APPENDIX J-1

Technical Noise Report

HOARE LEA

Drumnahough Wind Farm.
Technical Noise Appendix.

REVISION 08 – 19 AUGUST 2020

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Audit sheet.

Rev.	Date	Description	Prepared	Verified
01	20/12/2019	First draft	RN	MMC
02	07/02/2020	Second draft following feedback	RN	MMC
03	06/05/2020	Third draft following additional feedback and construction traffic assessment.	RN	MMC
04	26/05/2020	Fourth version with consistency update	RN	MMC
05	09/07/2020	Additional clarifications	MMC	
06	15/07/2020	Consistency update	RN	MMC
07	06/08/2020	Further clarifications following legal review	MMC	
08	19/08/2020	Updated traffic values	RN	MMC

Contents.

Non-Technical Summary

Hoare Lea Acoustics (HLA) have been commissioned by SSE Renewables to undertake a noise assessment for the construction and operation of the proposed Drumnahough Wind Energy Project. Noise will be emitted by equipment and vehicles used during construction and decommissioning of the wind farm and by the turbines during operation. The level of noise emitted by the sources and the distance from those sources to the receiver locations are the main factors determining levels of noise at receptor locations.

Construction Noise

Construction noise has been assessed by a desk-based study of the construction activities associated with the proposed development on a worst-case basis. 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 proposed restrictions of hours of working. Specific measures to control noise and vibration effects from blasting associated with borrow pit quarrying are also set out. It is concluded that noise generated through construction activities will have a temporary negligible effect and noise generated from construction traffic will have a temporary minor effect. Therefore, overall construction related activities will have a temporary minor effect, which is not significant.

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

Operational Noise

The noise generated by the substation and energy storage equipment at the nearest residential locations is considered negligible and not significant given the separation distance of more than 800 m involved.

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

Noise levels from operation of the turbines have been predicted for those locations around the site most likely to be affected by noise, which are all located approximately 1 kilometre or more from the turbines. Surveys have been performed to establish existing baseline noise levels at a number of these properties. Noise limits have been derived from data about the existing noise environment following the method stipulated in national planning guidance. Predicted noise levels take full account of the potential combined effect of the noise from the proposed development along with Meentycat wind farm, Culliagh wind farm, Meentycat Cark extension wind farm and Meentycat Meenbog extension wind farm. Other, more distant wind farms were not considered as they do not make an acoustically relevant contribution to cumulative noise levels.

Predicted operational noise levels have been compared to the limit values to demonstrate that turbines, of the type and size which will be installed, can operate within the limits so derived. It is concluded, therefore, that operational noise levels from the wind farm will be within levels deemed to be acceptable for wind energy schemes based on the applicable 2006 guidelines from the Department of the Environment, Heritage and Local Government.

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 Drumnahough Wind Farm (the project) on the residents of nearby dwellings. The assessment considers both the construction and operation of the project and also the likely effects of its de-commissioning. Assessment of the operational noise effects accounts for the cumulative effect of the proposed development as well as other wind farms nearby. Other wind farms considered were those closest and consisted of: Meentycat wind farm (approximately 1 kilometre south east of the proposed development), Culliagh wind farm (approximately 0.6 kilometres south), and the Cark and Meenbog extensions to Meentycat wind farm (approximately 0.4 kilometres east and 1.5 kilometres south west respectively). Other, more distant wind farms were not considered as their potential noise contribution was considered negligible.

1.1.2 Noise and vibration which arises from the construction of a wind farm is a factor which should be taken into account when considering the total effect of the proposed development. 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 the 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 construction and traffic chapters of the Environmental Impact Assessment Report (EIAR).

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 lying around the proposed development will therefore generally form the basis of the assessment of the levels of noise against accepted standards.

1.1.4 The main noise sources associated with the substation are likely to be power transformers and cooling fans. Operational noise associated with any ancillary services for the substation (such as energy storage) would arise from ventilation/air conditioning systems, and electrical plant items such as inverters and transformers.

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

2. Policy and Guidance Documents

2.1 Wind Farm Noise Guidance – Ireland

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

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

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

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

2.1.4 More recently (December 2019), revised Wind Energy Development Guidelines have been published in draft form only at this stage.

2.2 Wind Farm Noise Guidance - UK

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

> *'Indicative noise levels thought to offer a reasonable degree of protection to wind farm neighbours, without placing unreasonable restrictions on wind farm development or adding unduly to the costs and administrative burdens on wind farm developers or local authorities'.*

2.2.2 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)[iii]. This was subsequently endorsed by the UK Government[iv] as current industry good practice and will therefore be referenced in the present assessment.

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

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

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

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

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

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

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

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

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

2.3 Construction noise guidance

2.3.1 BS 5228-1:2009 (amended 2014)[vi] 'Code of practice for noise and vibration control on construction and open sites – Part 1: noise' (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 the significance of any effects.

2.3.2 Similarly, BS 5228-2:2009 (amended 2014)[vii] 'Code of practice for noise and vibration control on construction and open sites – Part 2: vibration' BS 5228-2 provides general guidance on legislation, prediction, control and assessment criteria for construction vibration. These standards have been adopted as the relevant method to predict and assess the effects of construction noise and vibration.

2.3.3 These standards are also often referenced in Ireland.

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'[viii] (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 (except associated with blasting) 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 could be required in some instances. The analysis of the related potential impacts (including vibration) has been made in accordance with BS 6472-2[ix] and BS 5228.

3.2 Wind Farm Operational Noise

3.2.1 To undertake the assessment of noise effects in accordance with the ETSU-R-97 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.

3.2.2 The foregoing steps, as applied to the proposed development, are set out subsequently in this assessment.

3.2.3 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.

3.2.4 The likely noise emissions from the proposed substation and energy storage will also be considered in relation to existing baseline noise levels and related guidance such as the Guidance Note for Noise: License Applications, Surveys and Assessments in Relation to Scheduled Activities (NG4)[x]. These guidelines in particular set out a series of stringent noise limit for commercial/industrial type noise of 35 to 45 dB L_{Ar}[1] (for night and day-time periods respectively) in areas of low background noise.

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 to 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)[y], 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 14:00 on Saturdays.

[1] Rated noise level, based on the L_{Aeq} level with a correction to account for the character of the noise in some cases.

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

Significance	Condition
Major	Construction noise is greater than 85 dB $L_{Aeq,T}$ for any part of the construction works or exceeds 75 dB $L_{Aeq,T}$ for more than 4 weeks in any 12 month period
Moderate	Construction noise is less than or equal to 75 dB $L_{Aeq,T}$ throughout the construction period, with periods of up to 75dB $L_{Aeq,T}$ lasting not more than 4 weeks in any 12 month period.
Minor	Construction noise is generally less than or equal to 65 dB $L_{Aeq,T}$, with periods of up to 70 dB $L_{Aeq,T}$ lasting not more than 4 weeks in any 12 month period
Negligible	Construction noise is generally less than or equal to 60 dB $L_{Aeq,T}$, with periods of up to 65 dB $L_{Aeq,T}$ lasting not more than 4 weeks in any 12 month period

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 UK Design Manual for Roads and Bridges (DMRB[xi]). 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 (such as BS 5228-2) 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, 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 10 mm/s.

3.4 Operational Noise Criteria

3.4.1 The acceptable limits for wind turbine operational noise are defined in the 2006 WEDG guideline document referenced above 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 these noise limits. Depending on the levels of background noise, the satisfaction of the derived noise limits can lead to a situation whereby, at some locations under some wind conditions and for a certain proportion of the time, the wind farm noise may be audible. However, noise levels at the properties in the vicinity of the proposed development will still be within levels considered acceptable under the applicable 2006 WEDG guidelines.

3.5 Consultation

3.5.1 Prior to undertaking the background surveys, a summary of the proposed monitoring locations and of the assessment methodology was forwarded to Donegal County Council for comment, and no adverse comments were received. This consultation was based on a preliminary project layout which was of a similar form to the layout currently proposed. The agreed noise monitoring locations are shown on the plan in Annex B. Further information about the equipment used and pictures of the survey locations are presented in Annex C.

4. Baseline

4.1 General Description

4.1.1 The proposed development will cover an area extending approximately 4 kilometres north to south and 4 kilometres west to east and is located in an area of relatively low population density in County Donegal, Ireland. The noise environment in the surrounding area is generally characterised by 'natural' sources, such as wind disturbed vegetation, birds and farm animals. Other sources of noise include intermittent local road and agricultural vehicle movements in the area.

4.2 Details of the Baseline Background Noise Survey

4.2.1 A total of four noise monitoring locations were used to represent the background noise environment for the nearest residences to the proposed wind farm site. The four locations are shown on the plan in Annex B and listed in Table 2.

Table 2 - Background Noise Monitoring Locations (approximate Irish Grid (IG) Easting / Northing)

No.	Property	Easting	Northing
1	H02	205126	408294
2	H04	204782	407792
3	H06	203444	406750
4	H10	202732	404181

4.2.2 The assessment has considered the effects of the proposed development at the monitoring locations noted above, as well as other residential properties: these assessment locations are listed in Table 3. The list of receptor locations is not intended to be exhaustive but sufficient to be representative of noise levels typical of those receptors closest to the proposed development. Three non-residential buildings were identified in the vicinity of the proposed development, which we understand are either derelict (IG 202470/405036 and IG 203396/406301) or farm buildings (IG 206174/407820). These were therefore excluded from the assessment.

4.2.3 In some instances, the results obtained from the four survey positions have been used to represent the background environment expected to occur at other nearby assessment locations. The use of the data in this way is justified by the dominant influence of 'natural' sources on background noise levels throughout the area (particularly at increased wind speeds) and similarities in the topography and tree coverage between the proxy and surveyed properties considered in the assessment. This approach is consistent with current good practice as set out in the IOA GPG. Locations where such representations have been made, and the source of the representations, are represented in Table 3. It is noted that where such representations have been made, the distance between the assessment location and nearest turbine is comparable to, if not greater than, the distance between the reference monitoring location and the nearest turbine.

Table 3 - Assessment Properties in the Vicinity of the Wind Farm (approximate Irish Grid (IG) Easting / Northing)

Property	Easting	Northing	Approximate Distance to Closest Turbine (m)	Closest Turbine (ID)	Survey Location
H01	206271	408262	2460	9	H02
H02	205126	408294	2095	9	H02
H03	205058	407957	1750	9	H04
H04	204782	407792	1590	9	H04
H05	204724	407758	1560	9	H04
H06	203582	406753	985	10	H06
H07	203217	406627	1110	11	H06
H08	202245	404662	1610	12	H10
H09	203062	404519	1130	12	H10
H10	202732	404181	1590	12	H10

4.2.4 The background noise monitoring exercise was conducted over a period of just over 11 weeks in total. However, due to delays in acquiring permission from landowners to measure baseline noise, some monitoring durations at some of the properties were shorter. Specifically, measurements were initially started at location H02 in July 2019, but subsequently access was obtained in August 2019 for location H04 which was considered to be quieter. Access to location H10 was also obtained in September. The survey durations for each property are detailed further in Annex C, and are considered sufficient to characterise the noise environment at the survey properties in all cases.

4.2.5 The equipment used for the survey comprised of Rion NL-31, Rion NL-32 and Rion NL-52 logging sound level meters, compliant with the IEC 61672-1:2002 Class 1 precision standard (IEC 61672-1:2013/2002 Class 1 for the NL-52) and therefore consistent with the recommendations in the IOA GPG. All meters were enclosed in environmental cases with battery power to enable 14 days continuous logging at the required ten-minute averaging periods. Outdoor enhanced windshield systems were used to reduce wind induced noise on the microphones and provide protection from rain. The spherical WS-03 windshields used on the NL-31 and NL-32 systems measure 30 cm in diameter and the NL-52 WS-15 windshield is 12 cm wide but was shown through testing to have an equivalent or improved performance to the WS-03 in windy conditions. These windshield systems have a two-layer design, were supplied by the sound level meter manufacturer and maintain the required performance (Class 1 or Type 1) of the whole measurement system when fitted. The environmental enclosures provided an installed microphone height of approximately 1.2 to 1.4 metres above ground level. The measurement systems and windshields used were therefore consistent with the requirements of ETSU-R-97 and the IOA GPG.

4.2.6 The sound level meters were located on the wind farm side of the property in question where possible, 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 locations are presented in Annex C.

4.2.7 All measurement systems were calibrated on their deployment, on each servicing visit (see Annex C) and upon collection of the equipment. 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 analysis period of at least 24 days for each location, which is in excess of the minimum of one week, compliant with the IOA GPG requirements.

4.2.8 All measurement systems were set to log the $L_{A90,10min}$ and $L_{Aeq,10min}$ noise levels continuously over the deployment period. The internal clocks on the sound level meters were all synchronized with Greenwich Mean Time (GMT) by the use of a Global Positioning System (GPS) receiver. The clock on the LIDAR 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.

4.3 Measured Background Noise Levels

4.3.1 The 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 using a LIDAR[2] located within the boundary of the development site (approximate ING easting/northing: 204960/404157). Values of wind speed at a standardised height of ten metres were calculated from those measured using the LIDAR ("standardised wind speed"). Full details of the calculation method are given in Annex F.

4.3.2 Figures D1 and D6 reproduced at Annex D show the range of wind conditions experienced during the different noise survey periods. During the quiet day-time and night-time periods wind speeds were typically less than 12 m/s. The wind was observed to be directed from the south westerly and south easterly directions for a large part of the survey period, with in addition a coverage over a wide range of wind directions including westerly winds.

4.3.3 Figures E1 to E8 of Annex E show the results of the background noise measurements at some of the significant assessment locations. 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 for each location, one for quiet day-time periods and the other for night-time periods, both derived in accordance with ETSU-R-97.

4.3.4 Data from all survey locations were inspected to identify periods which may have been influenced by extraneous noise sources, giving rise to atypical and elevated levels. The IOA GPG requires that any data directly affected by rainfall be excluded from the analysis, indicated on the charts as blue circles. A rain gauge was installed during the noise survey period; data from this gauge were therefore used to exclude those periods where rain was indicated.

4.3.5 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 low influence on background sound levels, due to the isolated nature of the monitoring locations with infrequent

[2] LIght Detection And Ranging: remote wind sensor using laser technology allowing measurements at different heights.

passing vehicles. Therefore, the possible effect of increased tyre noise from wet roads is not considered relevant to this site.

4.3.6 In terms of water flow noise, there were water courses present in the vicinity of H02 and H04 after periods of rainfall, due to presence of a small runoff stream alongside the road. At H02, elevated noise levels due to watercourse noise were noticed following heavy rainfall. A detailed review of the data and time history showed sharp increases in noise followed by a progressive decrease with time after periods of rainfall at this property. Consequently, atypical elevated background noise levels at H02 following heavy rainfall periods were excluded from the analysis.

4.3.7 However, for H04, the stream noise was minimal and considered to have only a minor influence on background noise levels, following suitable choice of monitoring location in the front garden, both distanced and raised away from the stream. At H10, due to shielding from the house, stream noise from the other side of the property was largely eliminated, thus having a minimal impact on background noise levels. Based on the above, rainfall is considered to have a limited effect on background sound levels, except at H02. At the remaining monitoring locations, a detailed review of the data did not identify trends indicating dominance of stream noise, such as horizontal rows of data clusters which would indicate that background noise varies little with wind speed due to the increased background noise from water flow. The monitoring locations were also positioned as far as practically possible from any residential drainage systems and boiler flumes to minimise any associated noise influence from these noise sources.

4.3.8 The measured background noise data may also have been increased by other extraneous sources or atypical events. Time-histories of the noise levels at each survey location were 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 data-set (particularly at low wind speeds) which were excluded. Any atypical data removed in this way from the analysis is indicated on the charts as red circles. Details of the excluded data periods are contained in Annex C.

4.3.9 At H06, measurement data acquired outside of downwind conditions, defined as between 45 and 225 degrees from north, were also discarded. This directional filtering was performed only at H06 as the property is situated on a potentially exposed slope in the River Swilly valley, whereas the other measurement properties are comparatively more sheltered. Due to the nature of the exposed terrain around H06, winds from south-west and north east wind directions tend to correspond to increased background noise level conditions compared to those experienced when downwind from the proposed development, *i.e.* winds from the south east.

4.3.10 The analysis and filtering of the data was undertaken in accordance with current good practice as set out in the IOA GPG.

4.3.11 The proposed development was not undergoing construction at the time of the baseline survey, and other wind farms were located sufficiently far away from the locations of Table 2, therefore measured levels have not been influenced by any contribution from construction noise or existing wind turbine noise, as required by the IOA GPG.

4.3.12 Following removal of those data points, best-fit lines were generated using a polynomial fit of a maximum of 2nd order, to best-fit the measured background noise data. 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, which are consistent with WEDG guidelines. The corresponding noise limits are summarised in Table 4 and Table 5. The noise limits have been set as the greater of either the prevailing measured background level plus 5 dB, or at a fixed lower limit of 40 and 43 dB(A) for day and night-time periods respectively. These minimum noise limits were selected as consistent with the 2006 WEDG guidelines when taking into account the general guidance of ETSU-R-97. The relevant fixed noise limits for day-time periods are also considered in further detail in section 5.7.

Table 4 - Day-time $L_{A90,T}$ Noise Limits Derived from the Baseline Noise Survey (dB) – Based on a 40 dB(A) lower limit, see section 5.7.

Property	Standardised 10 m Wind Speed (m/s)								
	4	5	6	7	8	9	10	11	12
H01	40.0	40.0	40.0	40.0	41.4	43.2	43.2	43.2	43.2
H02	40.0	40.0	40.0	40.0	41.4	43.2	43.2	43.2	43.2
H03	40.0	40.0	40.0	40.0	41.3	43.2	45.3	47.5	49.9
H04	40.0	40.0	40.0	40.0	41.3	43.2	45.3	47.5	49.9
H05	40.0	40.0	40.0	40.0	41.3	43.2	45.3	47.5	49.9
H06	40.0	40.0	40.0	40.0	40.1	43.1	46.5	50.1	50.1
H07	40.0	40.0	40.0	40.0	40.1	43.1	46.5	50.1	50.1
H08	40.0	40.0	40.0	40.0	40.0	40.0	42.2	44.9	48.0
H09	40.0	40.0	40.0	40.0	40.0	40.0	42.2	44.9	48.0
H10	40.0	40.0	40.0	40.0	40.0	40.0	42.2	44.9	48.0

Table 5 - Night-time $L_{A90,T}$ Noise Limits Derived from the Baseline Noise Survey (dB)

Property	Standardised 10 m Wind Speed (m/s)								
	4	5	6	7	8	9	10	11	12
H01	43.0	43.0	43.0	43.0	43.0	43.0	43.4	43.4	43.4
H02	43.0	43.0	43.0	43.0	43.0	43.0	43.4	43.4	43.4
H03	43.0	43.0	43.0	43.0	43.0	43.0	43.3	44.4	45.4
H04	43.0	43.0	43.0	43.0	43.0	43.0	43.3	44.4	45.4
H05	43.0	43.0	43.0	43.0	43.0	43.0	43.3	44.4	45.4
H06	43.0	43.0	43.0	43.0	43.0	43.9	48.4	53.4	58.9
H07	43.0	43.0	43.0	43.0	43.0	43.9	48.4	53.4	58.9
H08	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.6	43.6
H09	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.6	43.6
H10	43.0	43.0	43.0	43.0	43.0	43.0	43.0	43.6	43.6

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. Temporary works on the public road network associated with the project are of very short duration and extent such that they do not require further consideration in this assessment.

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 6 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 property which would be closest to the activity for a portion of construction, and the predicted noise level. It must be emphasised that these predictions only relate the noise level occurring during the time when the activity is closest to the referenced property. In many cases such as access track construction and turbine erection, the separating distances will be considerably greater for the majority of the construction period and the predictions are therefore the worst-case periods of the construction phase.

Table 6 - Predicted Construction Noise Levels

Task Name	Plant/Equipment	Upper Collective Sound Emission Over Working Day $L_{WA,T}$ dB(A)	Nearest Receiver	Minimum Distance to Nearest Receiver (metres)	Predicted Upper Day-Time L_{Aeq}
Construct temporary site compounds	excavator / dump truck / tippers / rollers/ delivery trucks	120	H12	2160	41
Construct site tracks	excavators / dump trucks / tippers / dozers / vibrating rollers	120	H03	880	50
Construct Sub-Station	excavator / concrete truck / delivery truck	110	H03	860	40
Construct crane hardstandings	excavators / dump trucks	120	H06	1040	48

Task Name	Plant/Equipment	Upper Collective Sound Emission Over Working Day $L_{WA,T}$ dB(A)	Nearest Receiver	Minimum Distance to Nearest Receiver (metres)	Predicted Upper Day-Time L_{Aeq}
Construct turbine foundations	Piling Rigs / excavators / tippers / concrete trucks / mobile cranes / water pumps / pneumatic hammers / compressors / vibratory pokers	120	H06	1040	48
Excavate and lay site cables	excavators / dump trucks / tractors & cable drum trailers / wacker plates	110	H06	1040	38
Erect turbines	cranes / turbine delivery vehicles / artics for crane movement / generators / torque guns	120	H06	1040	48
Reinstate crane bases	excavator / dump truck	115	H07	1041	43
Reinstate road verges	excavator / dump truck	115	H03	880	45
Lay cable to sub-stations	JCB / saws / hydraulic breaker / dump truck/ tipper / wacker plate / tandem roller / tractor & cable drum trailer / delivery truck	115	H03	860	45
Borrow Pit Quarrying	Primary and secondary stone Crushers / excavators / screening systems / pneumatic breakers / conveyors	125	H05	1880	47

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 sometimes audible at various times throughout the construction phase. However, comparing the levels (up to 50 dB L_{Aeq}) to the significance criteria presented previously indicates that all on-site construction activities identified will have effects of negligible significance.

5.1.6 Construction traffic passing to and from the site will also represent a potential source of noise to surrounding properties. The Traffic and Transportation Assessment (Appendix H-1) includes predicted peak flows of traffic likely to be generated during the construction. The importation of materials for the construction of the proposed development would use three dedicated haul routes, resulting in worst-case peak movements of 12 two-way HGV movements per hour associated with pouring the turbine concrete foundations.

5.1.7 The most sensitive receiver locations in respect of vehicle movements are properties which are located along the site access track and which are relatively isolated. Large vehicles can generate noise levels in the order of 108 dB (sound power level L_{wA}) when in motion, assumed as a worst case for this assessment. However, these types of plant usually pass a receiver location quickly. When stationary, the same vehicles will be operating in idle which considerably lowers the noise output to the environment.

5.1.8 The construction site haul route A to the north that leads from the R251/R250 Regional Roads onto the L2703 local road site entrance of the proposed development, will pass closest to properties such as H02 at a distance of approximately 15 metres. Based on the prediction methodology in BS 5288-1, this will give rise to a maximum predicted noise level of 61 dB(A) L_{Aeq} at H02, based on 12 vehicles per hour travelling at 25 km/h.

5.1.9 The secondary construction site access route B leads from the north east L1044/L1014 to the proposed development. Vehicles on this route will pass closest to a property located at IG 210284 404237, approximately 5 metres from the haul route. This will give rise to a maximum predicted noise level of 64 dB(A) L_{Aeq}, based on 12 vehicles per hour travelling at 25 km/h at this representative property. This level of traffic is however unlikely given that this route will only be used temporarily for mobilisation and construction at the onset of the project.

5.1.10 The third haul route C to the south east leads from the N13 National road, to the L2744 and L1014 local roads into the proposed development. Vehicles on this route will pass closest to properties such as that located at IG 214038 400509, approximately 10 metres from the haul route. Based on a worst case 12 vehicles per hour travelling at 25 km/h, this gives rise to a maximum predicted noise level of 62 dB(A) L_{Aeq} at this property.

5.1.11 For all three haul routes, predicted worst-case noise levels do not exceed a level of 65 dB L_{Aeq} over the working day, which corresponds to minor effects based on the criteria of Table 1. Noise levels are likely to be lower for most of the construction period.

5.1.12 Construction traffic movements on existing local surrounding roads also represent a potential source of noise effects to surrounding properties. Daily traffic values for the baseline (without the project) and with development cases for 2024 are set out in Appendix H-1 (Tables 1.4 and 1.8).

5.1.13 Both predicted baseline and local and regional roads on the construction access route are below or close to the minimum flow volume of 1000 vehicles per day that is required by the CRTN methodology to enable reliable predictions. However, the above predictions of noise from the construction traffic using the BS 5228 methodology concluded that associated noise levels would not exceed 65 dB. As above, this corresponds to a minor effect based on the criteria in Table 1, which is not significant.

5.1.14 The predicted increase in traffic on the N13 and N15 national roads, using the CRTN methodology resulted in predicted noise level increases of 0.4 dB(A) and 0.6 dB(A) respectively. Based on the criteria set out in the Design Manual for Roads and Bridges (DMRB), the predicted short-term maximum change in traffic noise level is less than 1 dB(A), which corresponds to a negligible effect and is not significant.

5.1.15 In conclusion, noise arising from the construction of the proposed development has been assessed and is predicted to result in temporary minor effects at worst, which is not significant.

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. Given the separation distances between the location of proposed borrow pits and the nearest noise sensitive receptors (approximately 1.8 kilometres as a minimum for proposed Borrow Pit 2) it is predicted that these activities would cause acceptable residual adverse effects.

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 the Local Authorities.

5.3 De-commissioning Noise

5.3.1 De-commissioning is likely to result in less noise than during construction of the proposed development. The construction phase (encompassing construction traffic and construction activities) has been considered to have a minor noise impact, therefore de-commissioning will, in the worst case, also have a minor impact, which is not significant.

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 Siemens-Gamesa SG-5.0-145 wind turbine. This model was selected from a range of potential representative models including, the Nordex N133-4.8, the Enercon E136-4.2 and the Vestas V136-4.3. The noise specification of the SG-5.0-145 was predicted to result in the greatest immission levels and therefore represents an effective worst-case based on current turbine technology.

5.4.2 12 turbines have been modelled using the layout as indicated on the map at Annex B. The candidate turbine is a variable speed, pitch regulated machine with a rotor diameter of 145 metres and a hub height of 95 metres. Due to its variable speed operation, the sound power output of the SG-5.0-145 turbine varies considerably with wind speed, being quieter at the lower wind speeds when the blades are rotating more slowly.

5.4.3 In addition to this general low noise characteristic at lower wind speeds the SG-5.0-145 candidate turbine also incorporates noise control technology. This allows the sound power output of the turbine to be reduced across a range of operational wind speeds, albeit with some loss of electrical power generation, to enable the best compromise to be achieved in any given situation between emitted noise and electrical power generation. Noise control of the candidate turbine is provided in a number of noise control modes with various noise/power output combinations. Similar noise reduction management systems are also offered by other wind turbine manufacturers. These systems are generally similar in that they rely on the turbine's computer-based controller adjusting either the pitch of the blades or holding back the rotational speed of the blades to reduce emitted noise under selected wind conditions (direction, speed or some combination of the two). In this manner noise management only comes into play (and therefore potential power generation capacity is only lost) for those conditions under which it is required.

5.4.4 For the purposes of the present assessment the wind turbines on the proposed development have been modelled assuming selective use of the 'Low Noise' control mode for certain turbines. Specifically, turbines 9 and 11 were assumed to operate using the Application Mode (AM)-4 and turbine 10 in the AM-5 noise control mode, and the other turbines of the proposed development operating in their unconstrained (standard) mode of operation.

5.4.5 Siemens-Gamesa have supplied specification noise emission data for the SG-5.0-145 turbine which has been derived from various sound power tests, and in the absence of specific information about uncertainty allowances in the data, a further correction factor of +2 dB was added to the specification data in line with advice in the IOA GPG. The sound power data has been made available for hub height wind speeds of 6 m/s to 12 m/s inclusive, then standardised down to 10 m wind speeds in Table 7a based on the proposed hub height of 95 m (see Annex F). In addition to the overall sound power data, reference has been made to Siemens Gamesa test reports for the unit to derive a representative sound spectrum for the turbine, based on an energetic average of the available information at each octave band. The overall sound power and spectral data are presented in Table 7a and Table 8.

5.4.6 Assessment of cumulative effects from operating the proposed development together with the adjacent Meentycat Cark Extension Wind Farm, Culliagh Wind Farm, Meentycat Wind Farm and the Meentycat Meenbog Extension Wind Farm also require source information for their turbine type. The data assumed for the Cark Extension Wind Farm is the NEG Micron NM52/900 and Siemens SWT-2.3-82VS turbine models, for Culliagh the Vestas V52-850 model, for Meentycat the Siemens 1.3MW and 2.3MW stall regulated models and for the Meenbog Extension, the Siemens SWT-2.3-82VS model. All are consistent with the turbine models understood to be installed or with the candidate turbine specified in the respective noise assessments for each cumulative Wind Farm considered. Noise emission data for these turbines are presented in Table 7b. In addition, a representative sound spectrum for the turbine models have been derived from the reported one-third octave band spectrum and converted to octave bands, presented here in Table 8.

Table 7a - Wind Turbine Sound Power Levels Used in the Noise Assessment - proposed development

Standardised Wind Speed (m/s)	Sound Power Level (dB L_{Aeq})		
	SG-5.0-145 standard operation (AM-0, 5.0 MW)	SG-5.0-145 AM-4 noise mode	SG-5.0-145 AM-5 noise mode
4	100.1	100.1	100.1
5	105.1	105.1	105.1
6	109.2	109.0	108.9
7	111.3	110.1	109.8
8	111.3	110.1	109.8
9	111.3	110.1	109.8
10	111.3	110.1	109.8
11	111.3	110.1	109.8
12	111.3	110.1	109.8

Standardised Wind Speed	Sound Power Level (dB L_{Aeq})		
(m/s)	SG-5.0-145 standard operation (AM-0, 5.0 MW)	SG-5.0-145 AM-4 noise mode	SG-5.0-145 AM-5 noise mode
Derived from:	*SG 5.0-145 NOISE EMISSION ANALYSIS document. 30/06/2019*	*SG 5.0-145 NOISE EMISSION ANALYSIS document. 30/06/2019*	*SG 5.0-145 NOISE EMISSION ANALYSIS document. 30/06/2019*

Table 7b - Wind Turbine Sound Power Levels Used in the Noise Assessment - Cumulative Sites

Standardised Wind Speed	Sound Power Level (dB L_{Aeq})				
(m/s)	NEG Micron NM52/900 (Cark Wind Farm)	Siemens SWT-2.3-82VS*	Vestas V52-850 (Culliagh)	Siemens 1.3MW Stall regulated (Meentycat)	Siemens 2.3MW Stall regulated (Meentycat)
4	98.1	91.0	92.7	95.2	99.0
5	98.1	97.0	97.5	97.8	104.5
6	99.5	102.0	102.3	100.5	105.0
7	100.2	105.0	104.2	101.7	105.8
8	102.2	106.0	104.7	103.0	106.5
9	103.2	106.0	104.7	104.2	108.8
10	104.6	106.0	104.7	105.5	111.0
11	106.0	106.0	104.7	106.8	113.1
12	107.4	106.0	104.7	108.0	115.2
Derived from:	*From Neg Micon Warranty*	*Data from a revised set of warranted levels from Siemens dated 30/10/2008*	*Data from previous wind farm test report in Germany. 10/2002*	*Derived from the highest of the numbers from two previous windfarm warranties.*	*Noise data from two previous wind farm warranties.*

* Meentycat Cark Extension & Meentycat Meenbog Extension

Table 8 - Octave Band Sound Power Spectrum (dB L_{Aeq}) For Reference Wind Speed Conditions (v_{10} = 8 m/s)

Octave Band Centre	A-Weighted Sound Power Level (dB(A))					
Frequency (Hz)	SG-5.0-145	NEG Micron NM52/900	Siemens SWT-2.3-82VS	Vestas V52-850	Siemens 1.3MW Stall regulated	Siemens 2.3MW Stall regulated
63	93.5	87.7	79.4	84.7	84.0	84.0
125	99.1	93.9	89.4	90.4	91.2	91.2

Octave Band Centre	A-Weighted Sound Power Level (dB(A))					
Frequency (Hz)	SG-5.0-145	NEG Micron NM52/900	Siemens SWT-2.3-82VS	Vestas V52-850	Siemens 1.3MW Stall regulated	Siemens 2.3MW Stall regulated
250	102.6	93.1	98.1	95.4	92.1	92.1
500	103.6	91.0	100.2	97.4	93.2	93.2
1000	105.4	92.7	100.5	96.9	92.5	92.5
2000	105.0	92.8	97.9	94.7	92.8	92.8
4000	98.8	88.2	96.0	88.9	89.6	89.6
8000	85.3	71.4	90.2	73.8	81.0	81.0
Derived from:	*SG 5.0-145 NOISE EMISSION ANALYSIS document. 30/06/2019*	*Summary of test report from previous wind farm. 13/12/2000*	*Data from a revised set of warranted levels from Siemens dated 30/10/2008*	*Data from previous wind farm test report in Germany. 10/2002*	*Derived from Delta Test report AV158/03*	*Spectra from 3 Delta Acoustics test reports, all at 8m/s normalised to 100dB(A) and log averaged.*

5.5 Choice of Wind Farm Operational Noise Propagation Model

5.5.1 The ISO 9613-2 model[xii] 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. The attenuation due to terrain screening accounted for in the calculations has been limited to a maximum of 2 dB(A) In situations of propagation above concave ground, a correction of +3dB was added. A table of screening corrections applied between each turbine and receptor considered is shown in Appendix B.

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

5.6 Predicted Wind Farm Operational Noise Immission Levels

5.6.1 Table 9 shows predicted noise immission levels at each of the selected assessment locations, for each wind speed from 4 m/s to 12 m/s inclusive, for the proposed development in isolation. 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 ETSU-R-97, obtained by subtracting 2 dB(A) from the calculated $L_{Aeq,T}$ noise levels based on the turbine sound power levels presented in Table 7a and Table 8.

Table 9 - Predicted $L_{A90,T}$ Wind Farm Noise Immission Levels at Each of the Noise Assessment Locations as a Function of Standardised Wind Speed for the proposed development operating in isolation.

Property	Standardised 10 m Wind Speed (m/s)								
	4	5	6	7	8	9	10	11	12
H01	22.0	27.0	31.0	32.7	32.7	32.7	32.7	32.7	32.7
H02	24.2	29.2	33.1	34.5	34.5	34.5	34.5	34.5	34.5
H03	25.1	30.1	34.1	35.5	35.5	35.5	35.5	35.5	35.5
H04	27.1	32.1	36.0	37.4	37.4	37.4	37.4	37.4	37.4
H05	27.3	32.3	36.3	37.6	37.6	37.6	37.6	37.6	37.6
H06	29.7	34.7	38.7	40.0	40.0	40.0	40.0	40.0	40.0
H07	28.4	33.4	37.4	38.8	38.8	38.8	38.8	38.8	38.8
H08	23.4	28.4	32.4	34.2	34.2	34.2	34.2	34.2	34.2
H09	26.7	31.7	35.8	37.6	37.6	37.6	37.6	37.6	37.6
H10	23.8	28.8	32.8	34.6	34.6	34.6	34.6	34.6	34.6

5.7 Assessment against Noise Limits

5.7.1 Figures E1 to E8 (Annex E) show the calculated wind farm noise immission levels at each of the noise monitoring locations, correspond to those already presented in Table 9.

5.7.2 The calculated noise immission levels are shown overlaid on the day-time and night-time noise limit curves of Table 4 and 5. 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.

5.7.3 The 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 criteria 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 relevant noise limits including any relevant tonality corrections.

5.7.4 The assessment (shown in tabular form Table 10 and Table 11) shows that the predicted windfarm noise immission levels meet the noise limits of Tables 4 and 5 (based on lower limits of 40 and 43 dB for day-time and night-time respectively) under all wind speeds and at all locations. These predicted noise immission levels have been made assuming worst-case downwind propagation.

Table 10- Difference between the derived Day-time Noise Limits and the proposed development's predicted $L_{A90,T}$ Wind Farm Noise Immission Levels (the proposed development operating in isolation) at Each Noise Assessment Location. Values are based on a 40 dB(A) 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
H01	-18.0	-13.0	-9.0	-7.4	-8.8	-10.6	-10.6	-10.6	-10.6
H02	-15.9	-10.9	-6.9	-5.5	-6.9	-8.7	-8.7	-8.7	-8.7
H03	-14.9	-9.9	-5.9	-4.5	-5.8	-7.7	-9.8	-12.0	-14.4
H04	-12.9	-7.9	-4.0	-2.6	-3.9	-5.8	-7.9	-10.2	-12.5
H05	-12.7	-7.7	-3.7	-2.4	-3.7	-5.6	-7.7	-9.9	-12.3
H06	-10.3	-5.3	-1.3	0.0	-0.1	-3.1	-6.4	-10.1	-10.1
H07	-11.6	-6.6	-2.6	-1.2	-1.3	-4.3	-7.6	-11.3	-11.3
H08	-16.6	-11.6	-7.6	-5.8	-5.8	-5.8	-8.0	-10.8	-13.8
H09	-13.3	-8.3	-4.2	-2.4	-2.4	-2.4	-4.6	-7.4	-10.4
H10	-16.2	-11.2	-7.2	-5.4	-5.4	-5.4	-7.6	-10.3	-13.4

Table 11 - Difference between the derived Night-time Noise Limits and the proposed development's predicted $L_{A90,T}$ Wind Farm Noise Immission Levels (the proposed development operating in isolation) at Each Noise Assessment Location. Negative values indicate the noise immission level is below the limit.

Property	Standardised 10 m Wind Speed (m/s)								
	4	5	6	7	8	9	10	11	12
H01	-21.0	-16.0	-12.0	-10.4	-10.4	-10.4	-10.7	-10.7	-10.7
H02	-18.9	-13.9	-9.9	-8.5	-8.5	-8.5	-8.8	-8.8	-8.8
H03	-17.9	-12.9	-8.9	-7.5	-7.5	-7.5	-7.8	-8.9	-9.9
H04	-15.9	-10.9	-7.0	-5.6	-5.6	-5.6	-6.0	-7.0	-8.0
H05	-15.7	-10.7	-6.7	-5.4	-5.4	-5.4	-5.7	-6.8	-7.8
H06	-13.3	-8.3	-4.3	-3.0	-3.0	-3.9	-8.4	-13.4	-18.9
H07	-14.6	-9.6	-5.6	-4.2	-4.2	-5.1	-9.5	-14.6	-20.1
H08	-19.6	-14.6	-10.6	-8.8	-8.8	-8.8	-8.8	-9.4	-9.4
H09	-16.3	-11.3	-7.2	-5.4	-5.4	-5.4	-5.4	-6.0	-6.0
H10	-19.2	-14.2	-10.2	-8.4	-8.4	-8.4	-8.4	-9.0	-9.0

5.7.5 This assessment therefore demonstrates compliance with a day-time lower noise limits set at the upper end of the range defined in ETSU-R-97 and consistent with the 2006 WEDG.

5.7.6 According ETSU-R-97, the lower 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 are considered below:

- Number of affected properties: The area of the proposed development and its immediate surroundings is generally of very low population density, with only isolated properties located to the north and west of the site. There are more properties in the Tullyhoner area, but this is located at a further distance from the site, approximately 2.3 km to the north east of the closest proposed development turbine (T09).
- Duration and level of exposure: The charts of Annex E show the predicted levels from the proposed development in relation to the range of measured background levels in quiet conditions during the day-time for key locations. It is apparent that these predictions are comparable to the range of measured background levels for the majority of the properties around the proposed development. At H09 and neighbouring locations, the worst-case predicted levels are more elevated relative to the measured noise levels at some wind speeds, however this represents noise levels which would be experienced from the proposed development in downwind conditions, i.e. north-easterly wind directions in this case, which will tend to occur less often given that south-westerly winds are generally prevailing: this will reduce the duration of exposure for these locations.
- Generation capacity: With a potential generation capacity of more than 50 MW, the proposed development alone represents a large-scale development. The power generating capacity of modern wind turbines has dramatically increased over that which was typical at the time the ETSU-R-97 guidelines were produced. For example, at the time the guide was produced, a windfarm site comprising around 120 turbines would have been required to achieve a similar generating capacity to that of the proposed development, thus highlighting the significance of the scheme. Reducing the lower limit applicable during day-time periods would have a substantial impact on the potential generation capacity of the scheme.

5.7.7 Based on the above considerations, it is considered wholly appropriate to set the day-time limit toward the upper end of the range, at 40 dB(A).

5.8 Cumulative Assessment

5.8.1 When considering cumulative noise effects with other wind farms in the area, four additional noise-sensitive locations south of the proposed development were considered: H11, H12, H13 and H14. An additional residential property, H15 was recently consented. Details of these additional assessment locations are set out in Table 12.

Table 12 - Additional Cumulative Assessment Locations (approximate Irish National Grid Easting / Northing)

No.	Property	Easting	Northing
1	H11	203811	401635
2	H12	207466	401482
3	H13	207434	401373
4	H14	207423	401246
5	H15	209478	403807

5.8.2 Table 13 shows the predicted noise immission levels for the proposed development in isolation at the additional locations of Table 12. Table 14 then shows predicted noise levels from the surrounding schemes operating without the proposed development, at all assessment locations including the additional cumulative locations in Table 12 above.

5.8.3 The IOA GPG suggests that cumulative noise effects need not be considered where differences between existing/consented and proposed wind farm noise levels are 10 dB or more. A comparison of Table 14 with the predictions of the proposed development in Table 12 above shows that at locations H12, H13,H14 and H15, the contribution from the proposed development is more than 10 dB below that from other schemes and therefore relatively negligible. Similarly, at locations H06 and H07 located further north, the contribution of other schemes is more than 10 dB below that from the proposed development at the key wind speeds from 6 m/s to 9 m/s (Table 9). Therefore, contributions from the surrounding schemes is considered relatively negligible for these properties and they are not considered any further.

Table 13 - Predicted $L_{A90,T}$ Wind Farm Noise Immission Levels at the additional locations of Table 12 for the proposed development operating in isolation as a Function of Standardised Wind Speed

Property	Standardised 10 m Wind Speed (m/s)								
	4	5	6	7	8	9	10	11	12
H11	18.2	23.2	27.3	29.2	29.2	29.2	29.2	29.2	29.2
H12	19.6	24.6	28.7	30.8	30.8	30.8	30.8	30.8	30.8
H13	19.2	24.2	28.3	30.3	30.3	30.3	30.3	30.3	30.3
H14	18.6	23.6	27.7	29.8	29.8	29.8	29.8	29.8	29.8

Table 14 - Predicted $L_{A90,T}$ Wind Farm Noise Immission Levels at Each of the Noise Assessment Locations from other cumulative schemes operating without the proposed development (including the additional cumulative assessment locations) as a Function of Standardised Wind Speed

Property	Standardised 10 m Wind Speed (m/s)								
	4	5	6	7	8	9	10	11	12
H01	25.9	27.3	28.5	29.5	31.1	32.1	33.5	34.9	36.4
H02	25.5	26.9	28.0	29.0	30.6	31.6	33.0	34.4	35.9
H03	26.3	27.6	28.7	29.7	31.3	32.3	33.7	35.1	36.5
H04	26.2	27.5	28.7	29.7	31.3	32.3	33.7	35.1	36.5
H05	26.3	27.6	28.7	29.8	31.4	32.4	33.7	35.1	36.6
H06	22.7	24.6	26.1	27.2	28.6	29.6	31.0	32.4	33.9
H07	22.0	24.0	25.5	26.7	28.0	29.0	30.4	31.8	33.3
H08	25.3	27.3	29.0	30.3	31.6	32.4	33.6	34.9	36.3
H09	27.1	29.1	30.9	32.2	33.5	34.3	35.4	36.7	38.0
H10	23.9	25.8	27.4	28.7	30.0	30.9	32.2	33.5	34.9
H11	26.0	29.1	32.1	33.8	34.7	35.2	36.0	36.9	38.0
H12	34.4	39.3	42.1	43.7	44.4	45.1	46.1	47.3	48.7
H13	33.8	38.6	41.4	42.9	43.5	44.4	45.5	46.7	48.2
H14	33.0	37.9	40.3	41.8	42.5	43.4	44.6	46.0	47.6
H15	39.5	43.0	44.9	46.1	47.2	48.6	50.1	51.7	53.3

5.8.4 Table 15 shows predicted cumulative noise immission levels at the remaining properties, for each standardised wind speed from 4 m/s to 12 m/s inclusive. This assumes that all other wind farms are operating with the proposed development turbine models as set out in section 5.4 and that all receptors are downwind of all wind turbines at the same time, which is a conservative assumption in many cases.

Table 15 - Predicted Cumulative $L_{A90,T}$ Wind Farm Noise Immission Levels at Each of the Noise Assessment Locations from nearby schemes operating with the proposed development (including the additional cumulative assessment locations) as a Function of Standardised Wind Speed

Property	Standardised 10 m Wind Speed (m/s)								
	4	5	6	7	8	9	10	11	12
H01	27.4	30.2	32.9	34.4	34.9	35.4	36.1	36.9	37.9
H02	27.9	31.2	34.3	35.6	36.0	36.3	36.8	37.5	38.2
H03	28.7	32.0	35.2	36.5	36.9	37.2	37.7	38.3	39.1
H04	29.7	33.4	36.8	38.1	38.3	38.6	38.9	39.4	40.0
H05	29.8	33.6	37.0	38.3	38.5	38.7	39.1	39.5	40.1
H08	27.5	30.9	34.0	35.7	36.1	36.4	36.9	37.6	38.4
H09	29.9	33.6	37.0	38.7	39.0	39.3	39.7	40.2	40.8
H10	26.8	30.5	33.9	35.6	35.9	36.1	36.6	37.1	37.8
H11	26.7	30.1	33.3	35.1	35.8	36.2	36.8	37.6	38.5

5.8.5 Tables 16 and 17 demonstrate that the cumulative noise predictions in Table 15 comply with the noise limits of Tables 4 and 5. As shown in Table 15, the cumulative noise predictions at H11 lie below a level of 40 dB(A), therefore below applicable noise limits.

Table 16 - Comparison between Cumulative L_{A90} Wind Farm Noise Immission Levels at the remaining Noise Assessment Locations from nearby schemes operating with the proposed development (including the additional cumulative assessment locations), against the 40 dB lower Day-time limit as a Function of Standardised Wind Speed. Negative values indicate cumulative noise predictions are within the limit.

Property	Standardised 10 m Wind Speed (m/s)								
	4	5	6	7	8	9	10	11	12
H01	-12.6	-9.8	-7.1	-5.6	-6.5	-7.8	-7.1	-6.3	H01
H02	-12.1	-8.8	-5.7	-4.4	-5.4	-6.9	-6.4	-5.7	H02
H03	-11.3	-8.0	-4.8	-3.5	-4.4	-6.0	-7.6	-9.2	H03
H04	-10.3	-6.6	-3.2	-1.9	-3.0	-4.7	-6.4	-8.2	H04
H05	-10.2	-6.4	-3.0	-1.7	-2.8	-4.5	-6.2	-8.0	H05
H08	-12.5	-9.1	-6.0	-4.3	-3.9	-3.6	-5.2	-7.4	H08
H09	-10.1	-6.4	-3.0	-1.3	-1.0	-0.7	-2.5	-4.8	H09
H10	-13.2	-9.5	-6.1	-4.4	-4.1	-3.9	-5.6	-7.8	H10

Table 17 - Comparison between Cumulative L_{A90} Wind Farm Noise Immission Levels at the remaining Noise Assessment Locations from nearby schemes operating with the proposed development (including the additional cumulative assessment locations), against the 43 dB lower Night-time limit as a Function of Standardised Wind Speed. Negative values indicate cumulative noise predictions are within the limit.

Property	Standardised 10 m Wind Speed (m/s)								
	4	5	6	7	8	9	10	11	12
H01	-15.6	-12.8	-10.1	-8.6	-8.1	-7.6	-7.3	-6.4	-5.5
H02	-15.1	-11.8	-8.7	-7.4	-7.0	-6.7	-6.5	-5.9	-5.1
H03	-14.3	-11.0	-7.8	-6.5	-6.1	-5.8	-5.7	-6.1	-6.3
H04	-13.3	-9.6	-6.2	-4.9	-4.7	-4.4	-4.4	-5.0	-5.4
H05	-13.2	-9.4	-6.0	-4.7	-4.5	-4.3	-4.3	-4.9	-5.3
H08	-15.5	-12.1	-9.0	-7.3	-6.9	-6.6	-6.1	-6.1	-5.2
H09	-13.1	-9.4	-6.0	-4.3	-4.0	-3.7	-3.3	-3.4	-2.8
H10	-16.2	-12.5	-9.1	-7.4	-7.1	-6.9	-6.4	-6.5	-5.8

5.8.6 In conclusion, the predicted cumulative noise immission levels from the proposed development when operating cumulatively with the nearby Wind Farms are compliant with the derived WEDG 2006 criteria at all locations and all wind speeds. This outcome has been achieved through use of turbine constraints applied to two of the candidate turbines for the proposed development, assuming worst case downwind predictions.

5.8.7 Satisfactory control of cumulative noise immission levels would be achieved through enforcement of the individual consent limits for the proposed development. Specific noise limits can be defined such that compliance of the proposed development with these noise limits would maintain the conclusion of the cumulative assessment and result in cumulative levels which do not exceed the derived noise criteria of Tables 4 and 5: see Tables 18 and 19 below.

5.9 Low Frequency Noise, Vibration and Amplitude Modulation

5.9.1 Low frequency noise (or “infrasound”) 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, modern turbines do not emit perceptible levels of infrasound and vibration at typical separation distances and therefore this does not require further specific assessment.

5.9.2 Annex A also discusses the most recently 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 UK-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. There is no definitive planning guidance as to the appropriate assessment of this aspect of wind farm noise in current Irish planning guidelines.

5.10 Substation and energy storage

5.10.1 The main noise sources associated with the substation are likely to be the power transformers and their cooling fans. The transformer noise is generally fairly constant once energised, whereas the cooling fans operate as needed, depending on load and ambient temperature. The noise from the transformers is usually tonal in nature with most energy contained within discrete frequency components at 50 Hz and harmonics thereof. The cooling fans are likely to be broad-band in nature but switch on and off. Battery storage facilities also have a combination of electrical plant as well as temperature control equipment but are less likely overall to have a noise which is tonal in nature.

5.10.2 The proposed substation is located approximately 800 m from the nearest noise-sensitive locations. Based on experience of similar installations, the associated noise levels at these properties is likely to be of less than 30 dB L_{Aeq} due to separation distances involved. This would be clearly below the most stringent noise limit of 35 dB L_{Aeq} recommended in the NG4 guidance for classified installations, even when accounting for the potential character of the noise and would be comparable to existing background noise levels currently experienced during quiet periods. Therefore, no specific mitigation measures are considered to be required in this instance.

5.11 Evaluation of Effects

Table 18 – Summary of effects

Potential Effect	Evaluation of Effect
Construction Noise	Noise levels have been predicted using the methodology set out in BS 5228. Based on assessment criteria derived and supported by a range of noise policy and guidance, overall construction noise levels are considered to represent a minor effect, and therefore considered not significant.
Operational Noise	Noise criteria have been established in accordance with the Irish WEDGs and consideration of UK guidance documents. It has also been shown that these criteria are achievable with a commercially available turbine suitable for the site. 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 in Ireland, and therefore considered not significant.

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 will be limited to the hours 07:00 to 19:00 Monday to Friday and 07:00 to 14:00 on Saturdays. Turbine deliveries would only take place outside these times with the prior consent of the Council and the Police. 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 Standards and discussed below:

- Blasting, if required, should take place under strictly controlled conditions and in consultation with the relevant authorities, 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 the local authorities;
- Vibration levels at the nearest sensitive properties are best controlled through on-site testing processes carried out in consultation with the Local Authorities. 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 in order to control air overpressure.

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 relevant noise limits, such as those of Tables 4 and 5, to be achieved at the surrounding properties. Noise limits specific to the proposed development are set out in Tables 18 and 19. They were determined such that compliance of the proposed development operating in isolation with these specific noise limits would maintain the conclusion of the cumulative assessment (discussed below) and result in cumulative levels which do not exceed the derived noise limits (Tables 4 and 5).

Table 18 - Specific Day-time $L_{A90,T}$ Noise Limits for the proposed development in isolation

Property	Standardised 10 m Wind Speed (m/s)								
	4	5	6	7	8	9	10	11	12
H01	39.0	39.0	39.0	39.0	40.4	42.2	42.2	42.2	42.2
H02	39.1	39.1	39.1	39.1	40.6	42.3	42.3	42.3	42.3
H03	39.5	39.5	39.5	39.5	40.9	42.8	44.8	47.1	49.5
H04	39.5	39.5	39.5	39.5	40.8	42.8	44.8	47.1	49.5
H05	39.5	39.5	39.5	39.5	40.8	42.8	44.8	47.1	49.5
H06	40.0	40.0	40.0	40.0	40.1	43.1	46.5	50.1	50.1
H07	40.0	40.0	40.0	40.0	40.1	43.1	46.5	50.1	50.1
H08	39.2	39.2	39.2	39.2	39.2	39.2	41.3	44.1	47.2
H09	38.6	38.6	38.6	38.6	38.6	38.6	40.8	43.6	46.6
H10	39.4	39.4	39.4	39.4	39.4	39.4	41.6	44.4	47.4

Table 19 – Specific Night-time $L_{A90,T}$ Noise Limits for the proposed development in isolation

Property	Standardised 10 m Wind Speed (m/s)								
	4	5	6	7	8	9	10	11	12
H01	42.0	42.0	42.0	42.0	42.0	42.0	42.4	42.4	42.4
H02	42.1	42.1	42.1	42.1	42.1	42.1	42.5	42.5	42.5
H03	42.4	42.4	42.4	42.4	42.4	42.4	42.7	43.8	44.8
H04	42.4	42.4	42.4	42.4	42.4	42.4	42.7	43.8	44.8
H05	42.4	42.4	42.4	42.4	42.4	42.4	42.7	43.8	44.8
H06	43.0	43.0	43.0	43.0	43.0	43.9	48.4	53.4	58.9
H07	43.0	43.0	43.0	43.0	43.0	43.9	48.4	53.4	58.9
H08	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.7	42.7
H09	41.6	41.6	41.6	41.6	41.6	41.6	41.6	42.2	42.2
H10	42.4	42.4	42.4	42.4	42.4	42.4	42.4	43.0	43.0

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 (Tables 18 and 19). Such monitoring should be done in full accordance with ETSU-R-97, relevant good practice and include penalties for characteristics of the noise such as tonality (if present). A suggested noise planning condition wording to that effect is included in Annex G.

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 10 residential properties lying around the wind farm have been selected as being representative of the closest located properties to the wind farm. An additional four properties further south of the windfarm are considered only for cumulative considerations. The minimum separation distance between the nearest turbine and the closest located residential property is approximately 985 metres. 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 four surrounding properties, as derived from measurements made over approximately 3-7 weeks at each location.

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 minor.

8.1.4 Operational noise from the wind farm has been assessed in accordance with the criteria set out in the 2006 Irish Wind Energy Development Guidelines (WEDG), supplemented by more detailed UK guidelines. This provides a robust basis for assessing the operational noise of a wind farm.

8.1.5 Applying the derived noise limits at the assessment locations 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. This outcome may be achieved through use of turbine constraints applied to some of the proposed development turbines. Specifically, this assessment has determined that a day-time lower 40 dB(A) noise limit is achievable for the proposed development, considering cumulative noise effects. This assessment has been based on the use of the manufacturer's warranted sound power data for the Siemens-Gamesa SG-5.0-145 wind turbine which is typical of the upper end of the noise emission levels for the range of turbines models which may be installed. In addition, worst-ase downwind propagation was assumed.

8.1.6 In summary, the overall levels of construction noise are considered to represent a minor effect, and therefore considered not significant. 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.

9. References

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

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

iii 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.

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

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

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

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

viii Calculation of Road Traffic Noise, HMSO Department of Transport, 1988 (UK).

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

x Guidance Note for Noise: License Applications, Surveys and Assessments in Relation to Scheduled Activities (NG4), Environmental Protection Agency, Office of Environmental Enforcement, Ireland (2016).

xi Design Manual for Roads and Bridges (DMRB), LA 111 Noise and Vibration, Nov 2019, The Highways Agency, Transport Scotland, Transport Wales, The Department for Regional Development (Northern Ireland) (UK).

xii 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.

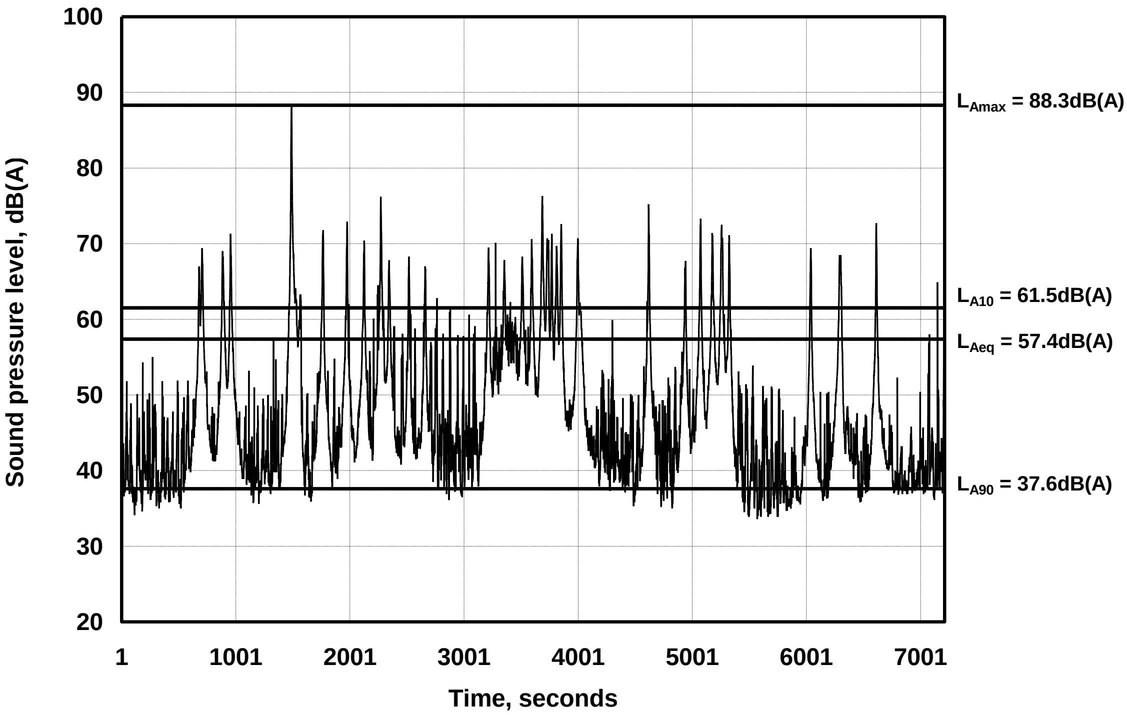
A.5 Before reviewing the potential effects of environmental sound on people, it is useful first to consider the means by which physical sound can be quantified.

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.

A.32

Low Frequency Noise and Vibration – Wind Farms

A.33 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.34 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.35 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.36 The fact that low frequency sound and infrasound from wind farms has only relatively recently 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.37 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.38 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.39 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.

C-Weighting

A.40 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.41 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.

G-Weighting

A.42 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.

Infrasound from wind farms

A.43 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 to cause health problems. It has, however, been the case that dedicated research investigations have shown this not to be the case.

A.44 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.45 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.46 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.47 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. 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.48 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 have frequently been 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 have 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.49 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.50 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.51 Even more recently, 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].

A.52 The DTI LFN Report is a comprehensive study containing many pages of detailed results of measurements of both infrasound and low frequency sound around the three wind farms included in the study. These measurements were undertaken using measurement systems capable of detecting noise down to frequencies of 1 Hz, with results being reported up to a frequency of 500 Hz, thus extending beyond the full spectrum of what is normally considered to cover both infrasound (<20 Hz) and low frequency sound (20 Hz to 200 Hz).

A.53 The measurement locations at the three wind farms were selected to be at residential properties where occupants had raised concerns relating to low frequency sound disturbance. Noise immission measurements are reported both externally to and internally to the properties in question. In addition to these noise immission measurements, the results of noise emission measurements undertaken on a number of wind turbines are also reported with the aim of quantifying the level of infrasound actually emitted from individual wind turbines and wind farms.

A.54 Before summarising the findings of the DTI LFN Report, it is noted that the prevalence of the perceived problem of infrasound and/or low frequency sound is not a widespread one. Quoting from the Executive Summary to the DTI LFN Report:

'of the 126 wind farms operating in the UK, 5 have reports of low frequency sound problems which attract adverse comment concerning the noise. Therefore, such complaints are the exception rather than a general problem which exists for all wind farms'.

A.55 The DTI LFN Report was actually commissioned primarily to investigate the effects of infrasound. This investigation was commissioned as a direct result of the claims made in the press concerning health problems arising from noise of such a low frequency 'that it is beyond the audible range, such that you can't hear it but you can feel it as a resonance'. For this reason the results pertaining to infrasound are reported separately from those pertaining to audible low frequency sound above 20 Hz.

A.56 In respect of infrasound, the DTI LFN 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.57 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.

A.58 Indeed, in the face of the apparent misunderstanding of the conclusions reached in the various reports on infrasound, and how these conclusions should be applied to consideration of the radiation of such noise from wind farms, the British Wind Energy Association have issued a fact sheet relating to the subject [5]. This fact sheet concludes:

'With regard to effects of noise from wind turbines, the main effect depends on the listener's reaction to what they may hear. There are no direct health effects from noise at the level of noise generated by wind turbines. It has been repeatedly shown by measurements of wind turbine noise undertaken in the UK, Denmark, Germany and the USA over the past decade, and accepted by experienced noise professionals, that the levels of infrasonic noise and vibration radiated from modern, upwind configuration wind turbines are at a very low level; so low that they lie below the threshold of perception, even for those people who are particularly sensitive to such noise, and even on an actual wind turbine site'.

Low Frequency Sound

A.59 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.60 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.61 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.62 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.63 The UK 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.64 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.65 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.66 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.67 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.68 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.69 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.70 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.71 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.72 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.73 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.

A.74 In Ireland, there is currently no fixed guidelines on the assessment of AM from wind farms.

References for LFN and AM Section

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

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

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

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

[5] 'Low frequency noise and wind turbines', BWEA Briefing Sheet, 2005

[6] 'Low frequency noise', Report by Casella Stanger for DEFRA, 2001

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

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

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

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

[11] Template Planning Condition on Amplitude Modulation (guidance notes), RenewableUK, December 2013.

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

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

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. 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 proposed development turbines, the Cumulative Wind Farm turbines, the noise measurement properties (red pentagon icon) and the additional noise assessment properties (black square outlined icon)

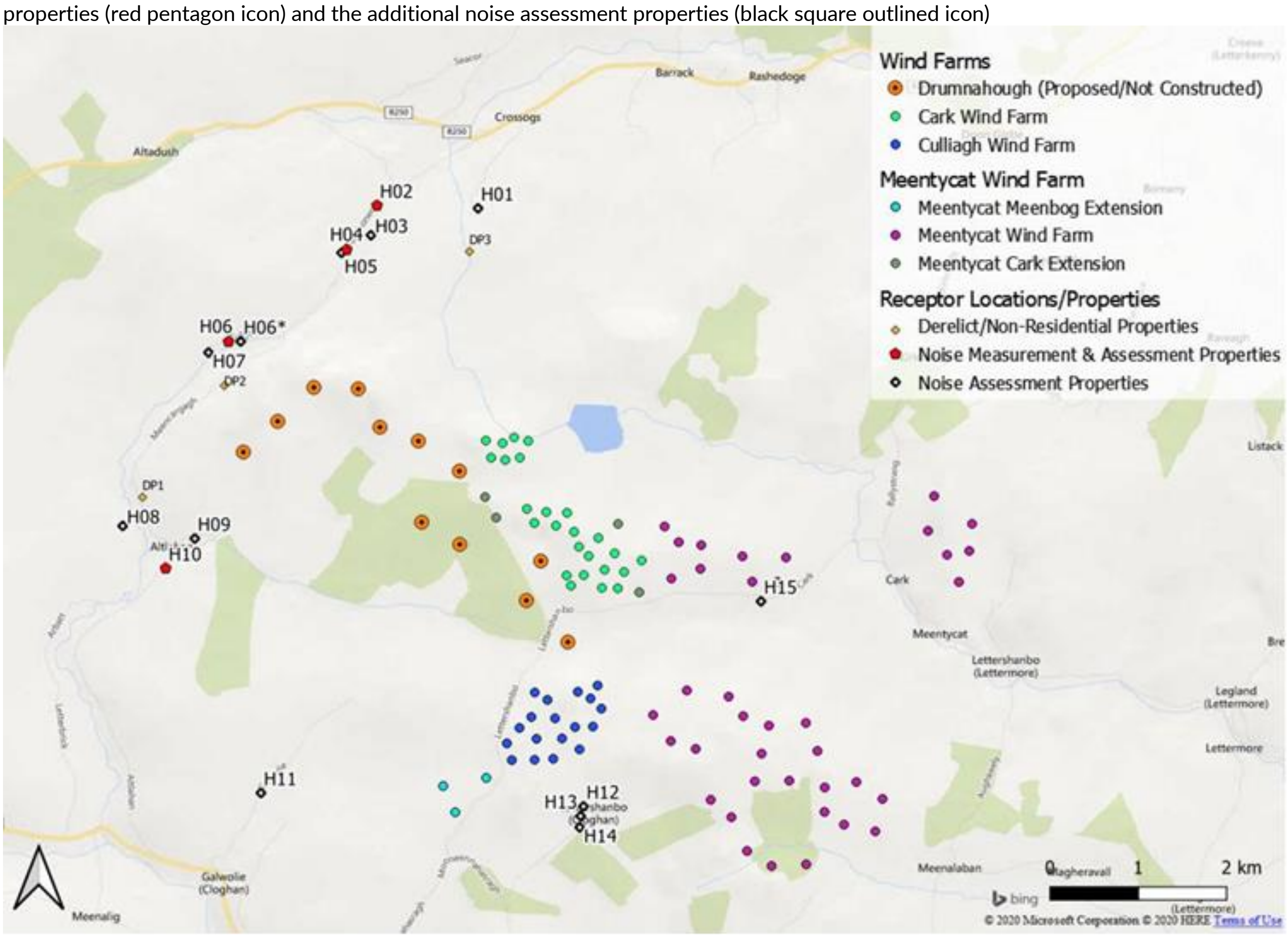


Table B1 – Drumnahough Turbine coordinates (Irish National Grid)

Turbine	Easting	Northing
1	207287	403343
2	206820	403821
3	206988	404269
4	206064	404452
5	205633	404704
6	206060	405283
7	205555	405612
8	205160	405781
9	204913	406212
10	204411	406229
11	204004	405846
12	203617	405497

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

Turbine number	Property														
	H01	H02	H03	H04	H05	H06	H07	H08	H09	H10	H11	H12	H13	H14	H15
1	2	2	2	2	2	2	2	0	0	2	0	2	2	2	0
2	2	2	2	2	2	2	2	0	0	2	0	2	2	2	0
3	2	0	2	0	0	2	2	0	0	0	0	2	2	2	0
4	2	0	2	2	2	2	2	0	0	0	0	2	2	2	2
5	2	2	2	2	2	2	2	0	0	0	0	2	2	2	2
6	0	0	0	0	0	2	2	0	0	0	0	2	2	2	2
7	0	0	0	0	0	2	2	0	0	0	2	2	2	2	2
8	0	0	0	0	0	2	2	0	0	0	2	2	2	2	2
9	-3	-3	0	-3	-3	0	0	0	0	0	2	2	2	2	2
10	0	-3	-3	-3	-3	0	0	0	0	0	2	2	2	2	2
11	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2
12	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2

Annex C – Noise Monitoring Information Sheets

Table C1 – Information on the measurement location, equipment and noise data at H04.

Measurement Location Name	H04
Measurement Location Description	The property is located approximately 1.5 km north of the closest proposed turbine position of the proposed development. The logger was installed in the front garden of the property, facing towards the proposed development to the south. Within the front garden/driveway area, the logger was positioned at the north eastern corner, to distance it from the neighbouring trees along the property border and the small stream between the road and front garden, minimising these two extraneous noise sources. Additionally, no boiler flumes or extractor fan outlets were present on this side of the property. Therefore, the chosen logger position was concluded to best represent the typical ambient noise climate experienced at the property. The ambient noise climate at this property was dominated by wind noise, however this source was observed to be less dominant on subsequent visits. Occasional sources of noise comprised passing vehicles. SLM Location (IG Easting/Northing): 204807/407793

Table 19 – from 06/08/2019 to 20/08/2019

Equipment	Type	Serial Number	Last Calibrated (UKAS)
Sound Level Meter	Rion NL-31	00910453	14/03/2018
Pre-amplifier	Rion NH-21	02294	14/03/2018
Microphone	Rion UC-53A	101799	14/03/2018
Calibrator	Rion NC-74	34172705	15/07/2019
SLM Range	20 – 110 dB(A)		

Table 20 - from 20/08/2019 to 01/10/2019

Equipment	Type	Serial Number	Last Calibrated (UKAS)
Sound Level Meter	Rion NL-31	00110032	18/10/2017
Pre-amplifier	Rion NH-21	00134	18/10/2017
Microphone	Rion UC-53A	102143	18/10/2017
Calibrator	Rion NC-74	34172705	15/07/2019
SLM Range	20 – 110 dB(A)		

File	Time Start (GMT)	Time End (GMT)	Cal Start	Cal End	Drift	Notes
01	06/08/2019 18:10	08/08/2019 10:20	94.0	94.2	+ 0.2	No significant drift
02	20/08/2019 16:10	03/09/2019 11:10	94.0	93.5	- 0.5	No significant drift
03	09/03/2019 11:30	17/09/2019 15:10	94.0	94.3	+ 0.3	No significant drift

File	Time Start (GMT)	Time End (GMT)	Cal Start	Cal End	Drift	Notes
04	17/09/2019 15:30	01/10/2019 09:32	94.0	94.1	+ 0.1	No significant drift

Data Exclusions
Any logger data acquired during periods of rainfall, measured using the rain gauge, was excluded. Stream/water runoff noise exclusions: - 0-3 m/s, > 32.4 dBA Atypical event exclusions: Quiet daytime: - 0-3 m/s, > 35 dBA - 8-11 m/s, > 47 dBA - Mon 30/09/2019 20:20 - 20:30, 21:10-22:00 Night-time: - 5-7 m/s, > 41.2 dBA - Mon 30/09/2019 23:10 - Tue 01/10/2019 00:40

Figure C1 View of the monitoring location at H04 looking North

Figure C2 View of the monitoring location at H04 looking East

Figure C3 View of the monitoring location at H04 looking South

Figure C4 View of the monitoring location at H04 looking South East

Table C2 – Information on the measurement location, equipment and noise data at H06.

Measurement Location Name	H06
Measurement Location Description	The property is located approximately 1.1 km north west of the closest proposed turbine position of the proposed development. The logger was installed on the front lawn of the property, facing towards the proposed development to the south east. Within the front garden/driveway area, the logger was positioned at the lawn border in the corner, closest to the front garden boundary and road at the front, to distance it from the front of the house, the trees on both sides of the property, and the workshop building/driveways behind the property, minimising these extraneous noise sources. Additionally, no boiler flumes or extractor fan outlets were present on the front wall of the property. Therefore, the chosen logger position was concluded to best represent the typical background noise climate experienced at the property. The ambient noise climate at this property was dominated by wind noise, however this source was observed to occur at reduced noise levels on the servicing visits. Occasional sources of noise comprised farm machinery and passing vehicles. SLM Location (IG Easting/Northing): 203477/406761

Equipment	Type	Serial Number	Last Calibrated (UKAS)
Sound Level Meter	Rion NL-32	00630481	07/09/2018
Pre-amplifier	RIon UC-53A	305115	07/09/2018
Microphone	Rion NH-21	09098	07/09/2018
Calibrator	B&K 4231	2545611	10/07/2018
SLM Range	20 – 110 dB(A)		

File	Time Start (GMT)	Time End (GMT)	Cal Start	Cal End	Drift	Notes
01	09/07/2019 11:10	23/07/2019 16:00	94.0	94.1	+ 0.1	No significant drift
02	23/07/2019 16:20	20/08/2019 16:40	94.0	93.8	- 0.2	No significant drift
03	20/08/2019 17:00	03/09/2019 02:00	94.0	94.0	0.0	No drift
04	03/09/2019 12:00	17/09/2019 17:40	94.0	93.8	- 0.2	No significant drift
05	17/09/2019 15:50	01/10/2019 09:30	94.0	94.0	0.0	No drift

Data Exclusions
Any data acquired during periods of rainfall, measured using the rain gauge, was excluded. Any data acquired when the wind direction was outside of the 180-degree downwind sector (45 to 225 degrees from north) was excluded. Atypical event exclusions: Quiet daytime: - 1-2 m/s, > 35 dBA L90

Data Exclusions
Night-time: - 9 - 13 m/s, 28 < LA90 < 35 - Sat 21/09/2019 00:10-06:00 - Thurs 25/07/2019 00:40 to 01:50

Figure C5 View of the monitoring location at H06 looking North

Figure C6 View of the monitoring location at H06 looking East

Figure C7 View of the monitoring location at H06 looking West

Table C3 – Information on the measurement location, equipment and noise data at H10.

Measurement Location Name	H10
Measurement Location Description	The property is located approximately 1.5 km south west of the closest proposed turbine position of the proposed development. The logger was installed adjacent to the north eastern border of the property, facing towards the proposed development to the north east. The monitoring location was installed in a field next to the property, as access was not possible within the property boundary itself. However, the chosen position was considered representative of the noise climate experienced in the outdoor amenity space of the property. Furthermore, the logger position was shielded by the house itself from the stream and tree noise along the south west border of the property, therefore minimising these extraneous noise sources. Additionally, no boiler flumes or extractor fan outlets were present on the nearside wall of the house or garage building. The ambient noise climate at this property was dominated by wind noise, however this source was observed to occur at reduced noise levels on the servicing visits. Occasional sources of noise comprised of sheep, trees and passing vehicles. SLM Location (IG Easting/Northing): 202779/404216

Table 21 – from 03/09/2019 to 17/09/2019

Equipment	Type	Serial Number	Last Calibrated (UKAS)
Sound Level Meter	Rion NL-52	00632047	15/08/2017
Pre-amplifier	Rion NH-25	32075	15/08/2017
Microphone	Rion UC-59	05214	15/08/2017
Calibrator	Rion NC-74	34172705	15/07/2019
SLM Range	20 – 120 dB(A)		

Table 22 – from 17/09/2019 to 27/09/2019

Equipment	Type	Serial Number	Last Calibrated (UKAS)
Sound Level Meter	Rion NL-52	00331820	25/07/2019
Pre-amplifier	Rion NH-25	21771	25/07/2019
Microphone	Rion UC-59	04886	25/07/2019
Calibrator	Rion NC-74	34172705	15/07/2019
SLM Range	20 – 120 dB(A)		

File	Time Start (GMT)	Time End (GMT)	Cal Start	Cal End	Drift	Notes
01	03/09/2019 13:50	17/09/2019 16:00	94.0	94.0	0.0	No drift
02	17/09/2019 16:50	01/10/2019 00:40	94.0	93.8	- 0.2	No significant drift

Data Exclusions
Any data acquired during periods of rainfall, measured using the rain gauge, was excluded. Atypical event exclusions: Quiet daytime: - Sun 08/09/2019 11:30 - 12:20 - Sun 22/09/2019 14:50 Night-time: - 10 - 13 m/s, < 35 dBA

Figure C8 View of the monitoring location at H10 looking South west

Figure C9 View of the monitoring location at H10 looking North west

Figure C10 View of the monitoring location at H06 looking North east

Figure C11 View of the monitoring location at H10 looking East

Table C4 – Information on the measurement location, equipment and noise data at H02.

Measurement Location Name	H02
Measurement Location Description	The property is located approximately 2 km north of the closest proposed turbine position of the proposed development. The logger was installed in the front garden of the property, facing towards the proposed development to the south. Within the front garden area, the logger was positioned at the lawn border in the corner, bordering the driveway and road. This distanced it from the front of the house, where trees and shrubbery were present, therefore minimising these extraneous noise sources and neighbouring livestock. Additionally, no boiler flumes or extractor fan outlets were present on the front wall of the property. Therefore, the chosen logger position was concluded to best represent the typical ambient noise climate experienced at the property. On return to the property for a service visit, watercourse noise was audible following a period of rainfall. A post-survey review of the data resulted in the exclusions of noise data pertaining to atypical noise events, rainfall and watercourse flow noise outlined below in Data Exclusions. The ambient noise climate at this property was dominated by wind noise, however this source was observed to occur at reduced noise levels on the servicing visits. Occasional sources of noise comprised of bird, sheep and passing vehicles. SLM Location (IG Easting/Northing): 205182/408327

Equipment	Type	Serial Number	Last Calibrated (UKAS)
Sound Level Meter	Rion NL-52	00632047	15/08/2017
Pre-amplifier	Rion UC-59	05214	15/08/2017
Microphone	Rion NH-25	32075	15/08/2017
Calibrator	Rion NC-74	34172705	15/07/2019
SLM Range	20 – 120 dB(A)		

File	Time Start (GMT)	Time End (GMT)	Cal Start	Cal End	Drift	Notes
01	09/07/2019 12:10	10/07/2019 13:50	94.0	94.2	+ 0.2	No significant drift
02	23/07/2019 13:50	04/08/2019 16:55	94.0	93.7	- 0.3	No significant drift
03	06/08/2019 15:50	20/08/2019 15:30	94.0	93.9	- 0.1	No significant drift
04	20/08/2019 15:40	03/09/2019 10:40	94.0	94.0	0.0	No drift

Data Exclusions
Any data acquired during periods of rainfall, measured using the rain gauge, was excluded. Atypical event exclusions: Quiet day: - Tues 06/08/2019 17:10 - 22:00 - Thurs 08/08/2019 17:50 - 18:40 - Mon 12/08/2019 19:40 - 22:00 - Fri 30/08/2019 17:20 - 19:40 Night: - Tue 06/08/2019 22:20 - Wed 07/08/2019 00:40 - Tue 20/08/2019 00:00 - 00:20 - Fri 23/08/2019 22:10 - 23:20 - Thu 29/08/19 05:30 - 23:50 - Fri 30/08/2019 04:50 - 05:30 - Mon 02/09/19 23:10 - Tue 03/09/19 06:00 Elevated watercourse noise exclusion periods: - Wed 10/07/2019 04:00 to Wed 10/07/2019 13:50 - Tue 06/08/2019 16:00 to Thurs 08/08/2019 06:00 - Fri 09/08/2019 23:30 to Fri 16/08/2019 18:50 - Tue 20/08/19 15:00 to Wed 21/08/19 23:50 - Mon 26/08/19 10:50 to Wed 28/08/19 20:30 - Fri 30/08/2019 13:10 to Sun 01/09/2019 16:30

Figure C12 View of the monitoring location at H02 looking North

Figure C13 View of the monitoring location at H02 looking East

Figure C14 View of the monitoring location at H02 looking South

Figure C15 View of the monitoring location at H02 looking West

Annex D – Wind Speeds and Directions

Figure D1 Wind speed and direction range during all quiet day-time periods (Property H04 data shown; other data excluded at some of the other locations).

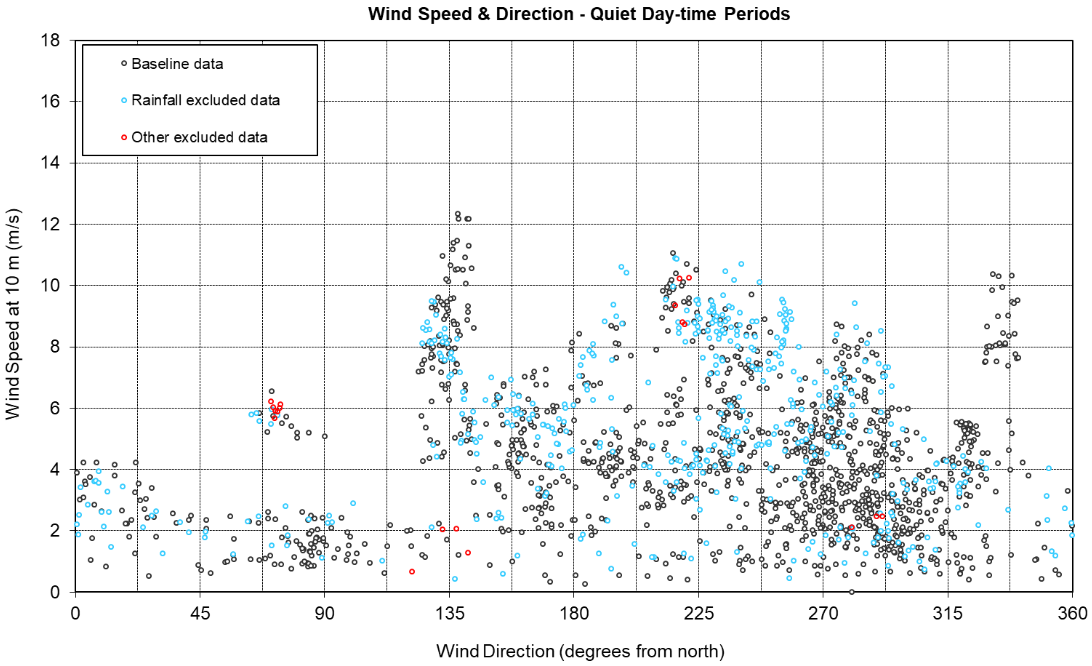


Figure D2 Wind speed and direction range during all night-time periods (Property H04 data shown; other data excluded at some of the other locations).

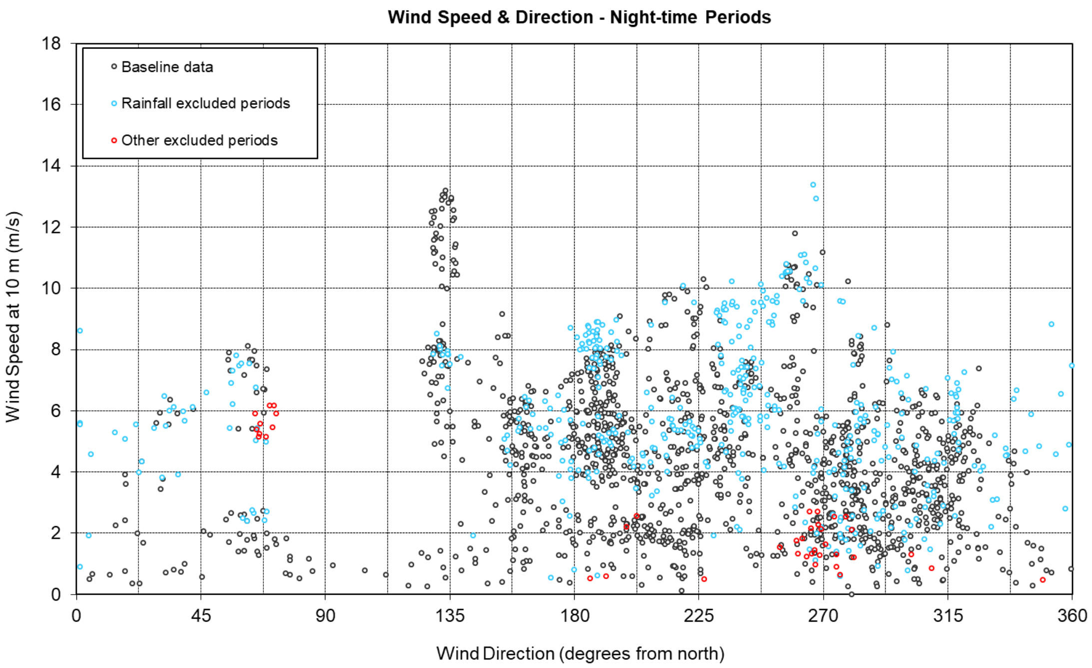


Figure D3 Wind speed and direction range during all quiet day-time periods (Property H06 data shown, with directional filtering; other data excluded at some of the other locations).

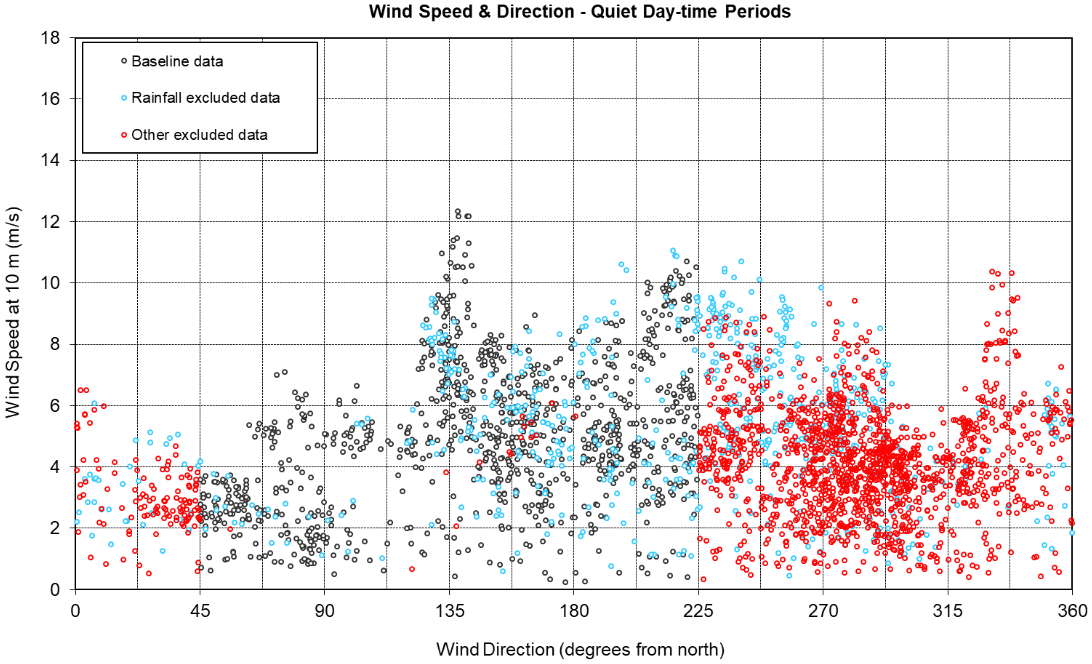


Figure D4 Wind speed and direction range during all night-time periods (Property H06 data shown, with directional filtering; other data excluded at some of the other locations).

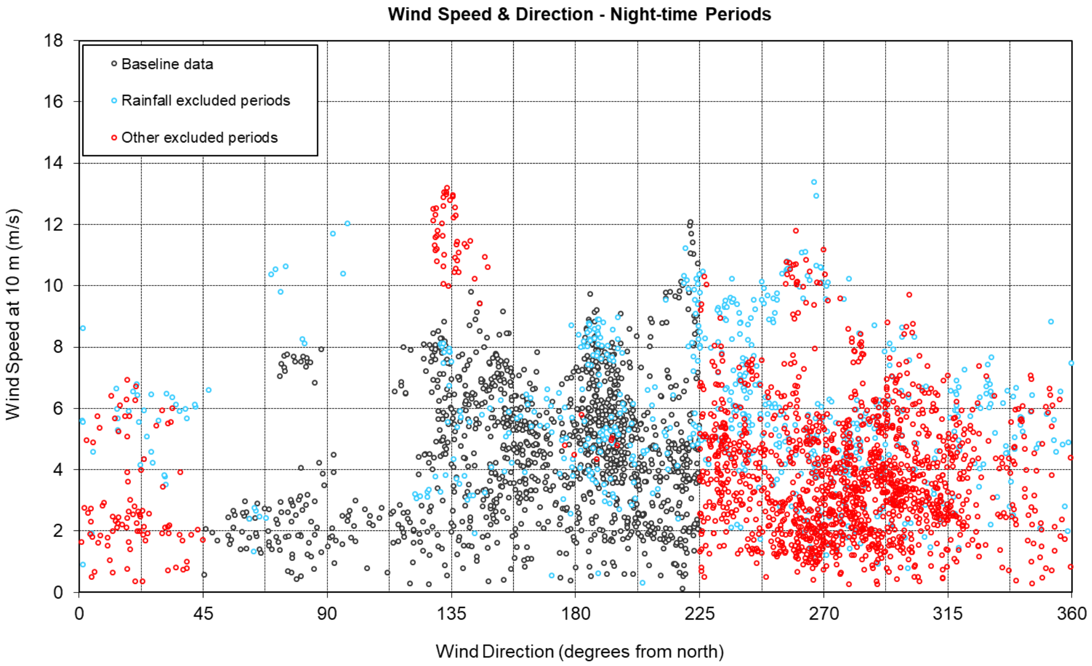


Figure D5 Wind speed and direction range during all quiet day-time periods (Property H10 data shown).

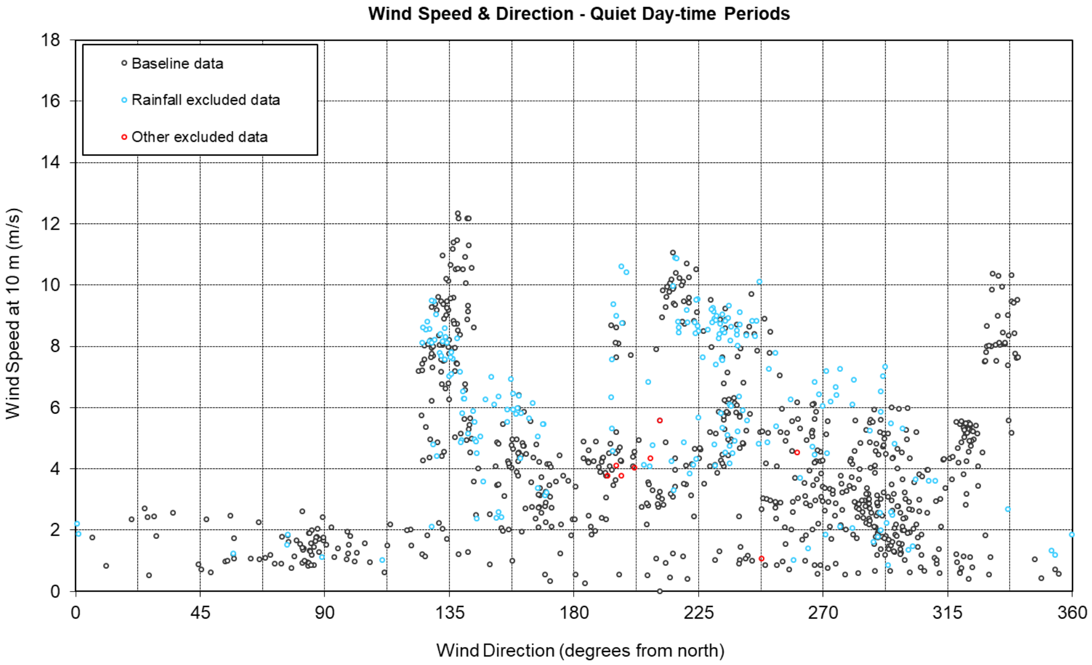


Figure D6 Wind speed and direction range during all night-time periods (Property H10 data shown).

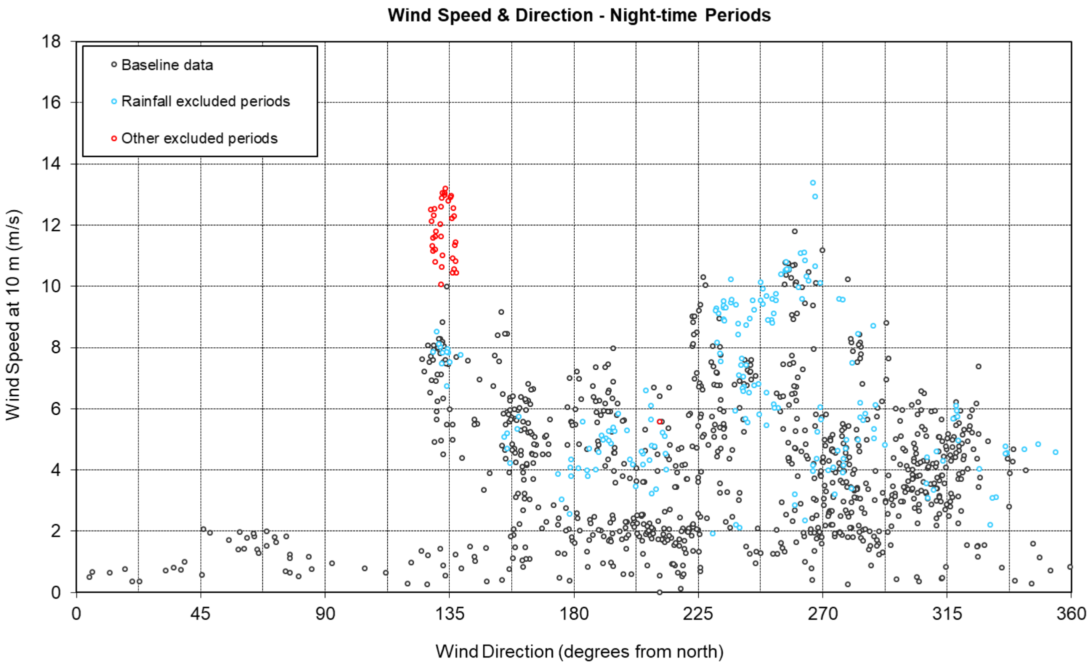


Figure D7 Wind speed and direction range during all quiet day-time periods (Property H02 data shown).

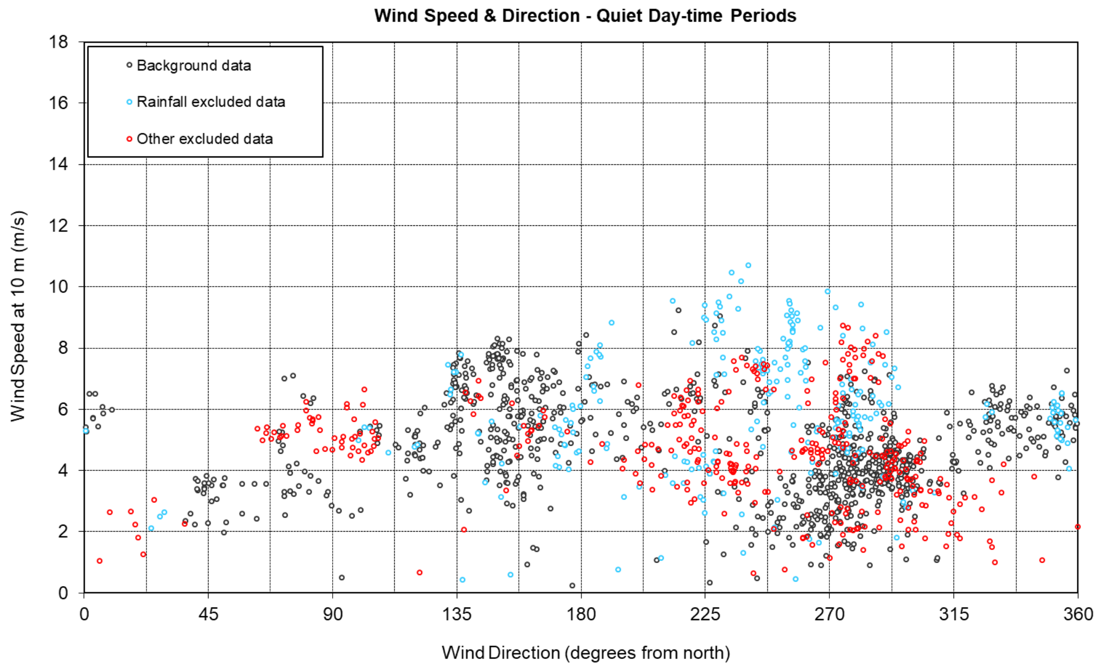
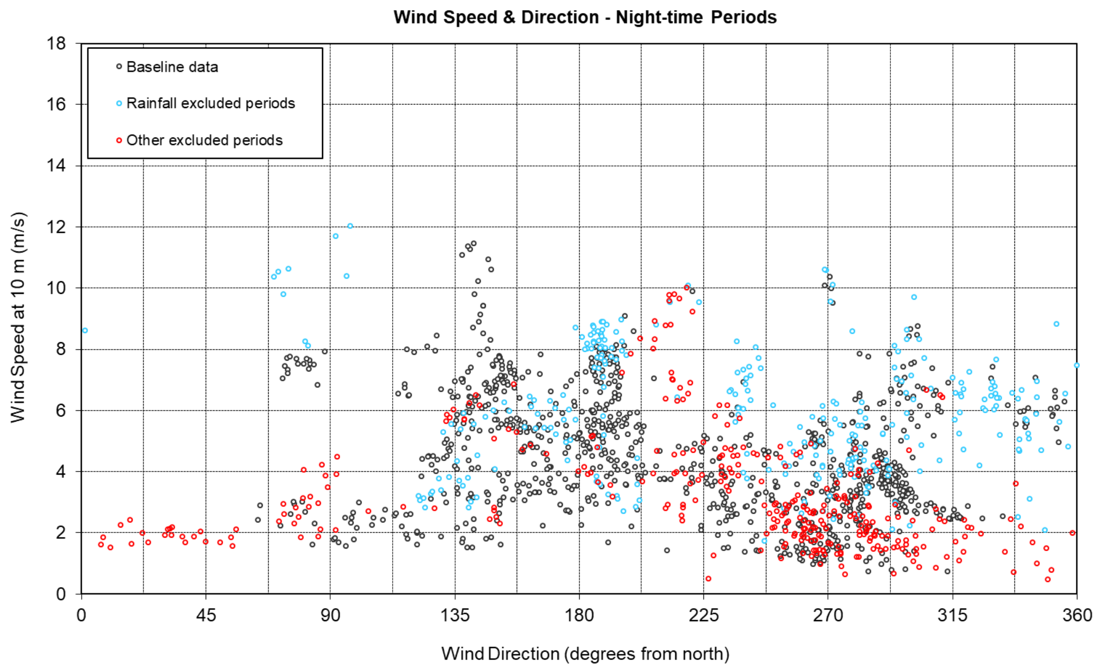


Figure D8 Wind speed and direction range during all night-time periods (Property H02 data shown).



Annex E – Background Noise and Noise Limits

Tables of derived Background Noise Levels

Table E1 - Derived day-time background noise levels per standardised 10 m wind speed

Measurement Property	Standardised 10 m Wind Speed (m/s)								
	4	5	6	7	8	9	10	11	12
H02	29.5	31.2	32.9	34.7	36.4	38.2	*	*	*
H04	30.2	31.5	32.9	34.5	36.3	38.2	40.3	42.5	44.9
H06	26.4	28.1	30.1	32.4	35.1	38.1	41.5	45.1	*
H10	26.4	27.5	28.9	30.5	32.5	34.7	37.2	39.9	43.0

** No data available.*

Table E2 - Derived night-time background noise levels per standardised 10 m wind speed

Measurement Property	Standardised 10 m Wind Speed (m/s)								
	4	5	6	7	8	9	10	11	12
H02	27.2	29.9	32.2	34.2	35.9	37.3	38.4	*	*
H04	30.6	32.1	33.5	34.8	36.0	37.2	38.3	39.4	40.4
H06	24.4	26.2	28.6	31.5	34.9	38.9	43.4	48.4	53.9
H10	26.9	27.6	28.7	30.1	31.7	33.7	36.0	38.6	*

** No data available.*

Table E3 - Total valid day-time background noise data quantities collected per wind speed bin

Measurement Property	Standardised 10 m Wind Speed (m/s)								
	4	5	6	7	8	9	10	11	12
H02	232	192	146	93	37	4	0	0	0
H04	203	195	106	71	77	46	26	14	4
H06	135	204	126	107	84	41	25	14	4
H10	105	107	46	19	56	43	28	14	4

Table E4 - Total valid night-time background noise data quantities collected per wind speed bin

Measurement Property	Standardised 10 m Wind Speed (m/s)								
	4	5	6	7	8	9	10	11	12
H02	160	137	120	99	55	11	7	6	0
H04	200	233	157	106	87	21	22	17	10
H06	186	211	180	138	103	24	11	4	3
H10	125	137	98	61	53	14	13	6	1

Figure E1 Chart of background noise levels against wind speeds, the best fit curve to the data, the derived noise limit curve for Property H04 during quiet day-time periods. Predicted immission noise levels are also shown for the proposed development, the other wind farms considered and the cumulative total.

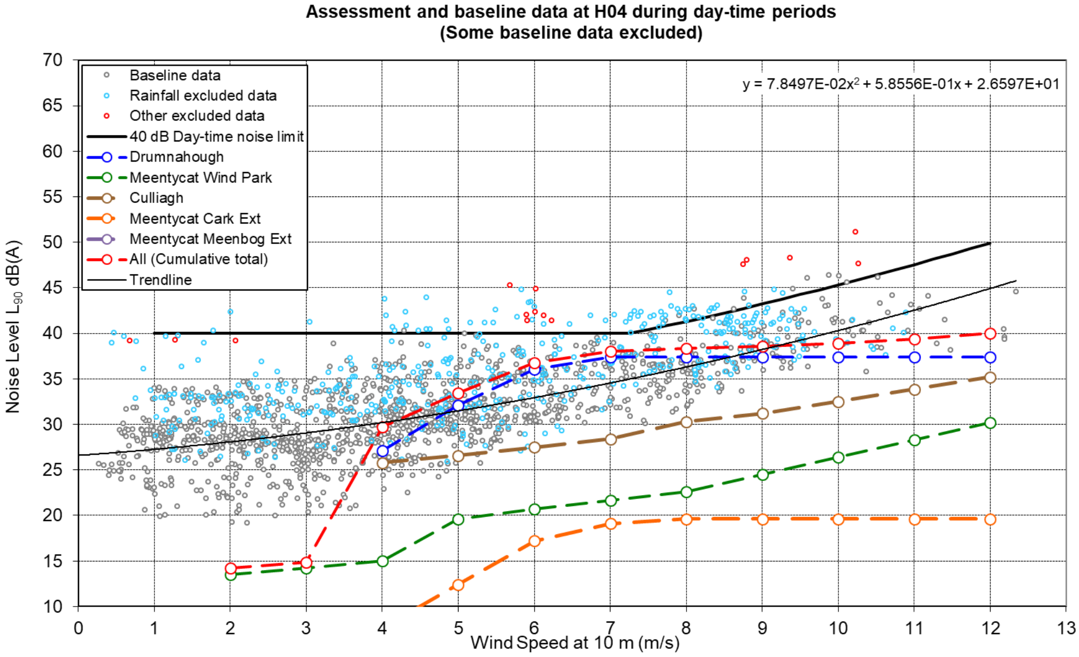


Figure E2 Chart of background noise levels against wind speeds, the best fit curve to the data, the derived noise limit curve for Property H04 during night-time periods. Predicted immission noise levels are also shown for the proposed development, the other wind farms considered and the cumulative total.

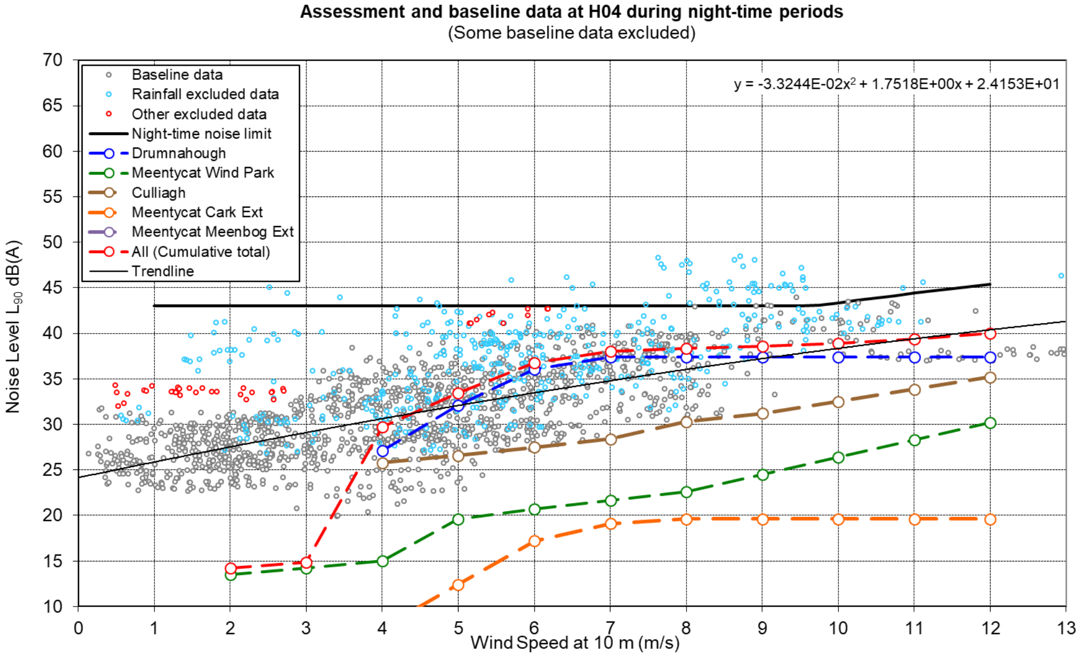


Figure E3 Chart of background noise levels against wind speeds, the best fit curve to the data, the derived noise limit curve for Property H06 during quiet day-time periods. Predicted immission noise levels are also shown for the proposed development, the other wind farms considered and the cumulative total.

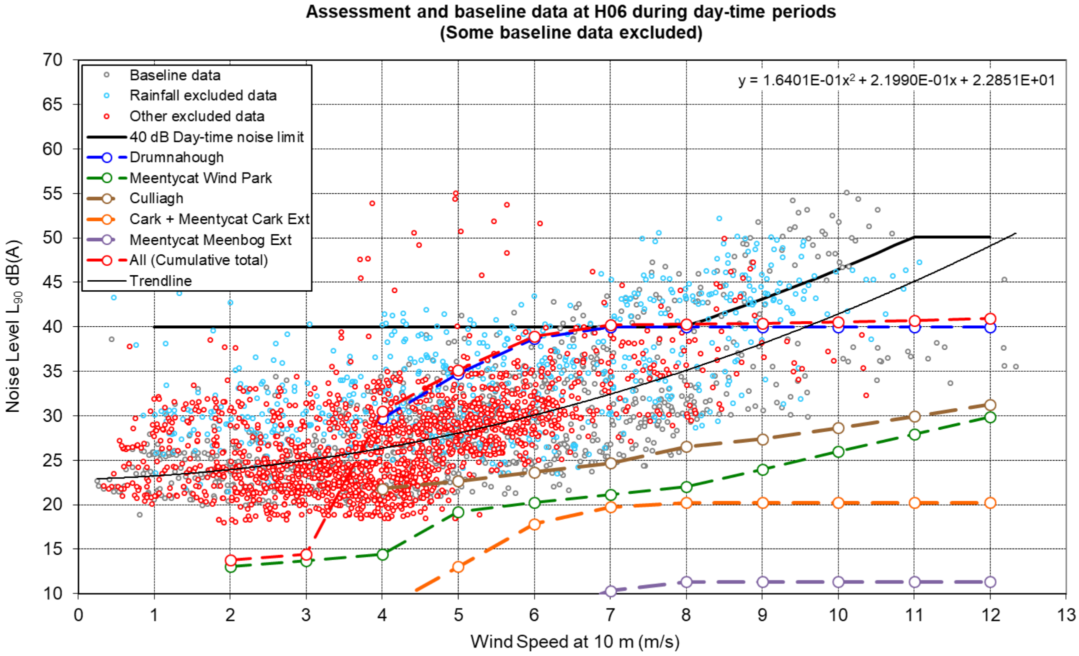


Figure E4 Chart of background noise levels against wind speeds, the best fit curve to the data, the derived noise limit curve for Property H06 during night-time periods. Predicted immission noise levels are also shown for the proposed development, the other wind farms considered and the cumulative total.

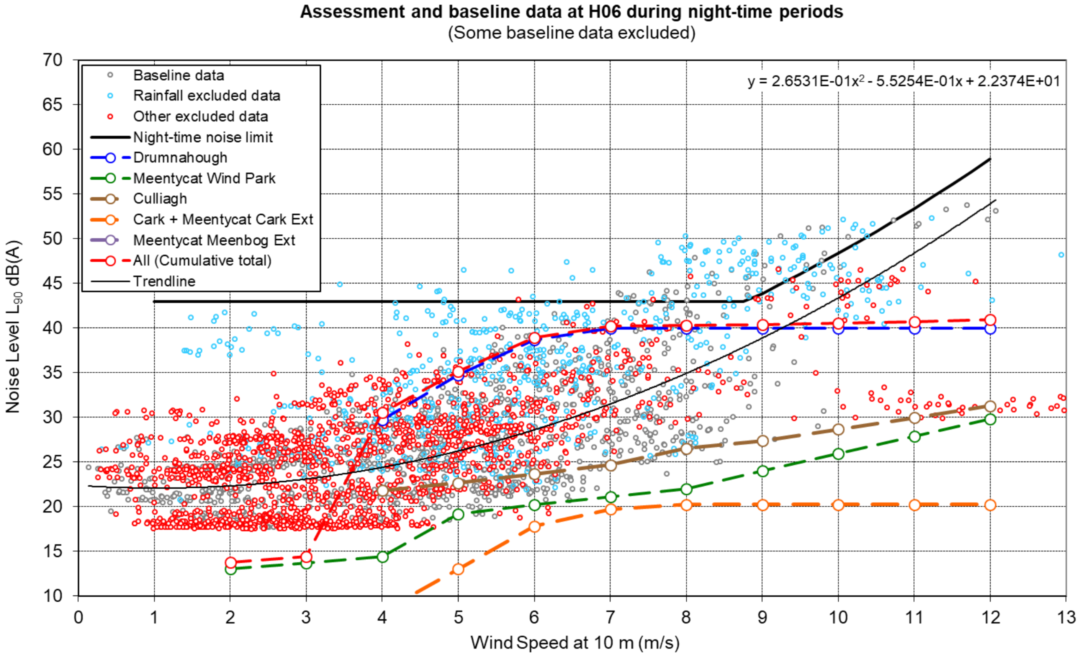


Figure E5 Chart of background noise levels against wind speeds, the best fit curve to the data, the derived noise limit curve for Property H10 during quiet day-time periods. Predicted immission noise levels are also shown for the proposed development, the other wind farms considered and the cumulative total.

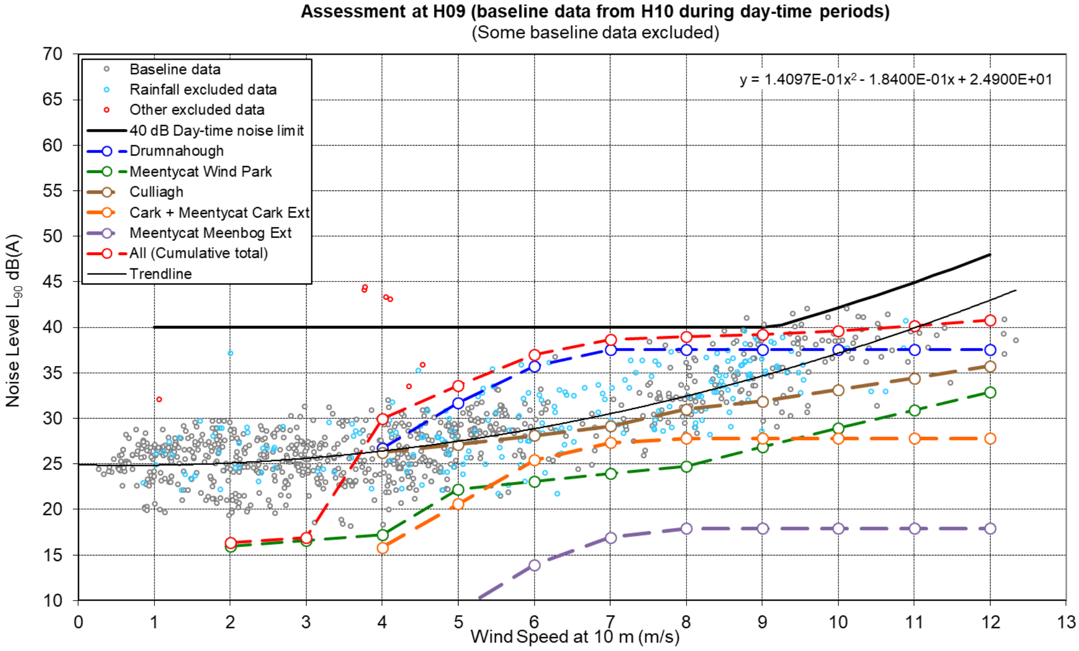


Figure E6 Chart of background noise levels against wind speeds, the best fit curve to the data, the derived noise limit curve for Property H10 during night-time periods. Predicted immission noise levels are also shown for the proposed development, the other wind farms considered and the cumulative total.

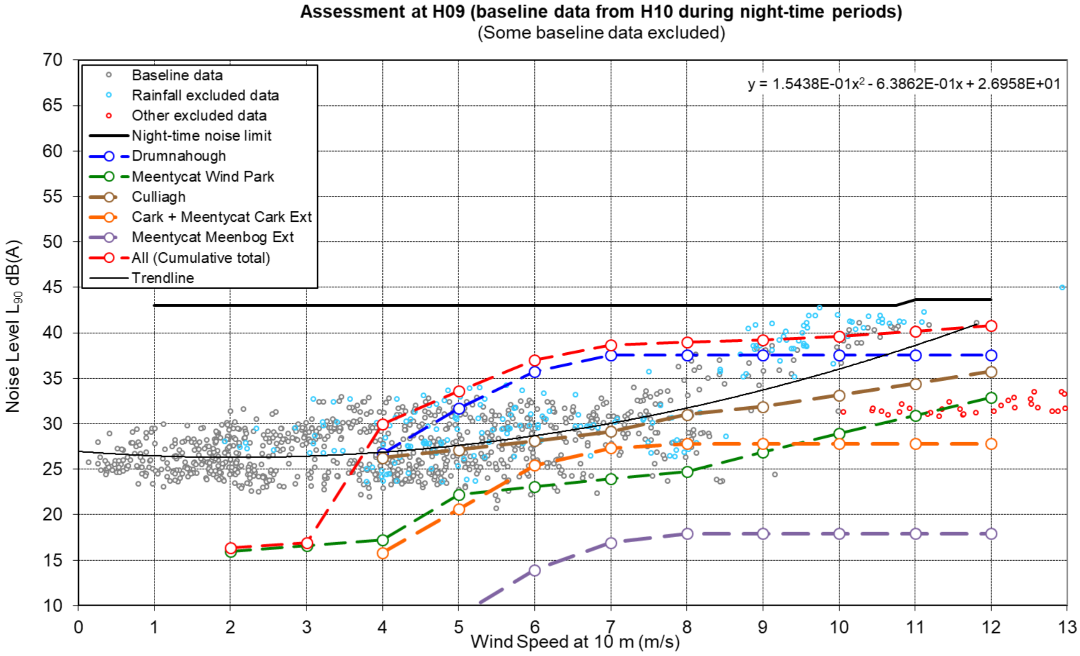


Figure E7 Chart of background noise levels against wind speeds, the best fit curve to the data, the derived noise limit curve for Property H02 during quiet day-time periods. Predicted immission noise levels are also shown for the proposed development, the other wind farms considered and the cumulative total.

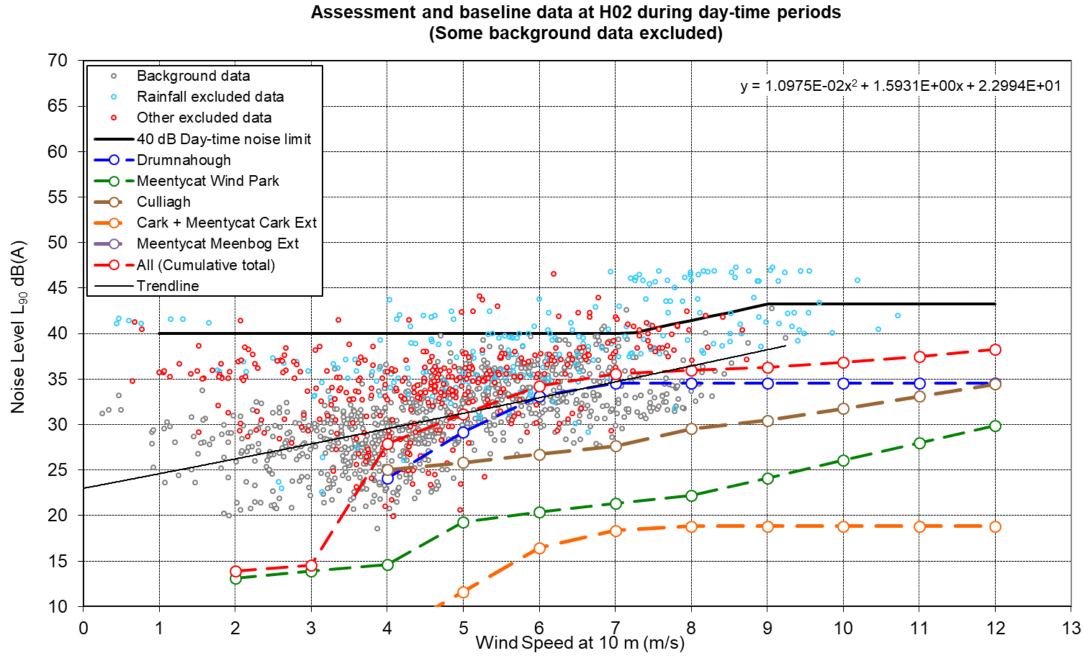
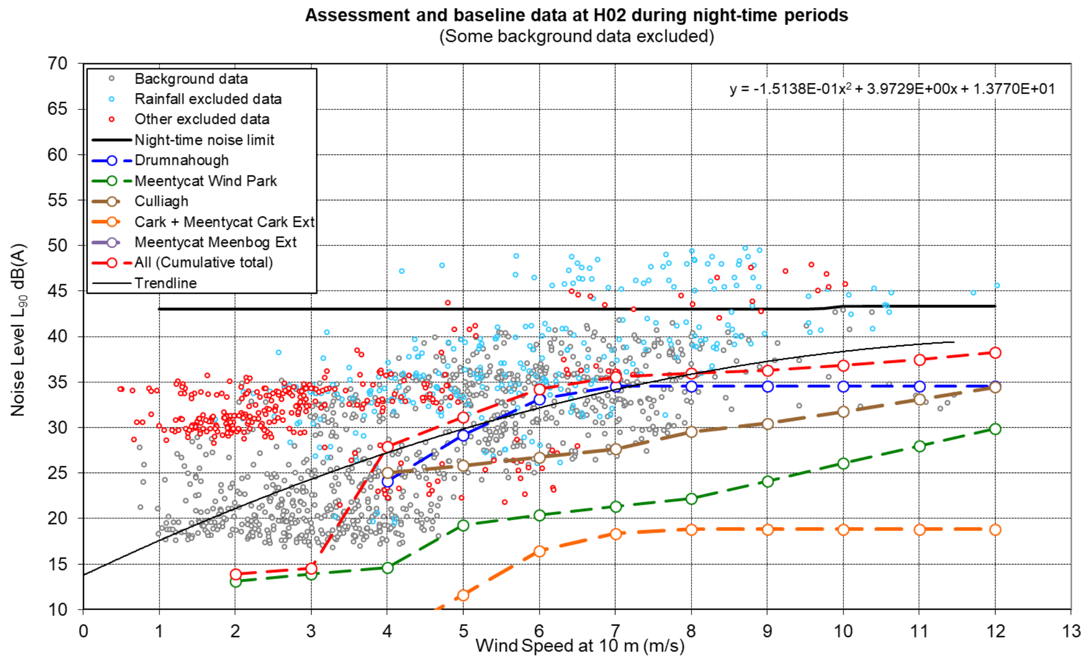


Figure E8 Chart of background noise levels against wind speeds, the best fit curve to the data, the derived noise limit curve for Property H02 during night-time periods. Predicted immission noise levels are also shown for the proposed development, the other wind farms considered and the cumulative total.



Annex F – Wind Speed Calculations

F.1 An important consideration when specifying the sound power outputs of wind turbines is the fact that wind speed varies with height above the ground. This effect is commonly termed 'wind shear'. Therefore, if the wind speed on a site is characterised in terms of, say, the wind speed measured at ten metres above ground level, then some means must be available for converting this ten-metre height wind speed to whatever the hub height of the proposed turbine will be. This is important because it is this hub height wind speed (i.e. the wind speed seen by the rotor of the wind turbine) that determines the actual sound power radiated by that turbine.

F.2 The example of a ten-metre height wind speed is selected here because this height is frequently adopted as a 'reference'. For example, in ETSU-R-97 [1] the wind speed dependent background noise levels are specified as a function of ten metre height site wind speeds. Likewise, the declared sound power data measured in accordance with the internationally adopted standard for the measurement of wind turbine sound power output, IEC61400-11 [2], is also referenced to a ten-metre height wind speed.

F.3 The ground roughness length, z, indicates the degree to which wind is slowed down by friction as it passes close to the ground: the rougher the ground, the more the wind is slowed down and the larger the roughness length. Table 11 of ETSU-R-97 gives examples of roughness lengths, as repeated here in Table F.1. Figure F.1 shows the wind speed profiles corresponding to the four ground roughness lengths given in Table F1.

F.4 However, it has been found from measurements that the influence of the ground may not be the only factor affecting the variation of wind speed as a function of height above the ground. Another key factor can be the amount of turbulence in the atmosphere itself.

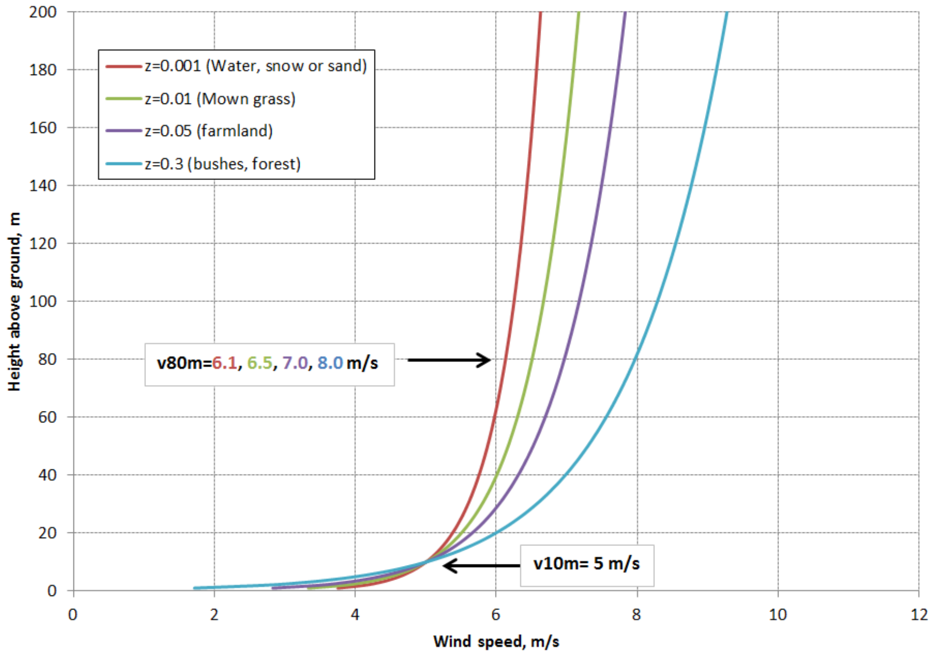
F.5 Generally speaking, under a typical day-time meteorological scenario, the atmosphere lying above the ground will exhibit what is termed 'neutral' characteristics. In such cases the atmosphere itself has little effect on the wind speed profile which is then controlled primarily by ground roughness. However, under certain conditions, typically on a summer's evening following a warm day, the radiative effects of the ground can cool the air lying close to the earth at a rate faster than the convective cooling of the air lying above. This can result in a highly stable atmosphere, one of the characteristics of which is a pronounced wind shear effect. This means that the relative difference between the wind speed at ten metres height and that at hub height during affected evening/night-time periods may be significantly greater than the difference which typically exists during day-time periods or other 'neutral' conditions.

Table F1 Table 11 of ETSU-R-97 showing the typical roughness lengths associated with different terrain types

Type of Terrain	Roughness Length, z (metres)
Water, snow or sand surfaces	0.0001
Open, flat land, mown grass, bare soil	0.01
Farmland with some vegetation (reference)	0.05
Suburbs, towns, forests, many trees and bushes	0.3

F.6 When undertaking noise certification measurements of wind turbine sound power outputs, the relevant procedure applies a standard means of converting between hub height and ten metres height wind speeds. This involves using a 'standard' roughness length of 0.05 metres in Equation F1, regardless of what the actual roughness length seen on the test site may have been. This 'normalisation' procedure is adopted to ensure direct comparability between test results for different turbines. However, when this standardised data is subsequently used to calculate the sound power radiated from an installed turbine on an actual wind farm site, it is important to convert between ten metres height wind speeds and hub height wind speeds using the actual wind speed differences experienced on the site itself. These hub height wind speeds may well be different from those calculated by assuming the standard 0.05 metres ground roughness length.

Figure F1 Wind speed profiles calculated for the four different ground roughness lengths listed in Table F.1. The figure adopts a fixed wind speed at ten metres height of v_{10}=5 ms^{-1} then presents the calculated wind speeds at other heights as the curved lines. The calculated wind speeds at 80 metres height corresponding to the assumed U10=5 ms^{-1} are also presented as numerical values, ranging from U80=6.1 ms^{-1} for a ground roughness length of z=0.001 metres to U80=8.0 ms^{-1} for ground roughness length of z=0.3 metres.



F.7 The relevance of this conversion between wind speeds at ten metres height and wind speeds at hub height has come under increasing scrutiny with the acknowledgement that, on some sites, the wind shear (i.e. the increase in wind speed with increasing height above ground level) can vary significantly between day-time and evening/night-time periods. This difference occurs for the reasons discussed above concerning the radiative cooling effects of the earth on the lower levels of air. When this effect occurs, the wind speed seen by the turbine blades at night can be significantly higher than that derived using either a 'standard' assumed roughness length based on the characteristics of the general terrain, or from using on a roughness length or shear factor based on longer term averaged measurements of the difference in wind speeds measured at two different heights. This issue, and the manner in which it has been accounted for in the case of the proposed development, is discussed in the following section.

Approach

F.8 The site of the proposed development has a temporary LIDAR remote sensing measuring system installed which measured wind conditions at various heights as follows:

- 40 metre Wind speed
- 40 metre Wind direction
- 50 metre Wind speed
- 50 metre Wind direction
- 60 metre Wind speed
- 60 metre Wind direction
- 70 metre Wind speed
- 70 metre Wind direction
- 80 metre Wind speed
- 80 metre Wind direction
- 90 metre Wind speed

- 90 metre Wind direction
- 100 metre Wind speed
- 100 metre Wind direction
- 110 metre Wind speed
- 110 metre Wind direction
- 120 metre Wind speed
- 120 metre Wind direction
- 130 metre Wind speed
- 130 metre Wind direction
- 140 metre Wind speed
- 140 metre Wind direction
- 150 metre Wind speed
- 150 metre Wind direction

F.9 Wind speeds are needed at a height of ten metres for correlation with measured noise data as specified in ETSU-R-97. ETSU-R-97 also requires the noise assessment be performed with a wind speed maximum of no more than 12 m/s at ten metres height. Whilst it would be possible to use the direct measurement of wind speeds at a height of ten metres, this approach has been questioned due to potential differences in the wind shear profile during the evenings and night-times when compared to the day-time. In accordance with the preferred methodology set out in the Institute of Acoustic Bulletin Good Practice Guide [3], all ten metre wind speed data is calculated from those which will be directly experienced by the wind turbines. Wind speeds are therefore related directly to those at hub height and calculated to be at ten metres height assuming reference conditions. Reference conditions are those used when reporting the measured and/or warranted sound power levels of the wind turbines and assume a ground roughness length of 0.05 metre. The process used to calculate the ten metres height wind speeds is therefore described below.

Methodology

F.10 ETSU-R-97 specifies that where measurements are not made using a ten-metre met mast, measurements at other heights may be used to provide ten metre height wind speeds by calculation. Equation F1 is given in ETSU-R-97 for this purpose.

$$U_1 = U_2 \cdot \frac{\ln\left(H_1 / z\right)}{\ln\left(H_2 / z\right)}$$

[F1]

Where:

H_1	The height of the wind speed to be calculated (10 metres)
H_2	The height of the measured wind speed
U_1	The wind speed to be calculated
U_2	The measured wind speed
z	The roughness length (0.05 metres in the case of reference conditions)

F.11 Equation F1 is of the same form as that given in BS EN 61400 11:2003 [2] for calculating ten metre wind speeds related to hub height wind speeds when providing source noise emission data for wind turbines. ETSU-R-97 suggests that the roughness length may be calculated from wind speed measurements at two heights, by inverting equation F1. Alternatively, wind shear can be described by the wind shear exponent according to equation F2 as follows:

$$U = U_{ref} \cdot \left[\frac{H}{H_{ref}}\right]^m$$

[F2]

Where:

U	calculated wind speed.
U_{ref}	measured wind speed
H	height at which the wind speed will be calculated
H_{ref}	height at which the wind speed is measured
m	shear exponent

F.12 In this case as well, the wind shear exponent may be calculated from wind speed measurements at two heights, by inverting equation F2.

F.13 Data from the LIDAR were available for the duration of the survey. These data were used to perform a calculation of the shear exponent found between the two wind speed measurements of 90 and 100 metres for every ten-minute period. Where wind speeds were the same at both heights or lower at greater height, the shear exponent was assumed to be zero. The shear exponents calculated for every ten-minute period were then used to calculate the hub height wind speed from that measured at 95 metres using equation F2. Equation F1 was then used to calculate a ten-metre height wind speed from the hub height wind speed every ten minutes assuming the reference roughness length of 0.05 metres.

Conclusions

F.14 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 ten metre wind speed data.

F.15 The method used to calculate ten metre wind speeds from those at hub height is the same as that used when deriving noise emission data for the turbines. Because the same method has been used, direct comparison of background noise levels, noise limits and predicted turbine noise immission levels may be undertaken. This method is consistent with guidance published in the Institute of Acoustic Bulletin Good Practice Guide [3].

References for Wind Speed Calculations

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

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

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

Annex G – Proposed Noise Planning Condition Wording

The rating level of noise immissions from the combined effects of the wind turbines hereby permitted (including the application of any tonal penalty), when determined in accordance with the guidance in ETSU-R-97 and the UK Institute of Acoustics Good Practice Guide, shall not exceed the values for the relevant integer wind speed set out in or derived from the Tables attached to this condition at any dwelling which lawfully exists or has planning permission at the date of this permission. Upon receipt of a written request from Donegal County Council, following a valid complaint to it alleging noise disturbance at a dwelling, the wind farm operator shall, at its expense, employ an independent acoustic consultant to assess the level of noise immissions from the wind farm at the complainant's property.

Table 1- Specific Day-time $L_{A90,T}$ Noise Limits for the Drumnahough Wind Farm in isolation

Property	Easting	Northing	Standardised 10 m Wind Speed (m/s)								
			4	5	6	7	8	9	10	11	12
H01	206271	408262	39.0	39.0	39.0	39.0	40.4	42.2	42.2	42.2	42.2
H02	205126	408294	39.1	39.1	39.1	39.1	40.6	42.3	42.3	42.3	42.3
H03	205058	407957	39.5	39.5	39.5	39.5	40.9	42.8	44.8	47.1	49.5
H04	204782	407792	39.5	39.5	39.5	39.5	40.8	42.8	44.8	47.1	49.5
H05	204724	407758	39.5	39.5	39.5	39.5	40.8	42.8	44.8	47.1	49.5
H06	203444	406750	40.0	40.0	40.0	40.0	40.1	43.1	46.5	50.1	50.1
H07	203217	406627	40.0	40.0	40.0	40.0	40.1	43.1	46.5	50.1	50.1
H08	202245	404662	39.2	39.2	39.2	39.2	39.2	39.2	41.3	44.1	47.2
H09	203062	404519	38.6	38.6	38.6	38.6	38.6	38.6	40.8	43.6	46.6
H10	202732	404181	39.4	39.4	39.4	39.4	39.4	39.4	41.6	44.4	47.4

Table 2 – Specific Night-time $L_{A90,T}$ Noise Limits for the Drumnahough Wind Farm in isolation

Property	Easting	Northing	Standardised 10 m Wind Speed (m/s)								
			4	5	6	7	8	9	10	11	12
H01	206271	408262	42.0	42.0	42.0	42.0	42.0	42.0	42.4	42.4	42.4
H02	205126	408294	42.1	42.1	42.1	42.1	42.1	42.1	42.5	42.5	42.5
H03	205058	407957	42.4	42.4	42.4	42.4	42.4	42.4	42.7	43.8	44.8
H04	204782	407792	42.4	42.4	42.4	42.4	42.4	42.4	42.7	43.8	44.8
H05	204724	407758	42.4	42.4	42.4	42.4	42.4	42.4	42.7	43.8	44.8
H06	203444	406750	43.0	43.0	43.0	43.0	43.0	43.9	48.4	53.4	58.9
H07	203217	406627	43.0	43.0	43.0	43.0	43.0	43.9	48.4	53.4	58.9
H08	202245	404662	42.1	42.1	42.1	42.1	42.1	42.1	42.1	42.7	42.7
H09	203062	404519	41.6	41.6	41.6	41.6	41.6	41.6	41.6	42.2	42.2
H10	202732	404181	42.4	42.4	42.4	42.4	42.4	42.4	42.4	43.0	43.0

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