.11 For the other roads considered, the maximum potential increase in the day-time average noise level during particular phases of the construction programme would be less than 2 dB: based on the criteria set out in the DMRB, this short-term change in traffic noise level would correspond to a minor impact at worst. For those roads where predicted increases are less than 1 dB, this would represent a negligible impact.

5.1.12

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

## 5.2 Construction Noise & Vibration Levels – Blasting

5.2.1 Because of the difficulties in predicting noise and air overpressure resulting from blasting operations, 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 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 potential effects of these activities is best achieved through on-site testing processes carried out in consultation with THC, as described earlier in this report.

5.2.3 This is more relevant to the borrow pit search areas identified nearest to Dalnessie. For the other search area identified, given the separation with Dalnessie of at least 2 km, it is very unlikely that these activities would cause unacceptable adverse effects, and therefore no specific mitigation is considered to be required for these activities.

## 5.3 Decommissioning Noise

5.3.1 Decommissioning is likely to result in less noise than during construction of the Proposed Development. The construction phase has been considered to have minor noise effects, therefore decommissioning will, in the worst case, also have minor noise effects.

## 5.4 Operational Wind Turbine Emissions Data

5.4.1 The exact model of turbine to be used at the site will be the result of a future tendering process and therefore an indicative turbine model has been assumed for this noise assessment. This operational noise assessment is based upon the noise specification of the Nordex N163 5.7 MW wind turbine. The wind turbines on the Proposed Development have been modelled using the layout as indicated on the map at Annex B (coordinates also provided). The candidate turbine (for the purpose of the noise assessment) is a variable speed, pitch-regulated machine with a rotor diameter of 163 m and a hub height of between 98.5 and 118.5 m (see Appendix B for turbine coordinates and assumed hub heights). Its noise emissions are considered representative of the upper level for turbines of this scale. Due to its variable speed operation the sound power output of the turbine varies considerably with wind speed, being quieter at the lower wind speeds when the blades are rotating more slowly.

5.4.2 Nordex have supplied specification noise emission data for the Nordex N163 5.7 MW turbine which are values the manufacturer considers to be typical of this model of turbine. This turbine is as standard supplied with blades which have modifications ('Serrated Trailing Edge Blades'), typically resulting in lower noise emission levels than turbines without this blade technology. A further correction factor of +2 dB was added to the Nordex specification data to allow for uncertainty in these data, which is consistent with advice in the IOA GPG and typically the largest allowance for uncertainty added to sound power levels suggested by the IOA GPG. Sound power data have been made available for a range of wind speeds at hub height, converted to standardised ten metre reference wind speeds for the range from 3 m/s to 12 m/s inclusive, for a hub height of 118 m (representative of the tallest hub height used on the site, with a negligible difference of less than 1 m). In addition to the overall sound power data, reference has been made to the documentation from the manufacturer for the Nordex N133 turbine (in the absence of specific data for the N163) to derive a representative sound spectrum for the turbine. The overall sound power and spectral data are presented in Table 8 and Table 9.

5.4.3 Assessment of cumulative effects from operating the Proposed Development requires source information for the turbine types similar to that presented in Table 8 and Table 9 for the other wind farm considered. The data assumed for the proposed Strath Tirry Wind Farm is based on a Vestas V117 model which is consistent with the candidate turbine specified in the noise assessment for that Wind Farm[xvii]. Noise emission data for the Vestas V117 turbine running unconstrained are also presented in Table 8, including a margin of +2 dB, the same as for the N163 data presented above. In addition, a representative sound spectrum for the turbine has also been derived from manufacturer information, presented here in Table 9.

**Table 8 - Wind Turbine Sound Power Levels Used in the Noise Assessment**

| Standardised Wind Speed (m/s) | Sound Power Level (dB $L_{Aeq}$) | |
|---|---|---|
| | Nordex N163 | Vestas V117 |
| 3 | 97.5 | 95.1 |
| 4 | 100.0 | 98.0 |
| 5 | 104.8 | 102.2 |

| Standardised Wind Speed (m/s) | Sound Power Level (dB $L_{Aeq}$) | |
|---|---|---|
| | Nordex N163 | Vestas V117 |
| 6 | 108.9 | 106.0 |
| 7 | 109.2 | 107.9 |
| 8 | 109.2 | 108.0 |
| 9 | 109.2 | 108.0 |
| 10 | 109.2 | 108.0 |
| 11 | 109.2 | 108.0 |
| 12 | 109.2 | 108.0 |
| *Derived from:* | *Based on Nordex Document F008_276_A13_EN Rev 5, 08/07/2021 for NordexN163/5.X turbine, data for 118 m hub height.* | *Based on Performance Specification V117-4.0/4.2 MW 50/60 Hz, Document no.: 0067-7063 V03 2017-11-29, Date: 29 /11 / 2017. Data for 'Mode 0'.* |

Table 9 - Octave Band Sound Power Spectrum (dB $L_{Aeq}$) For Reference Wind Speed Conditions ($v_{10}$ = 8 m/s) – normalised to a nominal value of 100 dB(A)

| Octave Band Centre Frequency (Hz) | A-Weighted Sound Power Level (dB(A)) | |
|---|---|---|
| | Nordex N163 | Vestas V117 |
| 63 | 92.1 | 80.3 |
| 125 | 97.8 | 87.5 |
| 250 | 100.1 | 92.3 |
| 500 | 100.9 | 94.6 |
| 1000 | 102.7 | 94.4 |
| 2000 | 103.2 | 91.7 |
| 4000 | 100.9 | 86.6 |
| 8000 | 90.3 | 78.9 |
| *Derived from:* | *Based on spectrum for N133 turbine, Nordex document 'Octave sound power levels', reference F008_272_A14_EN, 01/03/2018 (data for STE variant).* | *Derived from Vestas Document DMS 0067-7587 V02, 'V117-4.0&4.2 MW Third octave noise emission', Date: 3 / 12 / 2017.* |

## 5.5 Choice of Wind Farm Operational Noise Propagation Model

5.5.1 The ISO 9613-2 model[xviii] 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.

5.5.2 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. For propagation to Dalnessie, no screening or concave ground profile was identified, and therefore no further corrections were added.

5.5.3 This method is consistent with the recommendations of the above-referenced Institute of Acoustics Good Practice Guide (IOA GPG) 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.

## 5.6 Predicted Wind Farm Operational Noise Immission Levels

5.6.1 Table 10 shows predicted noise immission levels at the selected assessment location for each wind speed from 3 m/s to 12 m/s inclusive. All wind farm noise immission levels in this report are presented in terms of the $L_{A90,T}$ noise indicator in accordance with the recommendations of the ETSU-R-97 report, obtained by subtracting 2 dB(A) from the calculated $L_{Aeq,T}$ noise levels based on the turbine sound power levels presented in Table 8 and Table 9.

**Table 10 - Predicted $L_{A90,T}$ Wind Farm Noise Immission Levels as a Function of Standardised Wind Speed for the Proposed Development alone.**

| Property | Standardised 10 m Wind Speed (m/s) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Dalnessie | 24.5 | 27.0 | 31.8 | 35.9 | 36.2 | 36.2 | 36.2 | 36.2 | 36.2 | 36.2 |

## 5.7 ETSU-R-97 assessment

5.7.1 Figures E1 and E2 (Annex E) show the calculated wind farm noise immission levels at the noise assessment location presented in Table 10 plotted as a function of standardised wind speed. The calculated noise immission levels are shown overlaid on the day-time and night-time noise limit curves. These limits curves have been derived by calculating best-fit regression lines through the measured background noise data to give the prevailing background noise curve required by ETSU-R-97. The noise limits have then been set either at the prevailing measured background level plus 5 dB or at the relevant fixed lower limit whichever is the greater.

5.7.2 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.

5.7.3 The assessment (shown in tabular form in Table 11 and Table 12) shows that the predicted wind farm noise immission levels meet the ETSU-R-97 derived noise limits under all wind speeds and at all locations, based on a lower day-time limit of 35 dB, and a lower night-time limit of either 38 dB (THC preference) or 43 dB(A) (as per ETSU-R-97).

**Table 11 - Difference between the ETSU-R-97 Derived Day time Noise Limits and the Predicted $L_{A90,T}$ Wind Farm Noise Immission Levels. Values are based on a 35 dB lower day time limit and negative values indicate the noise immission level is below the limit.**

| Property | Standardised 10 m Wind Speed (m/s) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Dalnessie | -10.5 | -8.0 | -3.2 | 0.0 | -1.6 | -3.8 | -6.1 | -8.6 | -11.3 |

**Table 12 - Difference between the ETSU-R-97 Derived Night time Noise Limits and the Predicted $L_{A90,T}$ Wind Farm Noise Immission Levels. Negative values indicate the immission level is below the limit**

| Property | Standardised 10 m Wind Speed (m/s) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Dalnessie (ETSU-R-97) | -18.5 | -16.0 | -11.2 | -7.1 | -6.8 | -6.8 | -6.8 | -9.1 | -12.4 |
| Dalnessie (THC preference) | -13.5 | -11.0 | -6.2 | -2.1 | -1.8 | -3.3 | -6.0 | -9.1 | -12.4 |

5.7.4 The ETSU-R-97 fixed part of the limit during the day-time should lie within the range from 35 dB(A) to 40 dB(A). The factors to be used to determine where in this range have been discussed at paragraph 3.2.4. These factors are considered each in turn:

- Number of properties: there is a very low number of properties affected by noise in the area which is relatively remote, with only two properties exposed to predicted noise levels above 35 dB(A).
- Duration and level of exposure: The charts of Annex E show that the predicted turbine noise (from the Proposed Development) is comparable to the range of measured baseline levels in quiet conditions during the day-time, although clearly higher than the lower levels measured at moderate wind speeds. However, the predictions are based on downwind conditions (wind blowing from source to receiver), and the actual levels which occur in practice will be considerably lower (10 dB(A) to 15 dB(A)) under upwind conditions. Bearing in mind the prevailing south westerly wind direction of the UK, this would in fact represent the majority of the time, and the predicted levels only those experienced for a limited set of conditions.
- Generation capacity: having a limit at the lower end of this range does not have an effect on the number of turbines installed, as compliance is predicted even in this scenario on the basis of worst-case assumptions. However, the generation capacity of the site, which is of more than 80 MW, is also a relevant consideration and would tend to justify an increased noise limit.

5.7.5 Based on the above considerations, it would be considered wholly appropriate to set the limit toward the middle of the 35 dB(A) to 40 dB(A) range. Nonetheless, a limit at the lower end of the range was assumed for the analysis, in line with the preference expressed by THC.

5.7.6 The turbines of the proposed Strath Tirry Wind Farm are more than 4 km from Dalnessie. If the Strath Tirry Wind Farm is consented, consultation responses from THC indicate that the consent would allow a further tolerance of 2 dB on the assumed level (on the basis of the Vestas V117 candidate turbine). But even accounting for this increase, given the large separation distances involved, and that Dalnessie would be screened from these turbines by the terrain, predicted noise levels from the Strath Tirry Wind Farm at the property would be below 20 dB $L_{A90}$. Such low noise levels would not make an acoustically relevant contribution[1] to predicted noise levels and can be ignored in the assessment.

5.7.7 Conversely, predicted levels from the Proposed Development at noise-sensitive locations closest to the proposed Strath Tirry Wind Farm, Dalmichy (easting/northing 257561 / 913053) and Blarbuie (easting/northing 256259 / 913938) do not exceed 25 $L_{A90}$, using the assumptions set out above. This also 10 dB below the lowest applicable ETSU-R-97 noise limit and is therefore not an acoustically important contribution and can be ignored in the assessment.

5.7.8 In conclusion, overall predicted noise levels are within the ETSU-R-97 noise limits derived above, based on the lowest choice the ETSU-R-97 noise limit for day-time periods.

## 5.8 Cumulative Construction Noise Analysis

5.8.1 The cumulative construction trip assessment in Chapter 12: Traffic and Transportation of the EIA Report sets out a worst-case scenario of potential increased traffic flows assuming simultaneous construction of several schemes. Although this scenario is very unlikely, the assessment of the potential associated impacts would be similar to the above assessment of the Proposed Development in isolation. For roads where this would represent a relatively high increase, the overall traffic flow levels would remain low, resulting in overall noise levels predicted to be below 65 dB $L_{Aeq}$. For other roads where traffic flows are higher, the relative increase associated with the cumulative construction traffic would be low (less than 2 dB). On this basis, the associated impacts would remain minor at most. In practice, the mitigation measures proposed would reduce the impacts in practice in any case.

## 5.9 Low Frequency Noise, Vibration and Amplitude Modulation

5.9.1 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.

5.9.2 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 and this will be subject to a period of testing and review over the next few years. The Scottish Government is currently reviewing these recommendations in the context of the Scottish planning system. In its scoping response, THC did not propose any specific control for AM outside of the existing powers of the Council to control nuisance under relevant legislation.

## 5.10 Substation and Battery Storage

5.10.1 The main noise sources associated with the substation are likely to be the power transformers and the cooling fans. Operational noise associated with any ancillary services such as battery energy

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

storage facility would arise from ventilation/air conditioning systems, modular inverters and lower-voltage transformers and higher-voltage transformers associated with grid connection (were this not to be shared with the main wind farm substation).

5.10.2 Given the large separation distances of more than 1 km between the substation and battery storage area and the nearest residential properties, experience of similar installations and professional judgement, the associated levels of operational noise are unlikely to be significant. Therefore, no specific mitigation is required in this instance.

# 6. Mitigation, Offsetting and Enhancement Measures

## 6.1 Proposed Construction Noise Mitigation Measures

6.1.1 To reduce the potential effects of construction noise, the following types of mitigation measures are proposed:

- Those activities that may give rise to audible noise at the surrounding properties and heavy goods vehicle deliveries to the site (except high volume HGV traffic associated with aggregate material import to site) would be limited to the hours 07:00 to 19:00 Monday to Friday and 08:00 to 13:00 on Saturdays .
- Turbine deliveries would only take place outside these times with the prior consent of THC and Police Scotland. Those activities that are unlikely to give rise to noise audible at the site boundary will continue outside of the stated hours.
- All construction activities shall adhere to good practice as set out in BS 5228.
- All equipment will be maintained in good working order and any associated noise attenuation such as engine casing and exhaust silencers shall remain fitted at all times.
- Where flexibility exists, activities will be separated from residential neighbours by the maximum possible distances.
- A site management regime will be developed to control the movement of vehicles to and from the Proposed Development site.
- Construction plant capable of generating significant noise and vibration levels will be operated in a manner to restrict the duration of the higher magnitude levels.

6.1.2 The potential noise and vibration effects of blasting operations will be reduced according to the guidance set out in the relevant British Standards and PAN50 Annex D and discussed below:

- Blasting should take place under strictly controlled conditions with the agreement of THC, at regular times within the working week, that is, Mondays to Fridays, between the hours of 10.00am and 16.00pm. Blasting on Saturday mornings should be a matter for negotiation between the contractor and THC;
- Vibration levels at the nearest sensitive properties are best controlled through on-site testing processes carried out in consultation with THC. This site testing based process would include the use of progressively increased minor charges to gauge ground conditions both in terms of propagation characteristics and the level of charge needed to release the requisite material. The use of onsite monitoring at neighbouring sensitive locations during the course of this preliminary testing can then be used to define upper final charge values that will ensure vibration levels remain within the criteria set out previously, as described in BS 5228-2 and BS 6472-2 2008;
- Blasting operations shall adhere to good practice as set out in BS 5228-2, and in PAN50, Annex D, Paragraph 95 in order to control air overpressure.
- A scheme will be submitted to THC for approval of blasting details, which will outline the mitigation measures to be adopted.

### 6.2 Proposed Operational Noise Mitigation Measures

6.2.1 The selection of the final turbine to be installed at the site would be made on the basis of enabling the relevant ETSU-R-97 noise limits to be achieved at the surrounding properties.

## 7. Monitoring

7.1.1 It is proposed that if planning consent is granted for the Proposed Development, conditions attached to the planning consent should include the requirement that, in the event of a noise complaint, noise levels resulting from the operation of the wind farm are measured in order to demonstrate compliance with the conditioned noise limits. Such monitoring should be done in full accordance with ETSU-R-97 and include penalties for characteristics of the noise such as tones (if present).

## 8. Summary of Key Findings and Conclusions

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

8.1.2 Only two noise-sensitive properties, at Dalnessie, are located in relative proximity from the development (approximately 1.5 km from the nearest turbine). 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 existing background noise levels at the property, as derived from measurements made over approximately 4 weeks at the property.

8.1.3 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 effects are considered to represent minor effects at most.

8.1.4 Operational noise from the wind farm has been assessed in accordance with the methodology set out in the 1996 DTI Report 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 in Scottish Planning Policy.

8.1.5 Applying the ETSU-R-97 derived noise limits it has been demonstrated that both the day-time and night-time noise criterion limits can be satisfied at all properties across all wind speeds, even when accounting for the stringent preferences of THC in this regard. This assessment has been based on the use of the manufacturer's sound power data for the Nordex N163 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.

8.1.6 In summary, the overall levels of construction noise are considered to represent a minor effect, and therefore considered not significant in EIA terms. 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 are acceptable in terms of the guidance commended by planning policy for the assessment of wind farm noise, and therefore considered not significant in EIA terms.

## 9. References

i Scottish Planning Policy (SPP), Scottish Government, 2014.

ii Planning Advice Note 1/2011: Planning & Noise, Scottish Government, March 2011.

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

iv 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, 1996.

v 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.

vi Letter from John Swinney MSP, Scottish Government, 29/05/2013

vii PAN1/2011 Technical Advice Note – Assessment of Noise, Scottish Government, March 2011.

viii Control of Pollution Act, Part III, HMSO, 1974.

ix BS 5228 Noise and Vibration Control on Construction and Open Sites, Parts 1 to 4.

x BS 5228-1:2009-A:2014 'Code of practice for noise and vibration control on construction and open sites – Part 1: Noise'.

xi BS 5228-2:2009-A:2014 'Code of practice for noise and vibration control on construction and open sites – Part 2: Vibration'.

xii Planning Advice Note 50: Controlling The Environmental Effects of Surface Mineral Workings, 1996.

xiii BS 6472-2:2008:Guide to evaluation of human exposure to vibration in buildings - Part 2: Blast-induced vibration.

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

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

xvi 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.

xvii Strath Tirry Wind Farm Wind Farm Environmental Impact Assessment Report, Chapter 10 Noise, December 2020.

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

# 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.

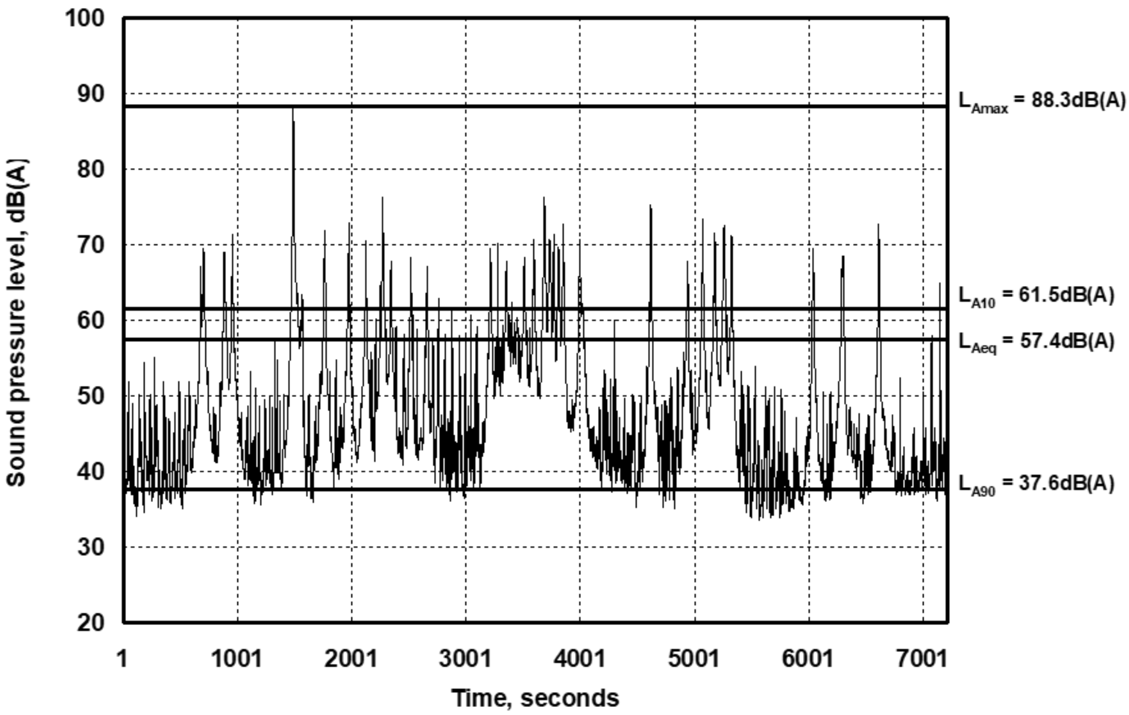
A.5 Before reviewing the potential effects of environmental sound on people, it is useful first to consider the means by which physical sound can be quantified.

### 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 [2] 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 [1]. Dr Leventhall notes that despite the numerous published studies there is little or no agreement about the biological effects of infrasound or low frequency sound on human health. Leventhall notes that direct evidence of adverse effects of exposure to low-intensity levels of infrasound (less than 90 dB) is lacking. He goes on to describe the low frequency hearing threshold i.e. the lowest levels which are audible to an average person with normal hearing. He notes the threshold at 4 Hz is about 107 dB, at 10 Hz it is about 97 dB and at 20 Hz it is 79 dB. As such, high levels of infrasound are required to exceed the hearing thresholds at such low frequencies. Leventhall therefore concluded that most people can be reassured that there will be no serious consequences to peoples' health from infrasound exposure.

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

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

A.66 In 2004/2005 researchers from Keele University investigated the effects of the extremely low levels of vibration resulting from wind farms on the operation of a seismic array installed at Eskdalemuir in Scotland. This is one of the most sensitive ground-borne vibration detection stations in the world. The results of this study were initially misinterpreted, as just discussed for the DEFRA/Leventhall report, in that if infrasonic vibrations from wind farms can be measured, then they must consequentially have some potential effect on humans. In order to clarify their position, the authors subsequently explained that [3]:

> *'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 [4]. This Report is quite categorical in its findings: infrasound is not the perceived health threat suggested by some observers, nor should it even be considered a potential source of disturbance. Quoting from the Executive Summary to the DTI LFN Report:

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

A.70 This has been subsequently confirmed by many international studies and reviews. For example, a study for the National Institute for Public Health and the Environment (RIVM) in the Netherlands [5] 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 [6] 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 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 [7] 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 research work was awarded to the University of Salford who reported on their findings in July 2007 [8]. 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 [9] 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. 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 outwith 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 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 [11] 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 [12] 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 [13] 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. The Scottish Government is understood to be reviewing this report in the context of the Scottish planning system.

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## 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 |

| Terminology | Description |
|---|---|
| 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.<br><br>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 |

| Terminology | Description |
|---|---|
| | 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 the layout of the turbines (green circles), the noise monitoring and assessment location (black/white circle).

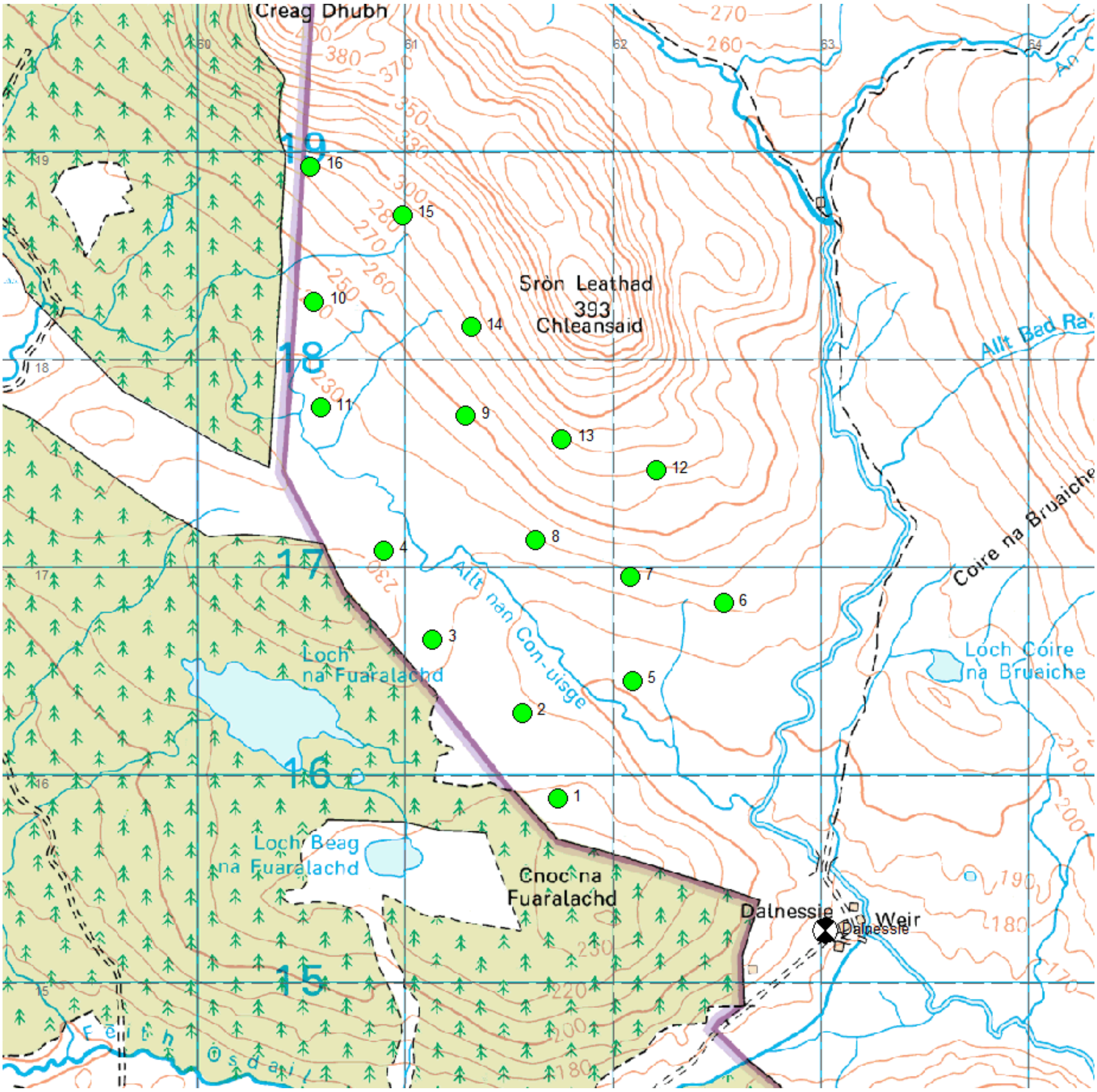


Table B1 – turbine coordinates

| Turbine | Easting | Northing | Modelled hub height |
|---|---|---|---|
| 1 | 261733 | 915888 | 118.5 |
| 2 | 261561 | 916303 | 118.5 |
| 3 | 261132 | 916655 | 118.5 |
| 4 | 260898 | 917081 | 118.5 |
| 5 | 262092 | 916456 | 118.5 |
| 6 | 262530 | 916828 | 118.5 |
| 7 | 262080 | 916955 | 118.5 |
| 8 | 261628 | 917134 | 118.5 |
| 9 | 261290 | 917730 | 118.5 |
| 10 | 260561 | 918282 | 118.5 |
| 11 | 260593 | 917771 | 118.5 |
| 12 | 262205 | 917468 | 98.5 |
| 13 | 261753 | 917618 | 98.5 |
| 14 | 261315 | 918159 | 98.5 |
| 15 | 260987 | 918699 | 98.5 |
| 16 | 260544 | 918931 | 118.5 |

# Annex C – Noise Monitoring Information Sheets

Table C1 – Information on the measurement location, equipment and noise data at Dalnessie.

| | |
|---|---|
| Measurement Location Name | Dalnessie |
| Measurement Location Description | The location at Dalnessie is relatively isolated but includes several properties and farm buildings. It is located south-east of the proposed development area. To the south of the property, a stream bed off from the River Brora was visible although dry at the time of the visit: it is understood to have flowing water at times during relatively wet periods.<br><br>The noise logger was installed on 16 April 2021. It was positioned on the north side of one of the properties, as this faced the proposed development area and relatively distant from farm activities and potential water noise to the south.<br><br>The chosen location was approximately 13 metres north of the rear garden fence of the property. This location was considered representative of the property's outdoor amenity area, but maximised the distance from trees located within the garden as well as reflective surfaces, in line with ETSU-R-97 and good practice guidance, and was partially screened from a boiler outlet located on the side of the house.<br><br>The main sources of noise audible were birds and distant vegetation noise from a forest approximately 300 m to the west. Noise from occasional farming activities and equipment was also audible in places but minimised at the chosen location.<br><br>A rain gauge was also installed in an open area within the rear garden, away from buildings, fences and walls that would shelter it from rainfall or cause water runoff into the bucket. Noise measurement periods during rainfall and the 10-minute periods prior to and following rainfall will be excluded from the analysis.<br><br>Logger Location (Easting / Northing): 263047 / 915263 |

| Equipment | Type | Serial Number | Last Calibrated (UKAS) |
|---|---|---|---|
| Sound Level Meter | Rion NL-52 | 632044 | 17/11/2020 |
| Pre-amplifier | Rion NH-25 | 32072 | 17/11/2020 |
| Microphone | Rion UC-59 | 17070 | 17/11/2020 |
| Calibrator | Rion NC-74 | 34172706 | 29/06/2020 |
| SLM Range | 20 – 120 dB(A) | | |

| File | Time Start (GMT) | Time End (GMT) | Cal Start | Cal End | Drift | Notes |
|---|---|---|---|---|---|---|
| 01 | 16/04/2021 13:02 | 02/05/2021 12:18 | 94.0 | 93.8 | - 0.2 | No significant drift |
| 02 | 02/05/2021 12:20 | 14/05/2021 12:42 | 94.0 | 94.1 | + 0.1 | No significant drift |

| Data Exclusions |
| --- |
| The following periods were excluded as atypical:<br>– During the day-time, periods with measured $L_{A90}$ >38 dB for wind speeds < 7 m/s or $L_{A90}$ >30 dB for wind speeds < 1.5 m/s.<br>– During the night-time, periods with measured $L_{A90}$ >35 dB for wind speeds < 3.5 m/s |

Figure C1 View of the monitoring location at Dalnessie looking North East

Figure C2 View of the monitoring location at Dalnessie looking South East

Figure C3 View of the monitoring location at Dalnessie looking South West

# Annex D – Wind Speeds and Directions

Figure D1 Wind speed and direction range during all quiet day-time periods.

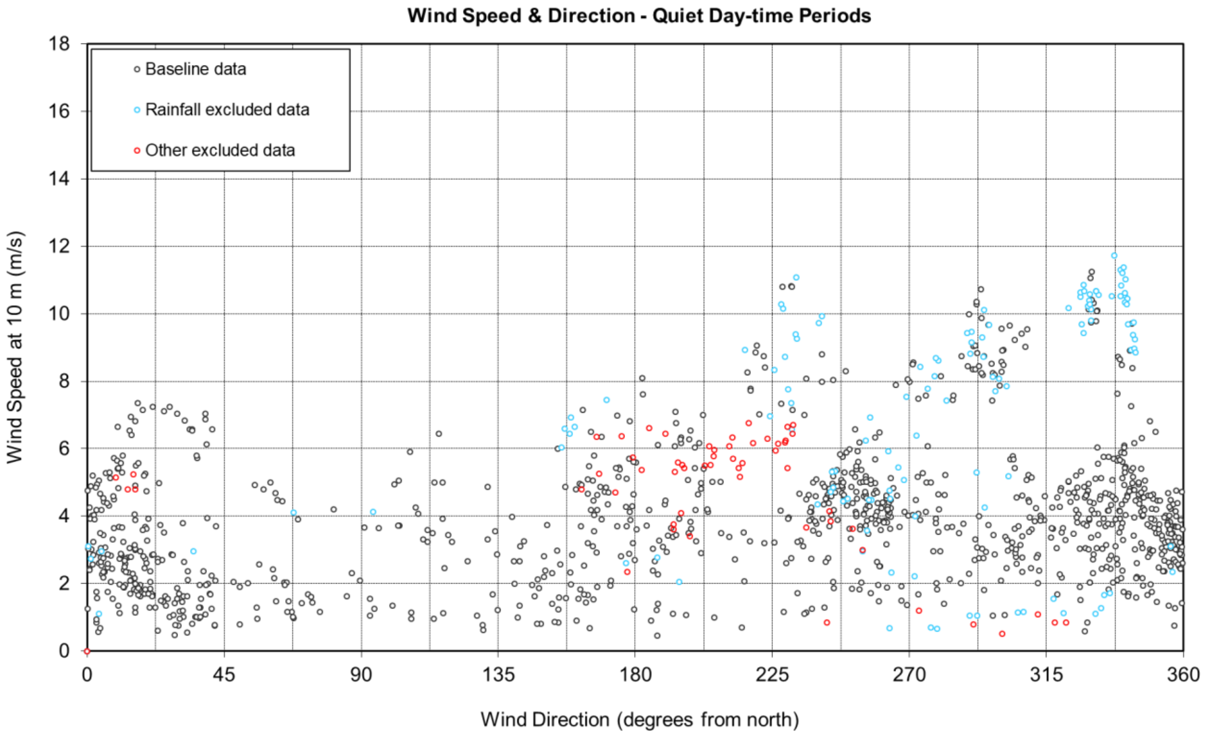
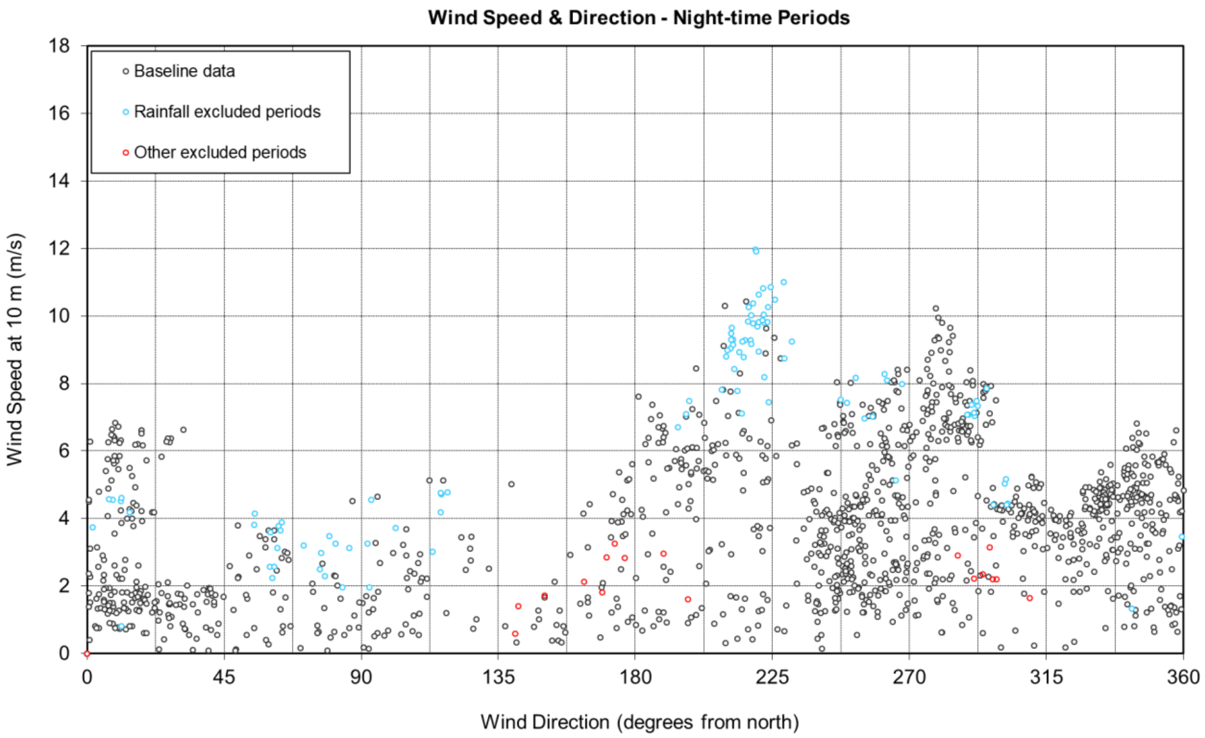



Figure D2 Wind speed and direction range during all night-time.



# Annex E – Background Noise and Noise Limits

Figure E1 Chart of background noise levels against wind speeds, the best fit curve to the data, the derived noise limit curve for Dalnessie during quiet day time periods. Predicted immission noise levels are also shown for the Development.

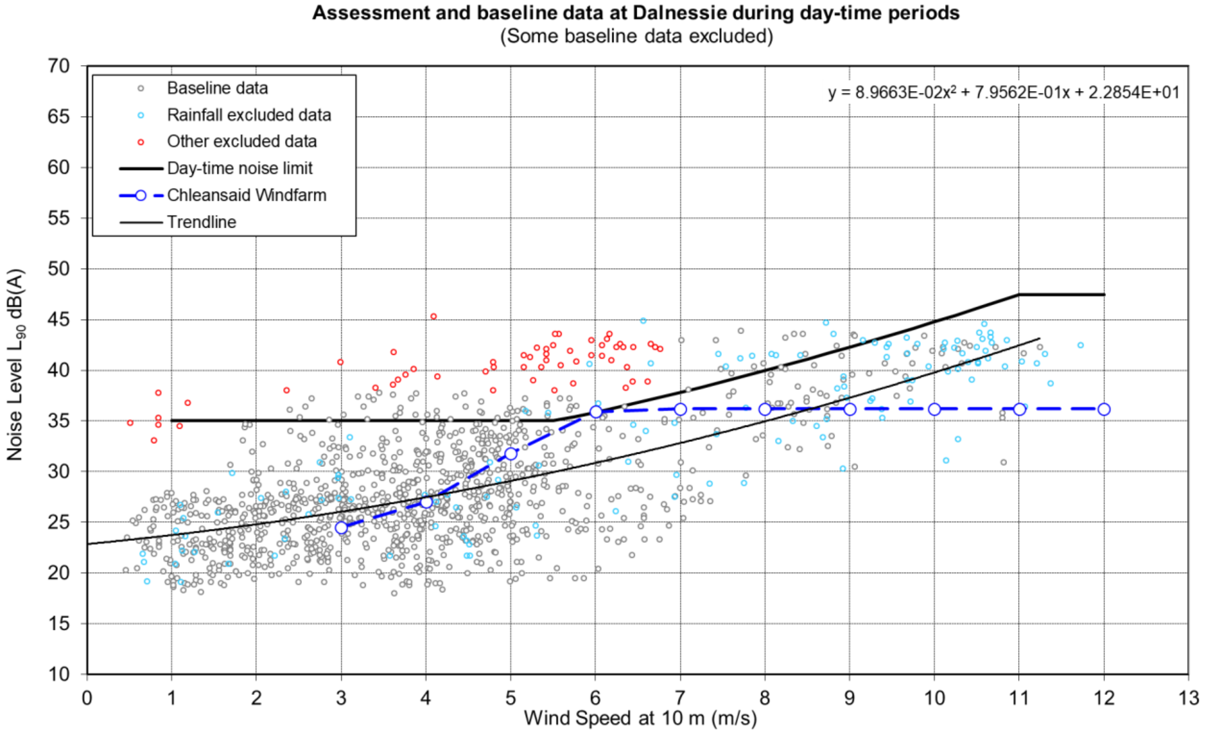
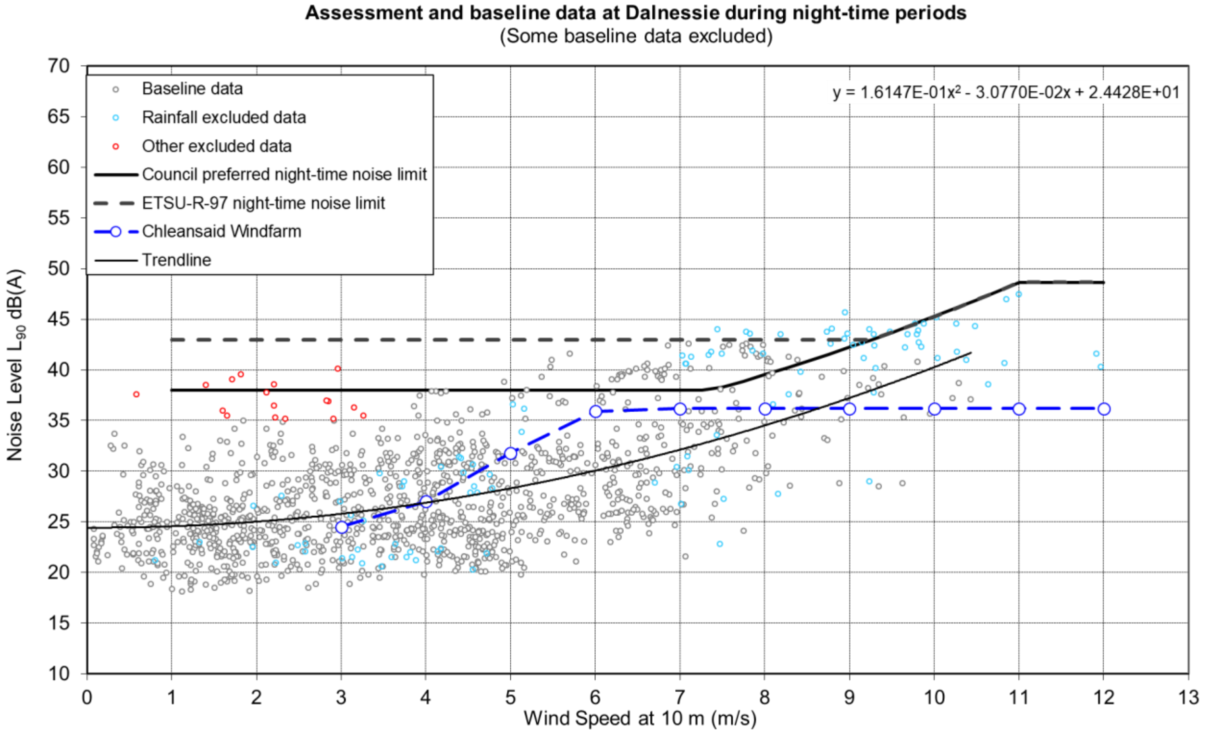



Figure E2 Chart of background noise levels against wind speeds, the best fit curve to the data, the derived noise limit curve for Dalnessie during night time periods (showing lower limits of 43 dB(A) and 38 dB(A), based on ETSU-R-97 or THC preferences respectively). Predicted immission noise levels are also shown for the Development.



# Annex F – Wind Speed Calculations

F.1 The IOA GPG[1] requires that noise data recorded every 10 minutes are related to standardised ten metre wind speeds experienced at the hub height of the turbines, at a location on the wind farm representative of the wind farm. These wind speeds can be either measured directly at the turbine hub height or derived by calculation from measurements at two heights, with measurements at the upper height not less than 60% of the turbine hub height and measurements at least 15 metres below that. These are referred to as 'Method A' or 'Method B' in the IOA GPG which describes these as the preferred methods to use. IOA GPG SGN4[2] provides additional guidance on these methods.

## Approach & Methodology

F.2 The site of the Development has a temporary 91 metre meteorological (met) mast installed which measured wind conditions at various heights including the following:

- 91 metre Wind speed (2 anemometers)
- 87 metre Wind direction
- 76 metre Wind speed (2 anemometers)

F.3 These measurement heights meet the requirements of the IOA GPG: the upper measurement height being at least 60% of the maximum hub height of 125 metres considered and the 76 m height anemometer being at least 15 metres lower than the upper measurement.

F.4 Wind speed data were used to perform a calculation of the shear exponent found between the two wind speed measurement heights for every ten-minute period, by using Equation 3 of IOA GPG SGN4. Where wind speeds were the same at both heights or lower at greater height, the shear exponent was assumed to be zero. The shear exponent so calculated for every ten-minute period was then used to calculate the wind speed at 125 m height (representative of the highest hub height which could be used at the site) using Equation 2 of SGN4 for each ten minute period. Equation 1 of SGN4 was then used to calculate a standardised ten-metre height wind speed from the hub height wind speed every ten minutes assuming the reference roughness length of 0.05 metres.

F.5 Wind speeds are standardised to a height of ten metres assuming a reference ground roughness length of 0.05 metres as described in the IOA GPG. This approach is of the same form as that given in BS EN 61400-11:2003[3] for calculating ten metre wind speeds related to hub height wind speeds when providing source noise emission data for wind turbines.

## Conclusions

F.6 By using this method, measured background noise levels were correlated to ten metre wind speeds calculated from wind speeds at hub height. Any likely difference in the shear profile during the 24 hours of the day will be accounted for within the method and be reflected in the resulting standardised ten metre wind speed data.

F.7 The method used to calculate ten metre wind speeds from those at hub height is the same as that used when deriving noise emission data for the turbines. Because the same method has been used, direct comparison of background noise levels, noise limits and predicted turbine noise immission levels may be undertaken. This method is consistent with guidance published in IOA GPG.

References for Wind Speed Calculations

[1] 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.

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

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

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