Jennifer Sherry

From:	procbordemail
Sent:	Tuesday 30 January 2018 12:01
To:	Jennifer Sherry
Subject:	FW: Email 3 of 3 - Your ref: PL 04.248152 (244439) PA Reg Ref: 14/557 & Your ref: PL 04.248153 (245824) PA Reg Ref: 14/6760
Attachments:	i) DB09-Acoustics Bulletin November-December 2017.pdf; j) DB10-2015 Programme v4.xls.pdf; k) DB11-R243630 Ardglass Inspectors Report.pdf; l) DB12-Marshall Day Report.pdf; m) ETSU-R-97.pdf

From: Bord
Sent: Tuesday 30 January 2018 09:26
To: procbordemail <procbordemail@pleanala.ie>
Subject: FW: Email 3 of 3 - Your ref: PL 04.248152 (244439) PA Reg Ref: 14/557 & Your ref: PL 04.248153 (245824) PA Reg Ref: 14/6760

From: Joe Noonan [mailto:jnoonan@nlcc.ie]
Sent: Monday 29 January 2018 16:49
To: Bord <bord@pleanala.ie>
Cc: Pippa Willows - Legal Secretary, Noonan Linehan Carroll Coffey <pippawillows@nlcc.ie>
Subject: Email 3 of 3 - Your ref: PL 04.248152 (244439) PA Reg Ref: 14/557 & Your ref: PL 04.248153 (245824) PA Reg Ref: 14/6760

Noonan Linehan Carroll Coffey
SOLICITORS
www.nlcc.ie

TO: An Bord Pleanála

FROM:

Joe Noonan
NOONAN LINEHAN CARROLL COFFEY
Solicitors
54 North Main Street
Cork.
T12 WY2D

Tel 021 4270518 Fax 021 4274347
www.nlcc.ie

Cyber-crime warning: Please be aware of cyber-crime when dealing with the electronic transfer of funds. Please note that we will only give or accept bank account details in writing on paper. We will **never** ask you to give us your bank account details by email, fax or over the phone. We will **never** give you our bank account details by email, fax or over the phone. If you receive an email claiming to be from us which contradicts this policy, please do not act on it and please let us know immediately

[Evolve:61b27260-f28e-4f62-802a-72941a978040]

An Bord Pleanála

Inspector's Report

Proposed Development:

Permission is sought for a 10 year planning permission to construct a wind farm consisting of 11 no. turbines (each with a maximum tip height of 156.5m), a sub-station including 1no. control building and associated internal equipment, septic tank and percolation area, 3no. borrow pits, a meteorological mast, new internal access roads, upgrading of existing internal access roads, underground cables and ancillary works, all within the townlands of Peafield, Portavarrig, Oldcourt, Ballynona North, Walshtown More (West) and Ballyogaha West Midleton, Co.Cork

The application was accompanied by an Environmental Impact Statement and a Natura Impact Statement

Planning Application

Planning Authority:	Cork County Council
Planning Authority Reg. Ref.:	13/04959
Applicant:	Ardglass Windfarm Ltd.

Type of application:	Permission
Planning Authority Decision:	Refuse permission

Planning Appeal

Appellants:	Ardglass Windfarm Ltd.
Observers:	1. Ardglass Wind Turbine Action Awareness Group 2. Cork Renewable Energy Group 3. Castlelyons Development 4. Seamus & Breda Sexton 5. Don Sheehan 6. Dr. Sharon McKenna & Malachy Ward 7. Andrew Ennis & Susan Liddy 8. Sharon Guiry & Others 9. James & Anne Cagney 10. Christy O'Mahony 11. Ricky Galvin 12. Margaret Galvin

Type of appeal:	First Party against refusal
Site Inspection:	7th & 8th October, 2014
Inspector:	**A. Considine**

Table of Contents

1.0 THE SITE

1.1 The proposed development is for the construction of 11 no. wind turbines and associated ancillary works all in the townlands of Peafield, Portavarrig, Oldcourt, Ballynona North, Walshtown More (West) and Ballyogaha West Midleton, Co.Cork. The site is located approximately 3km to the north-east of Ballincurrig, 5km to the north west of Dungourney, 7.5km to the south east of Rathcormac and approximately 13km to south west of Tallow. Middleton is located approximately 9km to the south. The site of the identified study boundary appears to have been delineated by the existing road network in the vicinity of the proposed development site.

1.2 The elevation of the subject site, which can be considered in two sections with a local road dissecting the site, is identified at +220m OD in the northern area and 150m OD in the southern area of the site. The site is essentially bound by local and county roads along the western and eastern boundaries, with a further county road dissecting the site almost in the middle, running west to east. In addition, there is a further county road which affects the site at the south eastern area. The site boundaries of the proposed development follows the line of the access roads, the areas of the proposed turbines and the other essential work areas. Although the area is considered quite rural in nature, the Board will note that there is a population visibly present in clusters of houses along the access roads and in the vicinity of the site. There are a number of houses located within 1km of the proposed turbines. In addition, while the presence of the IDL Maturation Plant can be considered as reinforcing the presence of development and people in the proximity of the proposed development site, the Board will note that this development is not very prominent in the landscape from the public roads in the vicinity of the site.

1.3 The site has a stated area of 83.42ha, and the total footprint of the development will cover 6.25ha. The site covers land in the ownership of a number of different people. For the purposes of the EIS submitted, the study area extends beyond the site area and looks at an area covering 957ha, of which approximately 501ha is in the ownership of Coilte. From the information provided in the EIS, it is noted that three of the proposed wind turbines and the smallest borrow pit will be located in the northern area of the site with the remaining eight turbines, two larger borrow pits and permanent meteorological mast will be located to the south. The proposed substation will also be located towards the south of the overall site, in the vicinity of T1 and T2 and will be accessible from the lower county road at the south eastern area of the site directly. The proposed temporary compound to facilitate the proposed development is to be located along the county road which dissects the site centrally.

1.4 Much of the site is located within a heavily forested upland plateau area which is both open and exposed within a primarily lowlying rolling landscape. The River Bride is located to the north of the site and runs in a west to east direction. In addition to the River Bride, there are a number of smaller rivers and streams including the Dungourney and Kiltha Rivers affecting the area. Much of the subject site is forested and a stated area of 36.8ha will be required to be felled to accommodate the proposed turbines and associated tracks. The clearing will include a 30m corridor along all access roads and a 70m radius around each turbine.

2.0 PROPOSED DEVELOPMENT

2.1 The proposed development, as per the public notice, is described as follows:

Permission is sought for a 10 year planning permission to construct a wind farm consisting of 11 no. turbines (each with a maximum tip height of 156.5m), a sub-station including 1no. control building and associated internal equipment, septic tank and percolation area, 3no. borrow pits, a meteorological mast, new internal access roads, upgrading of existing internal access roads, underground cables and ancillary works, all within the townlands of Peafield, Portavarrig, Oldcourt, Ballynona North, Walshtown More (West) and Ballyogaha West Midleton, Co.Cork

The application was accompanied by an Environmental Impact Statement.

2.2 The proposed wind farm consists of eleven wind turbines of tip height up to 156.5 metres, a substation, a meteorological mast, three borrow pits, the construction of approximately 2.7 km of new site tracks and the upgrading of approximately 6.6 km of existing tracks and associated site development works. It is stated that the proposed turbines will be connected to the national grid at the Midleton 110kv substation at Carrigogna. The precise route of the of the underground grid connection has not as yet been determined.

2.3 6 of the proposed turbines will be located within the forested area while the remaining 5 will be located on open farmland. The turbines located to the south of the site are to be constructed around two hills where the elevations have been indicated at +210m and 217m OD respectfully. The smaller cluster of 3 turbines located to the north of the L7612 is located on lands where the elevations are indicated at +190m to 210m OD. The turbines are laid out in an irregular pattern with a minimum separation distance of 600 metres between turbines.

2.4 As part of the overall development, a substation and meteorlogical mast are also proposed. Both of these elements are to be located in the southern area of the overall site in the vicinity of T1, T2 and T3. Two of the proposed borrow pits are also to be located in this area while the third is to be located in the northern area of the overall site. The information provided indicates that the overall site area is comprised of parts of four landholdings. It is also indicated that the developers propose to set up a Community Investment Scheme to assist local community schemes subject to a number of criteria which include that projects being supported must be environmentally friendly, must promote energy efficiency and must benefit a large number of people and which beings the community closer to the wind farm. An initial €150,000 contribution is proposed with subsequent payments over 19 years of approximately €30,000 per annum.

3.0 ENVIRONMENTAL IMPACT STATEMENT

3.1 Legislative Context:

The proposed development falls within the scope of Part 2, Schedule 5 Development for the purposes of Part 10 (Environmental Impact Assessment) of the 2001, Planning & Development Regulations. As stated above, an Environmental Impact Statement was submitted with the planning application, and is presented in four volumes which includes appendices and photomontages. The EIS provides a non-technical summary, details of the environmental report including all environmental matters associated with the proposed development, and relevant appendices to the main statement. I have read this EIS in its entirety. The EIS provides a non-technical summary as well as a reasoning for the EIS, including its scope and the structure and methodology of same. The EIS submitted provides information in relation to a number environmental aspects and describes the potential affects the development will have on the receiving environment. It is also to be noted that the EIS is also advertised in the public notices pertaining to the development.

The following is a summary of the issues arising:

3.2 Volume 1 - Non-Technical Summary:

The EIS provides a Non-Technical Summary associated with the main EIS document. This NTS is presented in accordance with the legal requirements for the preparation of an EIS in that it clearly presents information relating to the development in clear and non-technical language. The project is described, as is the site selection process, the need and justification for the project, the methodology employed in the preparation of the EIS, consultations undertaken and alternatives, including sites, and design, considered. The NTS also provides an assessment of the environmental impacts associated with the relevant aspects of the environment.

3.3 Volume 2 - EIS:

3.3.1 The main body of the EIS submitted in support of the planning application consists of 15 chapters, which consider the potential impacts of the proposed wind farm on the receiving environment. The EIS submits that the construction phase of the project will be approximately 12 months and will generate jobs for up to 20 technical consultants, contractors and maintenances staff during the design construction and operation of the proposed wind farm. It is indicated that the wind farm will be part of the Gate 3 grid connection process and will utilise the capacity of the grid connection offer. The installed capacity of the wind farm will be +20MW, in order to satisfy the grid connection offer secured.

Each chapter of the EIS deals with a specific element of environmental impact as follows:

1. Introduction
2. Existing site setting
3. Description of development
4. Policy & legislation
5. EIS Scoping: The key issues
6. Ecology
7. Geology, Hydrogeology and slope stability
8. Hydrology and Water Quality
9. Landscape and Visual
10. Noise
11. Human Environment
12. Cultural Heritage
13. Telecommunications and Aviation
14. Air and Climate
15. Interaction of the Foregoing.

The following is a summary of the main impacts identified:

3.3.2 Ecology:

Chapter 6 of the EIS deals with Ecology and the information provided details the methodology employed in the preparation of this chapter. The EIS identifies seven designated sites within 10km of the site of which three are Natura 2000 sites. There are no designated sites identified within 3km. Fehily Timoney & Co. were commissioned to prepared an Appropriate Assessment Screening Report and this report is presented in Appendix D, Volume 3 of the EIS. The EIS notes that a number of organisations were consulted in the preparation of the Ecology chapter of the EIS. A habitat survey was undertaken, to include specific species and bird surveys, and a habitat map was prepared. The EIS provides a description of the receiving environment and provides an evaluation of ecological importance of the ecological features present on the site.

The EIS notes that the nearest pNHA is located approximately 6.1km to the south west of the study area being Ballynaclashy House which is identified as a nursery colony of the whiskered bat and is of national importance. Leamlara Wood, pNHA is located 6.3km also to the south west of the site and is identified for the presence of semi-natural oak woodland in east Cork. The nearest SAC is located 3.1km to the north of the site, being the Blackwater River, so designated for alluvial wet woodlands and Yew wood, both of which are priority habitats. There are a number of other Annex I habitats present in the SAC including floating river vegetation, estuaries, tidal mudflats, *Salicornia* mudflats, Atlantic salt meadows, Mediterranean salt meadows, perennial vegetation of stony banks and old Oak woodlands. This SAC supports a variety of Annex II species including Sea Lamprey, River Lamprey, Brook Lamprey, Freshwater Pearl Mussel, Crayfish, Twaite Shad, Atlantic Salmon, Otter and the Killarney Fern. The River Blackwater is also noted for its high conservation value for the populations of bird species. Cork Harbour SPA and Great Island Channel SAC and pNHA are located 9.1km to the south of the site, which are hydrologically linked to the subject site.

Screening for Appropriate Assessment was undertaken (appendix D of Volume 3 of the EIS). It is noted that the River Blackwater (Cork/Waterford) SAC, Site Code 002170, was not assessed within this report as it is upstream of the proposed development and is not within the likely zone of impact of the proposed wind farm. It was determined that a full AA was not required, due to the distance of the proposed development from Cork Harbour and the dilution effects of the marine environment. The AA Screening Report concludes that no significant impact on designated habitats is expected to occur. Details of habitat types and their associated values are provided for within the EIS, and in chapter 6.

The EIS also presents details of a mammal survey and a bat survey where the following protected species were recorded – fox, rabbit, Irish Hare, Fallow Deer, American Mink, Irish Stoat and red squirrel. The mammal survey also notes that it is possible that Otter may be present due to the proximity of the Dungourney River, but it is submitted that as the river is small in the vicinity of the site, it is unlikely to support breeding otters. In terms of bats, the Common Pipistrelle and the Soprano Pipistelle both of which are listed on the Annex IV of the EU Habitats Directive were found to be present on the site during the survey, but the EIS notes that activity levels were low.

The Birds Survey was carried out over the summer and winter periods, using on site surveys and counts. The survey concluded that the only Bird Watch Ireland amber listed species recorded on the site was the kestrel and it is concluded that it is unlikely that this species breed within or close by the subject site. The Red-Listed Yellowhammer and Golden Plover, also an Annex I species under the EU Birds Directive, were also noted on the site during the March vantage points watch in 2012. Overall it is concluded that due to the low biodiversity of the site, the limited range of flora and fauna and the habitats present being common, and the lack of evidence of breeding of protected bird species, the ecological value of the site is described as being of moderate local value.

The EIS describes the potential impacts associated with the proposed development in terms of the construction, operational and decommissioning phase, as well as providing a small assessment on the cumulative impacts associated with other developments in the area. Mitigation measures are considered. In terms of mitigation, Chapter 6 of the EIS refers the reader to the mitigation measures presented in chapters 7 and 8 and advises that with the implementation of mitigation measures, the proposed development adequately considers the ecological issues in its design and will therefore result in an overall neutral and imperceptible residual impact.

3.3.3 Geology, Hydrogeology and Slope Stability:

The EIS presents chapter 7 in order to provide information with regard to the environmental at the location of the proposed development works in terms of geology, hydrogeology and slope stability and seeks to describe same. The report discusses the potential impacts that the construction and operation of the proposed development may have on them and mitigation measures are proposed where necessary. The assessment was carried out through a desk top study, field visits and site investigations and extends to advising that the site walkover did not find any evidence of peat on the site. In this regard, it was concluded that a Peat Stability Assessment was unnecessary.

The EIS considers that the risk to ground waters is generally negligible and that surface water is the main sensitive receptor which is dealt with in chapter 8 of the EIS. The potential impacts associated with the proposed development in terms of ground water are considered in the document and the risk of pollution from hydrocarbon spills, leakages at borrow pits and from the waste water treatment system are identified as the primary risks. In terms of potential impacts associated with the proposed development, the EIS identifies the impacts associated with the construction and decommissioning activities at the site. Chapter 7 of the EIS concludes that submitted to mitigation measures, the construction, operation and decommissioning of the windfarm will have an negligible impact in terms of geology, hydrogeology and slope stability.

3.3.4 Hydrology & Water Quality:

Chapter 8 of the EIS describes the aspects of the hydrogeological environment that could be affected by the activities associated with the construction of the wind farm. An impact assessment was carried out to determine whether the project poses a significant impact to the hydrology and water qualtiy aspects of the environment, with mitigation measures proposed to reduce any potential negative impacts associated with the wind farm. The assessment describes the methodology employed for the impact assessment presented.

In terms of hydrology, the EIS identifies the prominent hydrological features, including all rivers and drainage features on and in the vicinity of the subject site, as well as providing information with regard to flooding events in the area. The chapter also discusses issues relating to the existing water quality and the Water Framework Directive (WFD). The EIS acknowledges that the water quality in the existing environment, and particularly the Dungourney River is considered to be mostly satisfactory with Good Ecological Quality, but poor quality further downstream in Middleton, with a Q value of 4.

Section 8.3 of the EIS deals with the proposed surface water management. The findings of the assessment suggest that there will be a negligible increase in impervious area as a result of the construction. The EIS notes that there are two existing watercourse crossings of significant tributaries on the site and the development will also require the provision of one new culvert. A small catchment is drained by rivulets above the rise of a tributary of the Dungourney River along the proposed access track between T1 and T2 and it is proposed to provide a series of 4no. 450mm diameter pipes to allow continuation of the natural flow regime in this area.

Potential risks are identified with regard to the construction, operational and decommissioning phases of the development, noting that the construction phase and decommissioning phases are likely to present the highest risk of impacts. Oil spills and increased runoff are identified as possible impacts arising from the operation of the wind farm. Mitigation measures are identified in section 8.5 of this chapter of the EIS. It is concluded that based on the measures identified to prevent the release of silt laden runoff from the site, a high degree of confidence can be assured in the mitigation measures proposed for hydrology and water quality and that any effects on the receiving environment will be of low significance.

3.3.5 Landscape & Visual:

The EIS presents a landscape and visual impact assessment report, in accordance with the various guidelines, in support of the proposed development. The assessment was carried out by MosArt Landscape Architects and Chapter 9 of the EIS provides details of the assessment methodology employed in the preparation of the Landscape and Visual Impact Assessment. The assessment was prepared using both a desk top study as well as site surveys and includes a number of photomontages. These photomontages are presented in Volume 4 of the submitted EIS. The landscape character of and in the vicinity of the identified study area is indicated, under the Draft Landscape Strategy for Cork, as a Landscape Type 10b: *Fissured Fertile Middleground (Rylane East to Waterford)*, with the following values:

Landscape Value:	Medium
Landscape Sensitivity:	High
Landscape Importance:	County

The Type 10b landscape is described as 'an elevated landscape which is fissured by fairly gentle slopes, with reasonably fertile agricultural land comprising a mosaic of small to medium sized fields with broadleaf hedgerows', and a landscape character that 'has characteristics of both flatter fertile farmland areas and the higher marginal hilly farmland'. The EIS notes that the medium value landscapes are defined as 'landscapes with positive characters and with local or county importance', whilst high sensitivity landscapes are considered to be 'vulnerable landscapes with the ability to accommodate limited development pressure. To the north of the site, the landscape is indicated as Landscape Character Type 6c – *Broad Fertile Lowlands.*

The EIS presents a Zone of Theoretical Visibility as part of the overall visual impact assessment, which represents the area over which the proposed development can theoretically be seen. The submitted ZTV represents the worst case scenario and the methodology employed in the assessment is described within Chapter 9 of the EIS. A ZTV map was prepared as part of the visual assessment and is identified as figure 9.4, using a radius of 20km.

In terms of the visual assessment presented, the EIS notes that the visual impact assessment, and associated photomontages, is based on a turbine with an overall height of 156.5m to blade tip, with a maximum hub of 100m with a rotor diameter of 113m. 17 no photomontages are provided as part of the EIS, Volume 4, and a written description is provided in relation to each. The identified 17 locations are indicated as being within 15.6km of the subject site. The EIS, considers the cumulative impact associated with the proposed development and existing features in the vicinity and concludes that 'given the highly visible nature of commercial wind energy developments, it is not generally feasible to screen them from view using on site measures'. The EIS states that 'the visual impact of the combined development is the same as the impact of the proposed wind farm on its own and there is no significant cumulative impact'.

Overall, it is consider that the significance of impact on the landscape is deemed to be moderate. In terms of visual impacts, it is concluded that the relative visual dominance of the scheme from each VRP is strongly related to viewing distance. From the majority of the VRPs, the magnitude of the visual impact is considered to be medium or low. In only two instances, the magnitude is deemed to be high. Overall, the EIS concludes that the although the study area is not currently a landscape characterised by the view of wind farms, it is not a landscape that is sensitive to such development or where this would be an unexpected feature. The impacts identified are considered to be acceptable and do not coincide with any particularly sensitive receptor.

3.3.6 Noise:

Chapter 10 of the EIS deals with noise and the EIS describes the methodology employed in the assessment of noise associated with the proposed development as is the potential impacts of noise. Vibration associated with wind farms is also discussed in this chapter. The existing noise environment was determined by means of a background noise survey at three identified noise sensitive locations where the ambient noise levels in the area were recorded. The three identified locations are within 1km of the turbines and represent 7 houses.

The EIS notes the operational compliance of the turbines with the daytime fixed limit of 45dB(A). Non-compliance with the night time limit of 43dB(A) is noted at three receivers with wind speeds of +6 to 7m/s, notably when the wind is from an easterly direction. The EIS concludes that the noise modelling used for the construction phase of the development shows that it is unlikely that the construction phase will cause significant nuisance. A number of mitigation measures are proposed to mitigate against the impact of noise in this phase. No vibration impact is expected from the operating turbines and no mitigation measures are considered necessary.

3.3.7 Human Environment:

Notwithstanding visual, landscape and noise impacts which are addressed in separate chapters, the EIS considers the potential impacts of the development on the human environment, which includes a consideration of mitigation measures, where they are deemed appropriate, in Chapter 11 of the EIS. The document describes the existing environment, identifying the main land uses within the study area as well as discussing the potential impacts on recreation and amenity, including tourism, associated with wind farms. In addition, the chapter provides details relating to socio economics, including property prices, material assets, roads and transport property values and the impacts of shadow flicker. A house survey carried out identified that there are 15 existing and permitted dwellings within the study boundary of the proposed wind farm with the closest house being 510m from the nearest turbine, T7.

Shadow flicker is a term used to describe the shadows cast by rotating blades of a wind turbine. The shadows cast are intermittent and results in a 'flicker' effect. The EIS submitted refers to the appropriate guidelines pertaining to shadow flicker, which provides that *shadow flicker at neighbouring dwellings within 500m should not exceed 30 hours per year or 30 minutes per day.* The EIS notes that there are no houses located within the 500m limit. The Shadow Flicker Assessment which was carried out identified 45 buildings within 10 rotor diameters (1,130m) of the proposed turbines. The results of the modelling notes that the DoEHLG total annual guideline limit of 30 hours is predicted to be exceeded at 22 locations assuming 100% sunshine. When 40% sunshine limit is applied, this figure is reduced to 3 locations, all of whom are contributing landowners participating in the proposed project. In terms of mitigation it is submitted that mitigation measures will be assessed and a procedure of evaluation of the existing screening, window orientation and the periods of shadow flicker actually occurring will be undertaken in consultation with any relevant land owner.

In terms of Material Assets, the EPA notes that material assets are *resources of intrinsic value which may be of either natural or human origin.* The EIS sets out issues associated with material assets in Chapter 11 and includes assets such as non renewable resources, renewable resources and utilities infrastructure. In light of the above, it is submitted that there will be potential impacts due to quarry and mine activities but notes that most of the material required by the development will be sourced within the site and that existing tracks are to be used. Due to the requirement to fell trees, there will be a negligible impact on this renewable forestry resource. It is submitted that the area felled will be replanted therefore, the overall impact on renewable resources will be neutral. With regard to utilities, it is submitted that the proposed development will contribute to the electricity network. There will be no impacts to the Bord Gais Transmission Pipeline and conditions requested by the company will be complied with.

In terms of roads & transport, the EIS notes the intended access route from Middleton. The purpose of this section of the EIS is to assess the traffic impact on the additional traffic movements that will be generated by the proposed wind farm development during both the construction and operational phases of the development. The EIS notes the requirements of the NRA document 'Guidelines for Traffic & Transport Assessments', and concludes that as the development will represent an annual increase of 3.9% over current traffic on the R626, ant that this is below the 10% NRA threshold, a Transport Assessment is not required.

The EIS deals only with the delivery of the turbines and it is estimated that during the construction phase a total of 40 trips will be made by employees, with a further 49 HGV trips. During operation, the wind farm will generate very little traffic movements. Mitigation measures are proposed as part of the EIS to include the preparation of a traffic management plan.

The EIS considers the likely effects of the proposed development on all aspects of the human environment, concluding that, following the temporary disturbances associated with the construction phase, for which there are mitigation measures proposed, it will have a small positive impact on both the socio economics associated with the construction of the wind farm together with the community benefit scheme proposed by the company, which will support local environmental improvement and recreational, social or community amenities and initiatives in the locality.

3.3.8 Cultural Heritage:

Chapter 12 of the submitted EIS seeks to address any potential issues arising in relation to the proposed development and impacts on the cultural heritage of the study area. An archaeological and cultural heritage impact assessment was undertaken as part of the EIS by Annette Quinn and Miriam Carroll of Tobar Archaeological Services. The assessment included both a desk top study and a field inspection of the proposed development area. The report details the legal framework and requirements regarding the protection of archaeological monuments and architectural heritage, and identifies the information sources employed in the desk top study of the site. The EIS identified 10 archaeological monuments within the study boundary all of which are Recorded Monuments, with an additional 80 monuments identified within 2km of the site. Of the 90 monuments identified, 37 no longer have above ground expression with a further 10 which are no longer accessible or visible in the landscape due to the forestry. No new archaeological monuments were discovered in the course of this assessment.

In terms of Architectural and Cultural Heritage, the EIS notes that there are no protected structures within the study area, and two within 2km of the site, both of which are thatched houses, refs RPS 80 and 773. One house is included in the NIAH, ref no. 20905406. This is a 19th C farm house located at Monalyre Cross Roads and at 670m from T3. There are a further 6 NIAH structures located in the wider area. A number of Cultural heritage features were identified in this assessment including a limekiln, four bridges, enclosed field and field boundaries and small 19thC settlements / farmsteads.

Mitigation measures have been considered in this chapter including the recommendations as follows:

- Pre development testing of T7 turbine base and other bases and hardstands on greenfield areas.
- Establishment of a 30m buffer zone around RMs CO054-142001 and 002
- Monitoring of all ground works to be carried out under licence.
- that the derelict stone house at Ballynona North be preserved in situ and avoided as part of the development.

In terms of the proposed development, the EIS acknowledges that archaeological remains may appear due to earth movements associated with the development. It is submitted that there will be potential impacts associated with the construction of T7 given the proximity of two fulachta fia, one being located within the boundary area associated with same. The

EIS submits that all construction works will be monitored under archaeological licence, and in consultation with the relevant authorities.

3.3.9 Telecommunications & Aviation:

Chapter 13 of the EIS deals with telecommunications and aviation. Potential impacts are described as possible electro-magnetic interference with radio navigation signals. Cork Airport is approximately 33km south west of the site. Given the distance, the IAA has confirmed that a radar assessment will not be required. In terms of impacts on telecommunications, interference can occur in two ways including signal scattering and signal obstruction. In terms of mitigation, a protocol has been prepared between RTE and the developer which sets out the developers obligation to correct any deterioration in television and radio signal reception. All IAA lighting requirements will be complied with. In conclusion, it is submitted that the proposed development will not have any negative impact on aviation subject to compliance with the stated IAA requirements. Compliance with the protocol will ensure that there will be no negative impact on TV or radio reception.

3.3.10 Air & Climate:

Chapter 14 of the submitted EIS deals with Air and Climate.

Air: The site is located within an Air Quality Zone D and the assumption is that air quality is good and any potential impact on air quality as a result of the proposed development will be confined to the construction phase. Wind farm developments have no direct air emissions. Data in terms of existing air quality is provided from the 2000 monitoring period in Blackpool, Cork City, 1997, Heatherton Park, 2002 all zone B and Glashaboy, 1995 and Cork Harbour 2007-2008 both zone D. It is submitted that the limits provided are likely to be significantly higher than those at the subject site. The main potential air pollutants are identified as site machinery, vehicle exhaust emissions and dust during construction. It is considered that the development is unlikely to significantly increase levels of air pollutants or cause a breach of the air quality standards.

Climate: In considering the potential impact of the development on climate, the EIS cites the necessity to develop alternative energy sources and that the burning of fossil fuels is a known contributor to global warning. It is submitted that the proposed development will result in the production of energy from a renewable source which, once fed to the national grid, has the potential to avoid several thousand tonnes of carbon dioxide being released to the atmosphere. It is concluded that the development will have a negligible indirect positive effect on the climate.

3.3.11 Interactions of the foregoing:

Chapter 15 of the EIS addresses the interaction of the previous environmental aspects in accordance with the requirements of Schedule 6 of the Planning & Development Regulations, 2001 as amended. The chapter considers the interactions by means of a matrix, Table 15.1. The EIS identifies two types of potential inter-relationships and interactions, being positive and negative, and considers the proposed development during both the construction and operational phases of the development. The environmental interactions are identified under the following headings:

			Const. phase	**Operational**
1.	Ecology	-	Tree felling Traffic Excavation Noise	Noise Visual Energy Output Drainage Traffic Change in land use
2.	Hydrology & Water Quality	-	Tree felling Traffic Excavation	Drainage Traffic Change in land use
3.	Geology & Hydrogeology	-	Tree felling Traffic Excavation	Drainage Geotechnical Change in land use
4.	Landscape	-	Tree felling Traffic Excavation Noise	Visual Change in land use

5.	Human Environment	-	**Const. phase** Tree felling Traffic Excavation Noise	**Operational** Noise Visual Energy Output Drainage Shadow Flicker Traffic Change in land use
6.	Archaeology & Cultural Heritage	-	**Const. phase** Tree felling Excavation	**Operational** Visual Change in land use
7.	Air & Climate	-	**Const. phase** Tree felling Traffic Excavation	**Operational** Energy Output Traffic Change in land use

3.4 Volume 3 - Appendices:

The EIS notes 10 no. appendices associated with the EIS and application. The detail of the appendices include as follows:

Appendix A: Consultation Correspondence
Appendix B: ESB Document on Turbine Transformers
Appendix C: Alternative Layouts
Appendix D: Ecology - Appropriate Assessment Screening Report
Appendix E: Geology & Hydrogeology
Appendix F: Hydrology
Appendix G: Noise
Appendix H: Human Environment
Appendix I: Cultural Heritage
Appendix J: Site Suitability Assessment

3.5 Volume 4 - Photomontages:

Volume 4 provides details of the visual impact assessment associated with the proposed development in the form of the photomontages.

4.0 REPORTS ON PLANNING FILE

4.1 The PAs report notes that two pre planning meetings were held between the Planning Authority personnel and representatives of the developers, in relation to this development.

4.2 There are 244 submissions noted on the planning file from third parties. I have read the content of all submissions. The issues raised in the objections are summarised as follows:

- Inadequacy of the submitted E.I.S., notably in relation to the consideration of alternative sites
- Unacceptable visual impact
- Noise implications
- Health implications
- Impacts on persons with existing medical conditions including Autism and Asperger's Syndrome
- Impact of shadow flicker on adjacent properties
- Lack of adequate pre planning consultations with the local community
- The site is not located in an area identified as being a Strategic Search Area in the Co. Development Plan 2009,
- Impact of the development on livestock and farming
- Safety implications of siting a wind farm in proximity to the permitted Midleton Distillery Maturation Plant and to a Bord Gas underground pipeline
- Impact of the development on property values in the area
- Impact on the ecology, amenity and tourism potential of the area
- Impact on the road network in the area
- Impact of the development on ground water.

4.3 Three submissions from elected representatives were received from the following:

- Cllr. Barbara Murray
- Cllr. Noel Collins &
- David Stanton. T.D

4.4 7 no. external reports were submitted to the Planning Authority in relation to the proposed development:

Felling Section, Forest Service, Department of Agriculture, Food and Marine: Report outlines information that should be included in an E.I.S in relation to wind farm development on forested land. The report notes that the developer must obtain a Felling Licence for the Department before trees are felled or removed.

An Taisce: Report states that an evaluation on ecological, amenity and landscape impact grounds is required.

Development Applications Unit, Department of Arts, Heritage and the Gaeltacht: Report notes no objection and recommends conditions be included should planning permission be granted.

Inland Fisheries Ireland: Report recommends that should permission be granted, include 3 no. conditions.

Bord Gas Networks: E-mail sent to CCC with accompanying documentation, advising no objection in principle to the proposed development subject to 1 no. condition being attached to any planning permission granted.

Health Service Executive: Report comments on seven issues related to the proposed development.

Health & Safety Authority: On the basis of the information provided, the Authority does not advise against the granting of permission in the context of Major Accident Hazard but notes that developments around Seveso establishments may have a potential impact on the future expansion of those establishments.

4.5 There are 6 no. reports noted from internal County Council Departments on the Planning Officers report from the following:

Road Design Officer: No comments or objections to make.

Area Engineer: Discusses issues relating to roads and surface water and provides for a number of conditions to be included in any grant of planning permission, including conditions relating to the repair of public roads.

Environment Section: Notes no objection to the proposed development, subject to compliance with 8 conditions.

Subsequent report dated 8/7/13 recommends that additional information be sought from the developers in relation to 10 issues relating to noise implications of the proposed development.

Ecologist: The report from the CCC Ecologist considers that there is insufficient information to complete Habitats Directive Assessment or to complete an assessment of impacts of the proposed development on the ecology of the proposed development site. The report concludes that additional ecological information and surveys are required under 7 headings.

Archaeologist: The report considers the proposed development in terms of the County Development Plan and the policy requirements contained therein. The report considers the direct and indirect impacts, architecture and cultural heritage and concludes that while there will be some indirect visual impacts associated with the proposed development, overall, there is no objection to the proposed development, subject to compliance with 3 conditions.

O'Callaghan and Moran Consultants (OMC): A report was prepared on behalf of Cork Co Council by OMC to address the geological, hydrogeological, hydrological and slope stability implications of the proposed development. This report, dated 1/7/13 considers the proposed development under the following headings:

- Geotechnical stability
- Borrow pits
- Dewatering
- Noise
- Mitigation measures

The report concludes by recommending that additional information be sought.

4.6 The Planning Authority considered the proposed development together with the information submitted in support of the proposal against the requirements of the County Development Plan and National Policy pertaining to Wind energy projects. The Senior Executive Planning Officers report also had regard to the many submissions made in relation to the proposed development as well as reports received from internal departments with the Planning Authority and from prescribed bodies. A number of concerns were raised in the report regarding the proposed development and potential impacts on the receiving landscape were raised. In addition, issues were considered in terms of hydrology, hydrogeology, geology and slope stability, ecology, shadow flicker, archaeological impacts, fire safety, turbine failure stability, cumulative impacts in relation to the permitted IDL Maturation Plant, noise, traffic and road safety issues and the consideration of alternative sites. The report concludes that there are a number of issues arising in relation to the proposed development and that further information is required.

4.7 Further information was sought in relation to 29 stated items.

4.8 A request from the developers sought an additional period of time in order to fully reply to the FI request. Three months was granted by the PA. A substantial response to the further information request was submitted to the PA on the 22nd April, 2014. The response deals with each issue raised in the FI request and provides for a number of appendices. On the 30th April, 2014, the development was re-advertised in local press. The response dealt with each item under nine headings with the response summarised as follows:

- Economics:
  The proposal is to install 11 no. 2.3MW turbines with the maximum potential power generation of 25.3MW. The developer has a grid connection offer of 21.6MW, but as the Commissioner of Energy Regulation allows the installation of up to 120% of the maximum export capacity, of the grid offer, which would be 25.92MW, the proposal is acceptable.

  The proposed development could provide sufficient electricity to power over 11,645 homes, contributing to the significant demand in Co. Cork.

  The wind farm could potentially avoid over 28,560 tonnes of CO_2 per year, and over 714,000 tonnes over the lifetime of the wind farm. The power output per year is estimated to be approximately 58,411 MWh per year and in terms of the tonne of oil equivalent (TOE), the development would avoid over 5,000 toe per year, or 125,000 toe over the lifetime of the project.

- Alternative Locations:
  Appendix B of the response provides the response to this issue, prepared by McCarthy Keville O'Sullivan, Planning & Environmental Consultants. The document presents the existing planning policy context and in terms of justification for the subject site, it is submitted that the areas identified Strategic Search Areas in the vicinity, they are fragmented and generally much smaller in nature than those identified within the other three SSA groupings. Due to the limited size and fragmented nature and local constraints, the SSA areas in this location limit the viability to provide for a significant wind farm development.

  A robust site selection process is demonstrated in the submission and notes the Draft Cork County Development Plan, 2013, noting that the subject site is entirely located within an area which is Open to Consideration.

  The site selection process was led by a detailed review of all relevant project constraints and facilitators from the outset as follows:

  > Proximity to grid: Having regard to the node assignment and grid offer at Carrigogna sub-station, potential sites were focused within 15km of the node connection point. The total land area amounts to 70,500 ha which represents a significant initial search area.
  >
  > Wind farm format: Several wind farm formats were considered and using a single site to accommodate the required grid capacity was deemed to consolidate the visual extent of the turbines and would be preferable to providing a number of smaller wind farms at various locations.

  Three areas in this area of Co. Cork were considered in terms of alternative locations for the wind farm and these are presented in Figure 2.1 of the FI response. The response provides for an analysis of each of these alternative sites considered. The report concludes that while the site selection process identified the subject site as the optimal location for the development, the development, if permitted, will not preclude or compromise the other wind energy developments within any of the other areas identified in the Strategic Search Area in the County Development Plan.

- Cumulative Impact:
  The response to the FI request considers that the proposed wind farm will contribute to an increased intensity of build development in combination with the maturation warehouse development. The character of this landscape has been that of a low intensity upland rural landscape with some remoteness and tranquillity. This is changing slightly towards a landscape of rural industry as a result of the distillery buildings. The wind farm will contribute to this change but is more typical of emerging trends in upland rural landscape than the distillery is. As the distillery is highly screened by conifer plantations from all directions except the south, there is little potential for significant cumulative visual impacts to occur.

- Visual Impact:
  A revised Zone of Theoretical Visibility at a scale of 1:50,000, as well as photomontages were submitted as requested in items 4 and 5 of the FI request. In terms of item 6 of the FI request, 6 additional photomontages were submitted and described.

- Borrow Pit:
  In response to item 7 of the FI request, the applicant refers to the content of the EIS and the findings of the trial pits that were undertaken on the site in August 2012.

  In response to item 8, which requested a materials balance calculation to confirm that the borrow pits as proposed are required and where the excess materials to reinstate them will be sourced, the applicant advises that the three borrow pits have a maximum potential excavation volume of 41,400m^3. The estimated volume of material to be excavated to facilitate the proposed development is approximately 29,900m^3. There will be no need to source surplus material to reinstate the borrow pits.

  Item 9 if the FI request sought an assessment of the need to dewater the borrow pit, and if required, an assessment of the impact on the surface water drainage system and / or associated flood risk. In response, the applicant submits that the trial pits encountered groundwater seepage within two of the three borrow pits locations at depths of 2.3m and 2.5m at borrow pits 1 and 3 respectively. Preliminary indications suggest that some drainage may be required during excavations, including pumping. Large scale dewatering is unlikely. A more detailed assessment of the need for dewatering will be made as part of the detailed design stage.

Item 29 of the FI request sought a detailed investigation to determine the suitability and availability of site stone material for the site access roads and hard standing. The response notes that the testing of materials will require rotary core drilling and associated lab testing which will be undertaken at detailed design stage. The existing tracks at the site were constructed using materials excavated on site.

- CEMP:
  An outline Construction and Environmental Management Plan has been prepared and is included in appendix I of the response to the FI request. It is submitted that this plan will be further developed by the contractor at the construction stage of the development.

- Deforestation:
  In terms of proposed replanting the applicant submits that a felling licence application will be made to the Forestry Service and under such licence, there will be a requirement to replant on other lands to compensate. A felling licence much be accompanied by a grant of planning permission and therefore follows once the planning process is complete.

- Noise:
  Items 12 to 21 for the further information request dealt with noise. The response to these issues are presented in the FI response document and appendix J which comprises a very comprehensive report from AWN Consulting. This report notes the issuing of a new document from the Institute of Acoustics (IoA), *"Institute of Acoustics Good Practice Guide to the Application of ETSU-R-97 for the Assessment and Rating of Wind Turbine Noise"*, (May 2013), and advises that the noise assessment presented in the EIS has been revised to reflect this

current best practice in terms of noise predictions, etc.

- Ecology:
  Items 22 to 27 of the further information request dealt with issues of ecology. The response notes that further surveys were carried out in order to address the issues raised by the PA. The results of the survey recorded an additional six avian species, which included the Sparrowhawk which is an amber listed species. A peregrine falcon was recorded offsite in December, 2013 during the winter vantage point surveys, as was the Lesser Black-bearded Gull. The Golden Plover appears to remain the most active red listed and Annex I species using the site with significant activity noted to the south of the site and in the western area of the application site. The report submits that overwintering birds may be subject to temporary disturbance during the construction phase of the project, but that the impacts will not be significant due to the widespread availability of suitable alternative habitat in the wider area. No hen harrier was observed at the site.

  A revised AA report has been prepared to address the issues raised in the FI request and a comprehensive habitat map is provided. A further Bat survey was carried out in September, 2013 where higher levels of activity were recorded. The Common Pipistrelle and the Soprano Pipistrelle were recorded but no roosts were found within the EIA study area. Mitigation measures are proposed to minimise bat collision. The removal of small areas of hedgerow and treelines will lead to a loss of foraging habitat for bats, but it is submitted that the removal will be on a small scale and the impact is not considered to be significant. Additional planting will compensate for the removal of habitats within the development footprint.

  The Annex I habitat, *Marsh Fritillary* was not recorded at the site.

4.9 Following receipt of the response to the further information request, there were a further 210 submissions noted on the planning file from third parties. I have read the content of all submissions. The issues raised in the objections are summarised as follows:

- The response to the issues raised in FI has not allayed concerns.
- Unacceptable visual impact

- Noise implications
- Health implications
- Impact of shadow flicker
- Lack of adequate pre planning consultations with the local community
- The site is not located in an area identified as being a Strategic Search Area in the Co. Development Plan 2009,
- Impact of the development on livestock and farming
- Safety implications of siting a wind farm in proximity to the permitted Midleton Distillery Maturation Plant and to a Bord Gas underground pipeline
- Impact of the development on property values in the area
- Impact on the ecology, amenity and tourism potential of the area
- Impact on the road network in the area
- Impact of the development on ground water.

4.10 Following receipt of the response to the further information request, there was a further submission from Cllr. Noel Collins.

4.11 Following receipt of the response to the further information request, there were a further 4 no. external reports were submitted to the Planning Authority in relation to the proposed development:

Geological Survey of Ireland: the submission details the available online information. It further requests that data collected during the EIA would be welcome as well as a copy of reports detailing any site investigations carried out.

Bord Gas Networks: No further comments to make.
Waterford County Council: Advises that details have been referred to the Senior Planner. A further submission advises that it is noted that the development will have a considerable zone of theoretic visibility extending as far as the Banks of the River Blackwater at Tallowbridge and to the south west of Lismore. On balance, there is no objection to the proposed development.

Inland Fisheries Ireland: Report requests that the original comments made be given full consideration. The report adds that specifically in relation to the crossing of spur road to T7, the IFI should be consulted in relation to the design and construction of this crossing point.

4.12 Following receipt of the response to the further information request, there were a further 4 no. reports noted from internal County Council Departments on the Planning Officers report from the following:

Area Engineer: No objection subject to compliance with 5 conditions. Second report seeks the inclusion of a condition requiring a development contribution of €23,000.

Environment Section: Following the consideration of the response to the further information request, the report concludes that clarification is required in relation to a number of matters before a decision issues. The final conclusion however is that the development should be refused for the following reason:

'It has not been demonstrated on the basis of the information submitted that the proposed development and operation thereof, would not, by reasons of noise and nuisance, injure the amenities of noise sensitive locations in the vicinity.'

Ecologist: The second report from the CCC Ecologist following receipt of the response to the further information request notes that concern remains with regard to a number issues and it is recommended that planning permission be refused on the basis that the information provided does not facilitate the PA to complete EIA and Screening for AA. Issues relate to the management of surface waters, impacts on species of birds of high conservation value and impacts on bats.

4.13 The SEP prepared a report following the submission of the response to the Planning Authority's further information request and deals with each issue in turn. The report concludes that, in accordance with the requirements of the CDP, the local visual impacts are an important consideration in the assessment of new proposed wind energy projects. In addition, the Draft CDP, 2013 is cited whereby the emerging policy includes an assessment in areas 'open for consideration' of residential amenity in relation to noise, shadow flicker and visual impact and can avoid adverse impacts on visual quality of the landscape and the degree to which impacts are highly visible over wider areas. In this regard, the consideration of visual impact is also considered in relation to residential amenity. The report concludes that the scale of the proposed windfarm development is not justified at this location. In addition to the visual impact, it is considered that the development, if permitted, will set a precedent for further wind farm developments of this scale in the area. It is recommended that permission be refused for the proposed development.

4.14 The Senior Planner also prepared a report in relation to the proposed development and noted the other reports from the Senior Executive Planner, third party submissions and other reports prepared in relation to the development. The report notes that key outstanding issues relate to the following:

1. Ecology (including AA)
2. Noise
3. Hydrology / hydrogeology
4. Visual impacts
5. Cumulative impacts

The report considers that, while a number of the issues raised might be dealt with by way of condition, when taken together, it has not been demonstrated that the development is acceptable in relation to environmental impacts. In terms EIA, it is noted that while the EIS is acceptable in relation to the scope of issues addressed, it is concluded that it has not been shown that the proposal would not have a significant negative impact on the environment. It is considered that the potential impacts on relevant sites have been screened out and therefore AA screening cannot be completed. The report concurs with the SEP that there are issues in relation to the visual impacts associated with the proposed development. The SP considers that the proposal is acceptable in overall visual terms. The critical visual impact relates to a number of houses in the vicinity of the site where the development as proposed will have an unduly negative impact on residential amenity, the possible mitigation of which cannot be dealt with by condition.

The report concludes as follows:

- The submitted documentation is unsatisfactory by reference to ecological, noise and hydrogeological impacts;

- The EIS is not satisfactory in this regard and it has not been shown that the proposal would not have a significant negative impact on the Environment;
- It is not considered that the potential impacts on relevant sites have been screened out and therefore AA screening cannot be completed;
- The proposal is acceptable in terms of overall visual impacts including impacts on scenic route. There are localised visual impacts which is considered will have localised negative impacts in terms of residential / visual amenity.

Refusal is recommended for two reasons.

5.0 DECISION OF THE PLANNING AUTHORITY

The Planning Authority refused planning permission for the proposed development for the following 2 no. reasons:

1 Having regard to the submissions made in connection with the application by reference to ecological, noise and hydrological/hydrogeological impacts (which is considered deficient) the planning authority are not satisfied that the proposed development would not have a significant and adverse impact on the amenities and environment of the area including significant adverse impacts on:

- noise sensitive locations in the vicinity,
- water quality and hydrology/hydrogeology of area, and,
- ecology of the area including protected species and sites.

The proposed development would therefore be contrary to the provisions of The Wind Energy Guidelines for Planning Authorities issued by the DoEHLG in June 2006 and would be contrary to the proper planning and development of the area.

2 Having regard to the number of residential properties in the vicinity of the site and notwithstanding the proposed mitigation measures contained in the submitted Environmental Impact Assessment and noting the deficiencies in submitted noise assessment it is

considered that the proposed development would adversely impact upon the existing residential amenities of a number of houses in the vicinity by reason of visual intrusion and noise. The proposed development would therefore be contrary to the proper planning and sustainable development of the area.

6.0 RELEVANT PLANNING HISTORY

6.1 There is no specific planning history associated with the subject site with regard to a wind energy project.

6.2 IDL Maturation Plant located 400m to the south of the subject site:
PA ref 10/8481: Permission was granted for the development of warehousing at the IDL Maturation Plant consisting of 40 warehouse structures (bulk flammable storage) each with a floor area of 1600 sq metres and a height of 11.5 metres was permitted on a 36.6 hectare site under planning permission 10/8481 and is currently under construction. The Board will note that there is a submission to the current application / appeal on behalf of the Midleton Distillery which outlines that company's long term proposals for the expansion of their permitted maturation plant at this location. It is also noted that the maturation facility is a Tier One Seveso Establishment.

6.3 In addition to the above, the Board will note that a number of planning permissions have been granted in the wider area and in proximity to the subject site for a number of one off houses.

7.0 POLICY CONTEXT:

7.1 Cork County Development Plan 2009

7.1.1 Within the Cork County Development Plan 2009, Wind Energy is addressed in terms of policy on transport and infrastructure in chapter 6. Policy INF 7-2 commits the planning authority to support the National Climate Change Strategy in seeking to reduce the emission of greenhouse gases. Policy INF 7-3 is an objective generally to encourage the production of energy from renewable sources including wind energy subject to normal proper planning considerations, including in particular the impact on areas of environmental or landscape sensitivity.

7.1.2 In relation to wind energy, and following a study of wind speeds and the landscapes of the County on a broad level, the Plan identified in broad strategic terms, two specific areas with regard to the provision of wind energy developments, under objective INF 7-4 and Figure 6.3:

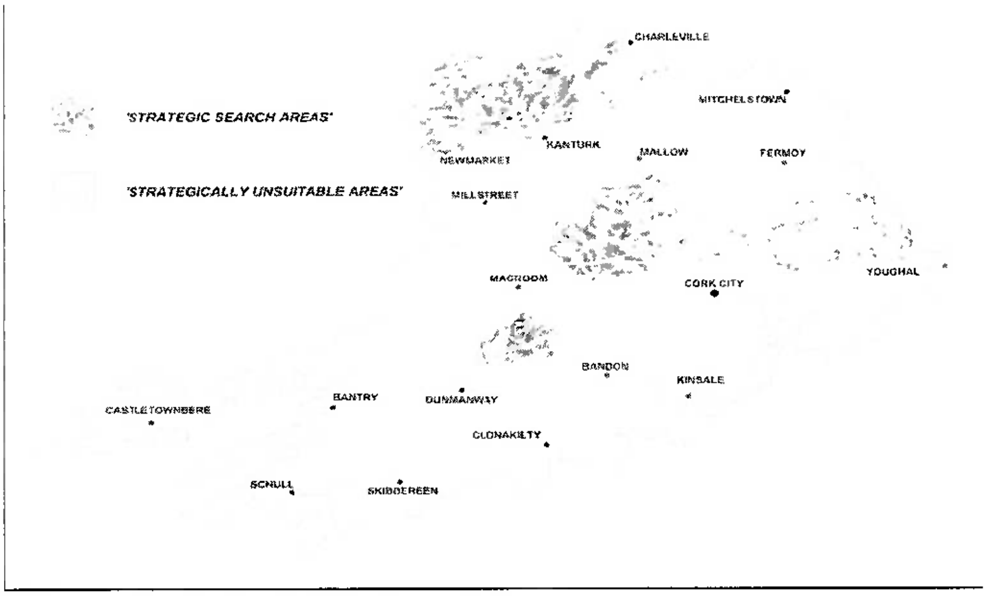


Figure 6.3: Strategic Wind Energy Areas

Strategic Search Areas: Areas which have both relatively high wind-speeds and relatively low landscape sensitivity to wind projects. Whilst not all locations within these areas would be suitable for wind projects they do give a strategic representation of generally preferred areas.

Strategically Unsuitable Areas. Areas which because of high landscape sensitivity, are considered generally to be unsuitable for wind energy projects. The Board will note that the subject site lies in neither described area.

7.1.3 The Plan also sets out that the identification of these areas does not give any certainty about the outcome of any particular wind energy proposal and, even within the strategic search areas, there will be particular constraints at individual sites. For example, within the identified search areas, important breeding and feeding grounds for rare and protected hen harriers can be found and these can be damaged or destroyed by inappropriate development.

7.1.4 INF 7-4 is the objective to encourage prospective wind energy businesses and industries. INF 7-4 deals specifically with Wind Energy Projects and provides that it is an objective of the council to encourage wind energy projects while avoiding strategically unsuitable areas identified in the plan. Part (c) of this policy deals with those areas that are identified as neither strategic search areas nor strategically unsuitable areas and provides that it is an objective in such areas to consider new, or the expansion of existing, wind energy projects on their merits having regard to normal planning criteria. The policy, provided in full in the appendix to this report, cites a number of planning criteria to be considered in this regard. Objective INF 7-5 deals with overhead power lines which are also considered relevant.

7.1.4 Chapter 7 of the County Development Plan deals with Heritage and Environment and the following policies are relevant in relation to the subject proposed development:

ENV 1-5:	which deals with Natural Heritage Sites:
ENV 1-8:	which deals with Legally Protected Plant and Animal Species:
ENV 1-9	which deals with Features of Natural Interest:

7.1.5 In relation to Landscape issues, the following policies are considered relevant:

ENV 2-11:	which deals with Scenic Routes:
ENV 2-13:	which deals with Development on Scenic Routes

7.1.6 Section 7.3 of the County Development Plan deals with Archaeological Heritage, and the following policies are considered relevant:

ENV 3-1:	which deals with Sites, Features and Objects of Archaeological Interest:
ENV 3-2:	which deals with Newly Discovered Archaeological Sites:
ENV 3-3:	which deals with Zones of Archaeological Protection:
ENV 3-4:	which deals with Archaeology and Infrastructure Schemes:

7.2 National Policy

National policy on renewable energy has arisen primarily in response to international agreements, most particularly the UN Framework Convention on Climate Change and the Kyoto Protocol. Current government policy in relation to renewables is outlined in the National Climate Change Strategy 2007 – 2012 which highlights the need for a radical strategy to meet the climate change commitments made under Kyoto.

7.2.1 *Sustainable Development – A Strategy for Ireland*, includes emphasis on the use of renewable resources.

7.2.2 *The National Spatial Strategy 2002 – 2020,* states, "in economic development the environment provides a resource base that supports a wide range of activities that include agriculture, forestry, fishing, aqua-culture, mineral use, energy use, industry, services and tourism. For these activities, the aim should be to ensure that the resources are used in sustainable ways that put as much emphasis as possible on their renewability" (page 114).

7.2.3 *National Biodiversity Plan 2002,* was prepared in response to Article 6 of the Convention on Biological Diversity and 'pays special attention to the need for the integration of the conservation and sustainable use of biological diversity into all relevant sectors.'

7.2.4 *Guidelines for Planning Authorities on Wind Farm Development and Wind Energy Development* - Planning policy guidance is outlined in "Wind Farm Development: Guidelines for Planning Authorities", 2006. The guidelines offer advice on planning for wind energy through the development plan process and in determining applications for planning permission and are intended to ensure consistency of approach in the identification of suitable locations for wind energy developments and acknowledge that locational considerations are important. These considerations include ease of vehicular access and connection to the electricity grid. It is acknowledged that visual impact is amongst the more important issues to be taken into account when deciding a particular application.

Any wind farm proposal will require an assessment of the possible ecological effects. Consideration should also be given to sensitive habitats and species as well as possible risks to birds including migratory birds. Regard should be had to special areas of conservation and other designated sites. Rural land uses other than housing are generally unlikely to conflict with wind farm developments. Conditions will generally be required to provide for the decommissioning of wind farms and ancillary developments on site.

Chapter 5 of the guidelines refers to other environmental considerations, including the impact on habitats and bird species, noise and electro-magnetic interference. Section 5.3 states that a planning application must be accompanied by information on such issues as slope stability and an assessment of whether the development could create a hazard of bogburst or landslide.

Chapter 6 of the draft guidelines refers to the assessment of siting and location of such development in terms of aesthetic considerations, landscape sensitivity, spatial extent and cumulative effect, with regard to landscape character types including hilly and flat farmland, mountain moorland and transitional landscapes. The factors to be assessed comprise landscape sensitivity, visual presence of the wind farm, its aesthetic impact on the landscape and the significance of that impact.

7.2.5 *South West Regional Planning Guidelines 2010-2022*

The vision of the RPGs is stated as follows:

> "to maintain and develop a sustainable and competitive economy, optimise the quality of life of its residents and visitors, protect and enhance its unique environment, culture and heritage.
>
> By 2022, the South West Region will be realising its economic potential and providing a high quality of life for its people by meeting their employment and housing, educational and social needs in

sustainable communities. At the same time it will reduce its impact on climate change and the environment, including savings in energy and water use and by strengthening the environmental quality of the Region."

One of the key principles identified in the RPGs as underpinning this stated vision includes promoting the security of energy supply and the development of renewable energy in the region in a sustainable manner.

RKI-01 of the RPGs sets out the key planning and development issues facing the region, while Section 1.3.37 of the RPGs identifies that "wave and wind technologies are expected to play a significant part in meeting additional demand with excess renewably generated power being exported through an enhanced transmission grid to other regions within the State."

Section 5.6.21 of the RPGs acknowledges that there is a growing network of wind powered electricity generators in both Cork and Kerry and significant potential exists for additional electricity generation by sustainable wind, wave and tidal energy sources.

Objective RTS-09 Energy and Renewable Energy, promotes the development of renewable energy resources in a sustainable manner. In particular development of wind farms shall be subject to:

- the Wind Energy Planning Guidelines
- consistency with proper planning and sustainable development
- criteria such as design and landscape planning, natural heritage,
- environmental and amenity considerations.

Objective REAS-05 Flood Risk Management states that it is an objective to ensure that significant developments in upland areas, such as *inter alia* wind farm developments, provide sufficient storm water attenuation so as to avoid the occurrence of river erosion or flooding downstream.

7.3 Wind Turbines Bill, 2012.

In the interests of presenting a complete consideration of legislative requirements, and for information purposes, I would refer the Board members to the above Bill which is currently with the Houses of the Oireachtas. This Bill seeks to provide clear guidance with regard to the minimum separation distances between residential properties and wind turbine generators. The minimum separation distances are determined by way of the overall height of the proposed turbines as follows:

(4) If the height of the wind turbine generator is –

(a) greater than 25m, but does not exceed 50m, the minimum separation distance requirement is 500m;

(b) greater than 50m, but does not exceed 100m, the minimum separation distance requirement is 1,000m;

(c) greater than 100m, but does not exceed 150m, the minimum separation distance requirement is 1,500m;

(d) greater than 150m, the minimum separation distance requirement is 2,000m;

8.0 GROUNDS OF APPEAL

8.1 This is a first party appeal against the decision of Cork County Council to refuse planning permission for the proposed development. The comprehensive document provides an introduction and background to the development as well as providing a description of the development characteristics and issues pertaining to planning policy. The document seeks to address the reasons for refusal as presented in the Planning Authority decision pertaining to the development

The specific grounds of appeal with regard to the reasons for refusal are summarised as follows:

8.2 Reason 1:

Refusal reason 1 relates to the adverse impacts on the amenities of the environment of the area including on noise, water quality and ecology. The grounds of appeal are summarised as follows:

8.2.1 Noise:

AWN Consulting prepared a submission in order to address the issues relating to noise as referred to during the PAs assessment of the proposed development. The appeal document provides a copy of this report and also a summary of its content and findings as follows

- The development can be designed to comply with the relevant guidance

- Further updated baseline noise monitoring was commissioned and worst case noise criteria have been derived based on the guidance.
- In the limited instances where levels are exceeded, it has been demonstrated that the relevant noise criteria curves can be complied with

Based on the minimum curtailment requirements identified, the technologies available to the market have lower noise ratings with them than those considered for the assessment and the strong likelihood that the final selected turbine model will have lower noise emissions associated with it, it is likely that the requirement for any curtailment strategy will be removed from the site.

8.2.2 Water Quality and Hydrology / Hydrogeology:

It is submitted that OCM, consulting company used by Cork County Council to consider certain aspects of the proposed development, considered that matters of hydrology and water quality have been comprehensively addressed in the EIS.

In terms of geology, hydrogeology and slope stability, it is submitted that OCM agreed with the findings of the EIS. Further information was requested with regard to a number of issues with clarification recommended following the receipt of the response to the FI request. The appellant notes that OCM considered that said clarification may be obtained by way of planning conditions, yet the PA decided to refuse permission. It is submitted that the appellant is confident that the borrow pit material to be extracted will be suitable for the purposes required. The level of detail required prior to a grant of planning permission is considered to be unprecedented.

Three borrow pits are proposed on the site and trial pits were undertaken at these locations. It is expected that the borrow pits will be easily excavated and that blasting will not be required. It is further considered that the material extracted will be suitable as the existing tracks on the site were constructed using material excavated on site. In terms of groundwater and seepage, it is noted that OCM confirmed the conservative approach taken by the applicant.

8.2.3 Ecology:

The grounds of appeal in this regard seeks to address the individual items raised by the Heritage Officer of Cork County Council in relation to ecology. There are 4 areas of concern considered as follows:

- Birds
- Habitat Directive Screening Report
- Habitats and
- Bats

a. Birds:

Comprehensive bird surveys were carried out between March 2012 and March 2014 and comprised of a number of elements. Detailed data on breeding birds was provided in the EIS and the RFI response. Only one red-listed species was recorded being the Meadow Pipit. There is little evidence that wind farms affect bird populations following construction.
The hen harrier was not recorded on the site.

The Golden Plover was recorded in low numbers at the site and it is believed that the species over-winter in the wider area. There were no breeding populations recoded during the bird surveys and while a number of flocks were noted over the site, the majority of activity was recorded outside the wind farm site boundary. It is concluded that disturbance displacement is not expected to have any long term impacts on wintering Golden Plover in the area.

Kestrel were recorded on the site three times during the surveys, twice during the winter and once during breeding season. It is considered that the Kestrel are unlikely to be impacted by collision at the proposed site.

A buzzard was recorded twice during all bird surveys at the site, in December, 2013. At both times, the Buzzard was flying at less than 30m and therefore it is considered unlikely that they will be significantly impacted from collision or disturbance / displacement. The Buzzard were not recorded during the breeding season.

Snipe were recorded on three occasions during 60 hours of VP watches, twice in December, 2013 and once in March 2013 with a total of 4 birds recorded. There are small areas of wet grassland at Peafield meadows and Portavarrig wetland which can be considered as suitable breeding ground for the Snipe and it is acknowledged that it may be at risk of collision during the breeding season.

Mitigation measures are indicated in the EIS and in the RFI response. In addition, it is proposed that additional trees and hedgerows will be planted along gaps in the existing hedgerows and treelines within the site in order to strengthen habitat areas and compensate for the removal of these habitats in other areas within the development footprint. In addition, the appellant commits to comply with the requirements of the Heritage Officer with regard to clearfelling and ground works to avoid the main breeding season.

b. Habitats Directive Screening Report:

The submitted AA Screening Report submitted to the PA described the Golden Plover recorded at Ardglass as over-wintering in the vicinity of the area and notes that this bird is widespread in Ireland during the winter months. It is considered unlikely that the birds recorded in the vicinity of the site commute to Cork Harbour, 9km from the site. It is further submitted that given that there is a low degree of interconnectivity between the Blackwater Callows and Cork Harbour and / or the Ardglass site, it is unlikely that the development will have a significant impact on the populations. Therefore, the findings of the AA Screening Report remain unchanged.

With regard to the impacts on water quality of the Great Island Channel SAC, it is submitted that extensive measures are detailed in the EIS dealing with potential surface water runoff and discharges such as the construction of swales, buffer zones, silt traps and settlement ponds. In addition, an outline Construction and Environmental Management Plan was submitted in response to the FI request response which included a drainage management plan and mitigation measures. It is concluded that it is not likely that there will be any impacts on the SAC, which lies 16.9km from the proposed site.

c. Habitats:

The response to the further information request detailed the extent of the semi-natural habitats to be removed as part of the proposed development. No natural habitats will be impacted. A total of approximately 570m of semi-natural habitats, or hedgerows and treelines are earmarked for removal to accommodate the development.

d. Bats:

Two bat surveys were carried out as part of the EIS in the summer of 2012 with two further surveys carried out in response to the further information request, in Autumn 2013 and Spring 2014. These surveys and findings were presented to the PA with mitigation measures detailed. With regard to the location of a small roost for Brown Long-Eared Bats in the vicinity of T2, mitigation measures include the monitoring of the roost prior to commencement of development to determine if the roost is still in use. If it is not a breeding roost, it is proposed to exclude and relocate the roost to a purpose built structure. If it is a breeding roost, the operations of T2 will be restricted during the active bat season.

In support of this appeal, it is now proposed to relocate the turbine, T2 to a location greater than 150m from the roost. Alternative location is presented on Figure 3.1 of this appeal submission.

8.2.4 <u>Reason 2:</u>

Refusal reason 2 relates to the adverse impacts on residential amenities, noting the number of residential properties in the vicinity of the site, notably in terms of visual intrusion and noise. The grounds of appeal are summarised as follows:

a: Shadow Flicker:

Results from model predict that there is potential for some shadow flicker to impact at some dwellings. Mitigation measures will ensure that shadow flicker remains below the recommended guideline limits. It is noted that the PA did not raise this issue as a concern.

b. Visual Amenity:

MosArt has prepared a response to the landscape and visual aspect of the reason for refusal and a number of photomontages have been presented in support of the proposed development. The submission notes that the PA considers that the proposed development will adversely impact on the existing residential amenity of a number of houses due to visual intrusion, it is considered that the level of impact on the landscape is not considered significant in EIA terms.

c. Noise:

A noise report has been submitted to address this issue. The submission seeks to deal with the issues raised in the Cork County Council Environmental Report, dated 19/06/2014, which contributed to the reason for refusal in terms of noise. The submission, appendix B in the appeal submission, deals with each issue raised in said report. The report provides an updated baseline noise monitoring and details the locations of the monitoring equipment, the instruments and procedures used. The document further provides an analysis of the results with an updated assessment of the predicted results.

The report submits that the conclusions presented in the original EIS have been confirmed in the updated assessment. In the limited instances where an exceedence is noted, it has been demonstrated through the consideration of wind directionality and the application of a curtailment programme the relevant noise criteria curves can be complied with in all instances. It is finally submitted that it is likely that the requirement for any curtailment strategy will be removed from the site.

This noise report provides a number of appendices as follows:

- Appendix A: Calibration Certificate
- Appendix B: IoA Article on Windscreens
- Appendix C: Directional Noise Contours
- Appendix D: Calibration Certificates (2014 Survey)
- Appendix E: Site Survey Log Sheets (2014 Survey)
- Appendix F: Directional Noise Predictions V Criteria Curves
- Appendix G: Siemens Technical Report
- Appendix H: Nordex Technical Report

9.0 OBSERVERS

There are 12 no observers noted in relation to this first party appeal as follows:

1. Ardglass Wind Turbine Action Awareness Group
2. Cork Renewable Energy Group
3. Castlelyons Development
4. Seamus & Breda Sexton
5. Don Sheehan

6. Dr. Sharon McKenna & Malachy Ward
7. Andrew Ennis & Susan Liddy
8. Sharon Guiry & Others
9. James & Anne Cagney
10. Christy O'Mahony
11. Ricky Galvin
12. Margaret Galvin

Two further observations were received but considered invalid.

The issues raised in the above observations are similar to those initial objections made to Cork County Council and are summarised as follows:

<u>Ardglass Wind Turbine Action Awareness Group:</u>
The submission presents observations under a number of headings and the main points are summarised as follows:

- Site selection has not been robustly justified and the consideration of alternative sites is inadequate in that the sole justification for the proposed site appears to be the securing of a grid connection.
- Visual impact assessment has a number of gaps in terms of the applied methodology which have the effect of distorting the degree of impact. A number of important view receptors have not received appropriate attention in this regard including scenic route no. 44, the National Primary Route and ACAs.
- The issue of noise has not been addressed appropriately and is noted as a reason for refusal by Cork County Council. The new noise data submitted by the first party as part of the appeal has been independently assessed and it is contended that the appellants assessment does not provide an appropriate description of the likely significant effects of the proposed project on the environment due to noise, nor does it address the requirements of the DoECLG guidelines in terms of ambient noise levels. It is considered that the site fails to meet the specified tests in the 2006 Guidelines by a large margin.
- It is submitted that issues relating to hydrology, hydrogeology and water quality have not been adequately addressed.
- Issues are raised regarding the ecology assessment presented in support of the proposed development and it is noted that the Council

has concerns in this regard. It is submitted that it is not possible for any competent authority to complete EIA and Screening for AA and the recent High Court Ruling in relation to Gaeltech Energy Developments Ltd., is cited.

- Cumulative impacts associated with other developments in the vicinity have not been accurately considered by the applicant, and reference is made to the permitted Midleton Distilleries development in the area.

There are a number of enclosures with this observation including:

- Appendix A: Site selection mapping
- Appendix B: Landscape & Visual Assessment
- Appendix C: Noise Assessment
- Appendix D: Ecology Assessment

Cork Renewable Energy Group:

The submission presents observations under a number of headings and the main points are summarised as follows:

- Environmental impacts
- Health & wellbeing
- Noise
- Private ownership v community development.
- Health & safety
- Economic justification
- Public Service Obligation
- Lack of current planning guidelines
- Tourism
- Flora & Fauna
- Alternative renewables are not being catered for in the County Plan
- Energy policy
- Aarhus Convention / Public Consultation
- Links to the grid and details of proposed connections
- Finance
- Planning policy
- Cumulative impact with the Irish Distillers development
- Impact on house prices
- Non-compliance with CDP policy

There are a number of enclosures with this observation including:

- References
- Rural Environment Protection Scheme 3
- Extracts from the Cork County Development Plan, 2009
- Cork Renewable Energy Groups response to the Green Paper on Energy Policy in Ireland, undated
- BW Energy, Evaluation of Grid Link Stage 1 report

Castlelyons Development:

Castlelyons Development is a voluntary Community group which formed in 2003 to discuss planning issues in the area. The observation includes two submissions made to Cork County Council during their assessment of the proposed development and the issues raised relate to the following topics:

- Impact on community and lack of consultation
- Noise and shadow flicker impacts
- Proximity to the gas line
- Visual impact on scenic area
- Impact on tourism industry
- Impact on existing businesses including horse training facility in the area.
- Impacts on Hogans Wood, a local amenity.

There are a number of enclosures with this observation including:
- Original submissions to Cork County Council

Seamus & Breda Sexton:

The submission presents observations under a number of headings and the main points are summarised as follows:

- Noise
- Visual impact
- Effects on wildlife
- Precedent
- Loss of amenity
- Lack of consultation
- Coiltes use of their lands goes against their stated core-purpose.
- Failure to consider alternatives
- Cumulative impacts

- Effects on local businesses / tourism
- Impact on health
- Lack of economic benefit to the local area
- Shadow flicker
- Lack of adequate guidelines / legislation.

Don Sheehan:

The submission presents observations under a number of headings and the main points are summarised as follows:

- Proximity of development to houses
- Noise
- Shadow flicker
- Visual impact
- Loss of amenity
- Lack of consultation
- Impact on property prices and the impact on property owners

Dr. Sharon McKenna & Malachy Ward:

The significant submission presents observations under a number of headings and the main points are summarised as follows:

- Noise and health
- Lack of consultation
- Safety issues
- Non-compliance with County Development Plan
- Loss of amenity
- Landscape destruction and visual impact
- Impacts on ecology
- Cumulative impacts
- Shadow flicker and inadequate assessment in the submitted EIS
- Lack of need for the development
- Failure to describe constructability, notably with regard to the use of the local road network and the proximity of houses.
- Disregard to the terms of the Aarhus Convention with regard to access to environmental information, public participation and access to justice.

There are a number of enclosures included with this submission including a recent editorial in the British Medical Journal, details of a study on proximity to buried infrastructure and details of wind turbine accidents

Andrew Ennis & Susan Liddy:

The submission presents observations under a number of headings and the main points are summarised as follows:

- No consultation
- Noise
- Shadow flicker
- Environmental impacts
- Visual impact
- Health impact

Sharon Guiry & Others:

The submission presents observations under a number of headings and the main points are summarised as follows:

- Noise
- Shadow flicker, including at night and the impacts on the night sky
- Visual impact raised and photomontages submitted are suboptimal
- Safety issues raised and lack of assessment and consideration given.
- Impacts on hydrology
- Impacts on ecology
- Other issues
    - Inadequate infrastructure to support the development
    - No details regarding dismantling
    - Impact of overdevelopment in rural area
    - Lack of consultation
    - Out of date guidelines

James & Anne Cagney:

The submission presents its objection relating to the proximity of a turbine to their home and the impact of noise and shadow flicker. It is further stated that there is concern for the impact the turbines will have on family health, the local environment and their enjoyment of it.

Christy O'Mahony:

The submission seeks to raise concerns regarding the impact of the proposed windfarm on his farm and livelihood.

Ricky Galvin

The submission presents observations under a number of headings and the main points are summarised as follows:

- Noise
- Shadow flicker
- Ice throw
- Impacts on the river. It is submitted that the mountain site for the development is peat and concerns are raised should there be a mudslide.
- Devaluation of property.
- Impact on farming and agriculture

Margaret Galvin:

This submission notes that planning permission has been granted for a house which is intended to be constructed so that the observer can return to her home farm.

10.0 RESPONSES

10.1 Planning Authority:

The Planning Authority has not responded to this appeal.

10.2 First Party Response to Observers:

The first party has not responded to the third party observations submitted.

11.0 ASSESSMENT:

Having regard to the nature of this appeal, and having undertaken a site visit, as well as considering the information submitted, I suggest that it is appropriate to assess the proposed development under the following headings:

- Compliance with policy
- Landscape/visual impact
- Residential Amenity
- Cultural Heritage Impacts
- Roads & Traffic
- Ecology
- Water Quality & Hydrogeology
- Adequacy of the EIS
- Other Issues

11.2 Compliance with policy

11.2.1 The Cork County Council County Development Plan 2009-2015 is the relevant policy document for the proposed development, and commits the planning authority to take a generally positive approach to wind energy developments. To this end, the Plan identifies two specific areas in relation to the development of wind energy projects, being strategic search areas and strategically unsuitable areas, as set out in Figure 6.3 of the Plan. Under the current County Development Plan, the proposed development site is not located within either of these specific areas. That said, the Board will note that the draft Cork County Development Plan, 2013 has identified that the subject site is located within an area which has been identified as being in an area where wind farm developments are 'Open to Consideration'.

11.2.2 As the subject site is not located within either of the above identified areas, policy objective INF 7-4 of the Cork County Development Plan is relevant. This objective is generally supportive of wind energy businesses and industries sets out policy in relation to wind energy. In assessing potentially suitable locations for projects, potential wind farm developers should focus on the strategic search areas identified in the Plan and generally avoid the identified strategically unsuitable areas. This policy also provides for the consideration of wind projects in areas that are identified as neither strategic search areas nor strategically unsuitable areas on their merits having regard to normal planning criteria. In addition, Objective ENV 2-6 is considered relevant whereby it is a requirement to protect the visual and scenic amenities of County Cork's built and natural environment.

11.2.3 In order to determine compliance with local policies, normal planning issues must be considered, as required in objective INF 7-4 is, and in particular, Part (c) of this policy, which deals with those areas that are identified as neither strategic search areas nor strategically unsuitable areas. It is an objective in such areas to consider new, or the expansion of existing, wind energy projects on their merits having regard to normal planning criteria. Normal planning criteria include a variety of issues which will be dealt with further in this assessment below. Having considered the proposed development and having read all of the information provided in support of the proposed wind farm, including the EIS, together with all of the local authority reports and third party submission, I would advise at this point in my assessment that I have concerns, particularly in relation to the scale and layout of the development together with what I consider to be excessive turbine height in this undulating rural landscape, the proximity to private houses and public roads and having regard to the inadequacy of certain details and assessments of impacts. In addition, I have concerns regarding the visual impacts and potential for operational noise associated with the turbines to affect the general amenities and the enjoyment of dwelling houses and of the surrounding rural environment of this area of Co. Cork.

11.2.4 All of my initial concerns as detailed above aside, I would consider that the development of a wind energy development can be considered as being potentially acceptable in principle on the application site.

11.3 Landscape/Visual Impact

11.3.1 There is no doubt that the visual impact of a wind turbine must be considered significant given the nature of the installation. Whether or not the impact is negative or positive is a matter of opinion. In terms of the potential visual impact in the subject landscape, having regard to the gentle hilly, low lying, open and exposed nature of the landscape, I consider that the turbines will be highly visible, particularly having regard to the proposed number, height and scale of the turbines proposed. That said, significance of the visual impact of the turbines needs to be considered in the context of the surrounding landscape and the existing development it supports. The Board will note from the submitted and attached photographs, that this area of East Cork maintains its open and rural landscape. It is noted that there are no significant developments in the area other than the IDL Maturation Plant which is located approximately 400m from the site. This plant is heavily screened with trees and as such, is not particularly prominent in this landscape, in my opinion.

11.3.2 The EIS presents a landscape and visual impact assessment report, in accordance with the various guidelines, in support of the proposed development. The assessment was carried out using both a desk top study as well as site surveys and includes a number of photomontages. The landscape character of and in the vicinity of the identified study area is indicated, under the Draft Landscape Strategy for Cork, as a Landscape Type 10b: *Fissured Fertile Middleground (Rylane East to Waterford),* with the following values:

Landscape Value:	Medium
Landscape Sensitivity:	High
Landscape Importance:	County

The Type 10b landscape is described as 'an elevated landscape which is fissured by fairly gentle slopes, with reasonably fertile agricultural land comprising a mosaic of small to medium sized fields with broadleaf hedgerows', and a landscape character that 'has characteristics of both flatter fertile farmland areas and the higher marginal hilly farmland'. The EIS notes that the medium value landscapes are defined as 'landscapes with positive characters and with local or county importance', whilst high sensitivity landscapes are considered to be 'vulnerable landscapes with the ability to accommodate limited development pressure. To the north of the site, the landscape is indicated as Landscape Character Type 6c – *Broad Fertile Lowlands.*

11.3.3 It is clear that the proposed development would be highly visible from a very wide and extended area and in particular, if permitted, the development would impart a notable change to landscape character at a very localised level. Overall, the EIS considers that the proposed development will have a moderate impact on the surrounding landscape. In terms of my consideration of the visual impact associated with the proposed development of a wind farm at this location, I am mindful that the applicant has already secured connection to the grid in proximity to the site. While I acknowledge this as a positive, it must be noted that the subject site is located within an area where there is a population of residents, and the visual impact of the proposed turbines will be present on the scenic routes in proximity to the site.

11.3.4 The EIS presents a Zone of Theoretical Visibility as part of the overall visual impact assessment, Figure 9.4, which represents the area over which the proposed development can theoretically be seen. A ZTV map has been prepared as part of the visual assessment. Overall the assessment as presented in the EIS, supplemented by the response to the further information request and appeal documents, considers that the development, in places, will represent an intrusion but not an obstruction in views across the landscape. It is concluded that visual impact associated with the proposed development fall within the range of effects which are typical arising for any commercial scale wind farm. In terms of the visual assessment presented, the EIS notes that the visual impact assessment, and associated photomontages, is based on a turbine with a maximum height of 131m. 17 no photomontages are provided as part of the EIS, with a further 13 provided in response to the FI request, and a written description is provided in relation to each. The identified locations are indicated as being within 20km of the subject site.

11.3.5 The EIS, considers the cumulative impact associated with the existing Middleton Distillery, and the associated permitted warehousing associated with same which is in the vicinity of the wind farm site. The applicant concludes that the proposed development will not result in a cumulative impact with the Midleton Distillery Maturation site, on the basis that the visual impact of the combined development is the same as the impact of the proposed wind farm on its own and there is not significant cumulative impact. It is further acknowledged that the development will contribute to a sense of increased intensity of built development. It is suggested that there is little potential for significant cumulative visual impacts to occur viewing both developments in combination. I also note the comments of the PA with regard to the quality of the information provided which does not accurately account for the additional features of windfarm developments including access roads, and the removal of tracts of existing conifer plantation. It is clear that the proposed development of a wind farm in any landscape will have a visual impact, however, I would concur with the concerns of the Planning Authority in terms of the current proposal.

11.3.6 There are a number of residential properties in the vicinity of the subject site. Having regard to the topography of the area, which might reasonably be considered flat and hilly farmland in terms of the 2006 Wind Energy Guidelines, where guidance is provided. In this regard, it is stated "that the essential key here is one of rational order and simplicity, as well as respect for scale and human activities." As such, due regard must be given to houses and farmsteads. The EIS, in my opinion, fails to really consider this potential of the visual impact to seriously affect the residential amenities of existing properties close to the site as required by the guidelines. I refer the Board to the EIS relating to the Human Environment which makes very little reference to the visual impacts associated with the development. That said, the visual aids provided facilitate some assessment of the visual impacts on the houses in the vicinity.

11.3.7 Further to the above, the guidelines, with regard to the height of the turbines, require "that turbines should relate in terms of scale to landscape elements and will therefore tend not to be tall. An exception can be considered on a high ridge or hilltop of relatively large scale." Having regard to the information provided together with the context of the subject site, I have serious reservations regarding the proposed scale of the turbines, which will rise to 156.5m in height. In terms of compliance with the guidelines, I would question whether adequate justification has been presented to consider an exception in this instance. The actual capacity of this gentle landscape to accommodate the proposed development of its scale is a concern, and it is clear, even from the information provided, that the development, if permitted will be highly visible over a large area, including adjacent counties. In the context of the wider East Cork area, I have a real concern that the introduction of such a significant industrial installation will dramatically alter the receiving wider landscape. Certainly at a more local level, the impact of the proposed development on the visual amenities of the area will be significant and negative in my opinion, and a grant of planning permission would set an undesirable precedent for similar type developments in the wider East Cork area.

11.3.8 Having undertaken a site inspection, I am of the opinion that there are a number of houses which have the potential to experience high adverse impacts associated with the proposed development. While I acknowledge the submission and conclusions of the first party, I would not agree that proposed development represents an acceptable level of landscape and visual impact across the study area. I concur with the concerns of the local residents who raise concerns in relation to the visual impacts associated with the wind farm. While in principle, I would not generally have an issue with the provision of the larger turbines as currently proposed, a grant of permission for same in this instance would significantly impact upon the existing visual and residential amenities of residents in the area, contrary to the proper planning and development of the area. The maximisation of energy output together with the existence of a connection offer, while important, should not be facilitated to the detriment of local residents or the protection of the landscape.

11.3.9 In terms of mitigation, the EIS refers only to design features of the turbines, including their colour, height, blade rotation and onsite landscaping of roads and structures associated with the proposed substation. In my opinion, and while these are appropriate mitigation measures associated with the overall visual impact of the proposed development, they fail to address the potential for the significant visual impact of the turbines at local residential properties, warranting real and genuine concern.

11.4 Residential Amenity

11.4.1 Noise

A: The general area of Killaveenoge West, Derreenaspeeg, Killaveenoge East, Curranashingane and Garranes, Drinagh and the adjacent townlands, can be accurately described as quiet and although rural, is well populated in the towns and villages of Ballincurrig 3km to the south west, Dungourney, 5km to the south east, Rathcormac, 7.5km to the north west and Tallow, 13km to the north, as well as other individual houses along the public roads. There is little noise generating activity in the vicinity and the main noise source is animal with some minimal traffic. On the dates of my inspection, I spent a lot of time walking the site and its environs in order to ascertain the existing noise levels associated with existing developments, including the Middleton Distillery which is located in close proximity to the site. The Board will note the submission of third parties supporting the Distillery and its proposed expansion. The Board will also note that the Planning Authority refused planning permission for the proposed development on the grounds that it was not satisfied that the proposed development would not unduly affect the amenities and the enjoyment of dwelling houses by virtue of excessive and continuous operational noise. It is also noted that the PA considered that the level of information provided in the EIS was limited.

B The provision of a wind turbine generates two types of noise, 1. the sound of the generator and 2. the 'swoosh' as the blades rotate through the air. The guidelines for wind energy provides information relating to the maximum permissible noise levels and the noise assessment submitted as part of the EIS identified 35 noise sensitive receptors within 1km of the site. The EIS concludes that the proposed development would meet noise criteria for residential properties in the area save for 3 identified houses, H44, H45 and H46. The Board will note that in response to the further information request from the PA, the first party has acknowledged a further 36 houses being located between 1-1.5km of the turbines, and a further 37 between 1.5-2km. As part of the appeal submission, the First Party has submitted that it has been proven that the development can be designed in order to comply with the guidance in the Wind Energy Development Guidelines, 2006 and that it is likely that the requirements for any curtailment strategy will be removed from the site.

C. Mitigation is discussed in the EIS, at section 10.5, where it is submitted that there are 3no locations highlighted where the proposed development exceeds the adopted day or night time noise criteria at wind speeds of 6-7m/s, and generally relate to turbines 7 and 11. All three properties are landowners who have given consent for the development and that they are aware of the potential minor inconveniences arising. Therefore, no mitigation measures are required. In terms of the appeal documentation, the Board will note that the number of properties where there will be exceedances in the worst case scenario has increased from 3 to 6. To this end, an updated potential curtailment matrix has been prepared, page 27 of Appendix B of the appeal documentation.

D: As part of the appeal, further noise measurements were undertaken in the vicinity of the site at 4 locations. As part of the submission, the first party has presented a worst case envelope based on the lowest average levels at the various wind speeds which range from 24.1dB $L_{A90,T,}$ at 4m/s wind speeds to 34.6dB $L_{A90,T,}$ at 12m/s wind speed during the day time and 19.7dB $L_{A90,T,}$ at 4m/s to 32.6dB $L_{A90,T,}$ at 12m/s at night time. The information submitted in support of the appeal indicates that the updated background noise survey was undertaken over a two week period in July, 2014, and the document provides details of the equipment used to take the measurements as well as locations of equipment and results of the surveys undertaken. I accept the methods and software used in the calculation of noise in the vicinity of the site as part of this assessment. I note the results and conclusions of the assessment, which suggests that the development if permitted will result in a change in noise level across the majority of the development will be a maximum of 1.5dB(A), at a wind speed of 7m/s.

E: The Wind Energy Guidelines, 2006, with regards to the setting of limits for noise emissions provides that:
"in general, a lower fixed limit of 45dB(A) or a maximum increase of 5dB(A) above background noise at nearby noise sensitive locations is considered appropriate to provide protection to wind energy development neighbours............Instead, in low noise environments where background noise is less than 30dB(A), it is recommended that the daytime level of the LA90 10 min of the wind energy noise be limited to an absolute level with the range of 35 to 40dB(A).

As such, and given fact that the Planning Authority has considered the level of information provided in the EIS is limited warranting a refusal of planning permission, it may be considered that there is a concern arising in this regard. Notwithstanding all of the information now at the disposal of the Board, I share the same concerns. In particular, the Board will note that the appellant has applied the upper limits for the assessment of this proposed wind farm, and not the +5dB(A) which I would consider to be more appropriate given that the updated baseline noise curves suggest that the existing environment enjoys noise levels in the region of 28.8dB at wind speeds of 7m/s during the day and 25.2dB at night time for the same wind speeds.

F: In terms of the potential for estimated noise levels associated with the proposed development having the potential to represent nuisance for residents in the area, I refer to the guidelines which suggest a *maximum increase of 5dB(A) above background noise at nearby noise sensitive locations is considered appropriate to provide protection to wind energy development neighbours.* At an increase of 5dB(A), the increase in noise levels is perceptible. In terms of the information provided as part of the appeal documents, and just by way of example of my concerns, taking one house, H47, which lies in proximity to the measuring equipment used at location identified NSLA, and at a wind speed of 7m/s, the baseline noise in this area has been recorded at 28.8dB $L_{A90,\ 10min}$ during the day and 25.2dB $L_{A90,\ 10min}$ at night. The predicted noise associated with the development is indicated at 40.7dB $L_{A90,\ 10min}$ which represents a potential increase in noise at this location of between +11.9 – 15.5 dB $L_{A90,\ 10min.}$ To apply the higher noise levels in this environment, while ensuring that the wind farm might comply in the main with the requirements, would have a significant and negative impact on the existing residential amenities of the area.

11.4.2 Shadow Flicker

A: In terms of shadow flicker, the applicant submitted an assessment which was carried out using the ReSoft Windfarm software programme. The phenomenon of shadow flicker requires that a number of specific criteria occur simultaneously, including the sun is shining and is at a low angle (after dawn and before sunset), and the turbine is directly between the sun and the affected property, and there is enough wind energy to ensure that the turbine blades are moving. It is contended by the applicant that the likelihood of all criteria occurring simultaneously is minimal.

B: The Wind Energy Development Guidelines, 2006 note that shadow flicker is not usually critical, but in *circumstances where the calculations indicate that occupied dwelling houses would be significantly affected, a condition requiring the non-operation of turbines at times when predicted shadow flicker might adversely impact on any inhabited dwelling within 500m of a turbine may be appropriate.* The guidelines also specify requirements in relation to quantifying the effect and where appropriate, measures to be taken to prevent or ameliorate the potential effect.

C: While the Guidelines recommend that shadow flicker should not exceed 30 hours per year or 30 minutes per day at any dwelling within 500m, the EIS submits that there are no dwellings located within 500m of a turbine. The assessment carried out for all houses located within 10 rotor diameters, and within 1,130m of the proposed development. 45 buildings houses in total have been identified as potentially being affected by shadow flicker using this criteria. The EIS suggests that 27 houses could be subject to shadow flicker in excess of 30 minutes per day with 22 houses being subject to shadow flicker in excess of 30 hours per year. These figures assume 100% sunshine and when the regional sunshine data is taken into account, and assumes 40% sunshine, these numbers are reduced to 3 houses being affected per year, H44, H45 and H46, all of which belong to participating landowners.

D: Mitigation is not explicitly proposed and the EIS suggests that where an issue arises, mitigation requirements will be assessed by way of a procedure of evaluation of the existing screening, window orientation and the periods of shadow flicker actually occurring and will be carried out in consultation with the relevant landowner. The EIS submits the following possible options, landscape screening, the installation of blinds or curtains or turbine control. The wind turbine control system could include the shutting down of particular turbines at specific times of specific days of the year. I accept the premise for the above conclusions, and I consider that the proposed development is acceptable in terms of the shadow flicker potential. However, and should the Board be minded to grant permission in this instance, a condition should be attached requiring the non-operation of the turbines at times when the predicted shadow flicker might occur, adversely affecting the adjacent houses.

11.4.3 Other Issues

While the issue of visual impact has been discussed above, I would wish to state at this point that, notwithstanding the potential impact of the proposed development on the general visual impact of the area, it is my opinion that a number of the proposed turbines, if permitted, have the potential to have a significant visual impact on a number of houses in the vicinity of the site. It is generally considered by the first party, that while a certain level of visual intrusion at a small number of properties will occur, the benefits from the project will further reduce the national reliance on fossil fuels. In addition, it is submitted that the wind farm should be allowed to maximise output which would be facilitated by the larger turbines. While it is appropriate and relevant to give weight to this issue, I consider that the proposed provision of 11 no. turbines in this area, rising to a height of 156.5m, will significantly and adversely impact upon the existing residential amenities of a large number of houses and properties in this area.

11.5 Cultural Heritage Impacts

11.5.1 The EIS notes that there are 10no. recorded archaeological sites within the identified study area, all of which are recorded monuments, with a further 80 recorded monuments identified within a 2km radius of the site. Of the 90 monuments identified, 37 no longer have above ground expression while a further 10 were no longer accessible or visible due to forestry. No new sites were identified.

11.5.2 In terms of the proposed development, the EIS acknowledges that archaeological remains may appear due to earth movements associated with the development. It is submitted that there will be potential impacts associated with the construction of T7 given the proximity of two fulachta fia, one being located within the identified boundary area associated with same. The EIS submits that all construction works will be monitored under archaeological licence, and in consultation with the relevant authorities. In terms of a recommendation in this regard, I consider it reasonable that a condition requiring monitoring and protection of archaeology in the vicinity be attached to any grant of planning permission.

11.5.3 In terms of Architectural and Cultural Heritage, the EIS notes that there are no protected structures within the study area, and two within 2km of the site, both of which are thatched houses, refs RPS 80 and 773. One house is included in the NIAH, ref no. 20905406. This is a 19th C farm house located at Monalyre Cross Roads and at 670m from T3. There are a further 6 NIAH structures located in the wider area. A number of Cultural heritage features were identified in this assessment including a limekiln, four bridges, enclosed field and field boundaries and small 19thC settlements / farmsteads.

11.5.4 The EIS provides a number of mitigation measures but ultimately concludes that there will be no direct impacts on the recorded monuments that have been identified. It is noted that while some turbines may be visible from archaeological monuments within the 2km study area, the overall impact is considered to be slight given their distances from same. In terms of impacts on architectural and cultural heritage, the EIS submits that as the nearest NIAH structure is located over 670m from the nearest turbine, together with the presence of coniferous forestry, there are no impacts on the house anticipated. The two farmsteads identified during the field work associated with this assessment noted that one stone building is located within 45-50m of T2. This building is to be preserved in situ and there will be impacts associated with the proposed development in terms of visual impact. The EIS submits that the landscape in this area has already been altered through the afforestation of the area. Residual impacts associated with the proposed development are considered to be low to medium subject to the implementation of the recommended mitigation measures.

11.5.5 The Board will note the comments of the Cork County Archaeologist with regard to the proposed development, and I would agree, that subject to the implementation of mitigation measures and appropriate conditions, the proposed development can be considered acceptable.

11.6 Roads & Traffic

11.6.1 Given the nature of the proposed development, it is clear that there will be disruption to existing traffic and road users in the construction phase of the development, and that the local road network will experience some additional volume. I would note that the construction phase is a temporary phase, and any disruption will not continue once the development is complete. Roads & Traffic & is dealt with under Chapter 11 of the EIS, which deals with Human Environment, where Section 11.1.7 describes roads and transport in the existing environment. Section 11.2.7 examines the potential impact of the development on the local road network. The assessment considers the impact of construction traffic in terms of the delivery of the turbines and the construction phase.

11.6.2 The Board will note that it has been determined by the applicant that given the estimated increase of 3.9% over current traffic on the R626 due to the construction phase of the development, there is no requirement for a traffic assessment as part of an environmental impact assessment. Based on the

NRA document Traffic & Transport Assessment Guidelines, it was considered that the proposed development does not require a Transport Assessment. It is estimated that during the construction phase of the development, approximately 49 traffic movements will be generated from HGVs and 40 movements by employees, amounting to a maximum of 89 movements daily in total. The construction phase is estimated last for 12 months.

11.6.3 In terms of mitigation, a transport management plan will be submitted to Cork County Council for discussion prior to the commencement of construction and which will address general construction traffic, oversized loads and emergency access. It is also noted that the junction at Peafield Crossroads will have to be widened to facilitate the delivery of the turbine components. No details in this regard have been provided and it is unclear from the information provided whether the relevant consents and permission has been secured to carry out said works. I note at page 195 of 246 of the EIS indicates that such permission has been given but no written evidence has been provided. It is further noted that tree canopies and hedges will require to be trimmed along the route which will be undertaken in consultation with Cork County Council.

11.6.4 The EIS identifies the possible route and public roads to be used in order to access the site. The EIS concludes that during the peak construction phase, "there will be a small increase in local traffic" but "it will not create any traffic congestion". Once constructed, the impact of traffic movements associated with the wind farm will be negligible. The impact of the development on the road network will be felt during the construction phase and then, only for a limited number of days.

11.6.5 In relation to the roads issues, the Board will note that the PA has raised no objections to the proposed development. I have real concerns that a full assessment of the proposed development, in particular the construction phase of the development, has not been undertaken and while it is implied that the level of additional traffic movements is estimated to amount to 3.9% of the current levels, given the nature of the proposed development, together with the quiet and very rural nature of the surrounding area, the impacts will be obvious and immediately felt. That said, and should the

Board be minded to grant planning permission in this instance, I consider that the issue of roads and access for delivery of equipment to the site will require the preparation of a full transportation plan where the schedules shall be agreed with the relevant engineer in the Roads Section of Cork County Council. Prior notification to local residents shall also be a requirement of this agreed schedule. The developer shall also be liable for any road repairs necessary following the completion of the development. As such, I consider that the temporary road and traffic impacts, which I consider will be significant, can be reasonably and appropriately mitigated.

11.7 Ecology:

Impacts on Habitats

11.7.1 There are no designated sites located within the proposed site boundary, although there are a number of habitats present on the site. There are seven designated sites however, within 10km of the proposed development site. The EIS notes that the nearest pNHA is located approximately 6.3km to the south of the study area, while the nearest SAC is located 3.1km to the north, being the Blackwater River (Cork / Waterford), Site Code 002170, so designated for alluvial wet woodlands and Taxas Baccata wood, both of which are priority habitats. The Great Island Chanel SAC, Site Code 001058 and designated for mudflats and sandflats not covered by seawater at low tide and Atlantic salt meadows, and Cork Harbour SPA, Site Code 004030, so designated for a number of species, are located approximately 9km to the south of the site. The EIS notes that screening for Appropriate Assessment was undertaken (appendix D of Volume 3 of EIS). It was determined that a full AA was not required, as the subject site is located downstream of the River Blackwater SAC and at a distance from the Cork Harbour SAC so that no significant impact on designated habitats in either Natura 2000 site is expected to occur. Details of habitat types and their associated values are provided for within the EIS, supplemented through the response to the further information request and the appeal submission.

11.7.2 The primary habitat within the study area is commercial conifer plantation (WD4) amounting to 50%+ of the overall site. This habitat is considered to be artificial and of low local value although it is acknowledged that the forest provides cover for a range of mammal species, and is used regularly by fallow deer. The second most prominent habitat comprises improved agricultural grassland (GA1), which is also generally considered to be of low ecological value save for the network of hedgerows (WL1) which comprises the field boundaries and which are considered to be of local ecological value. In addition there are a number of treelines (WL2) which are located along the existing forestry tracks and public roads. These areas are considered to be of local ecological and conservation value. Five biodiversity areas are identified within or adjacent to the EIA study area with the historical Ballynona Wood located to the south of the site, Peafield Meadow, Portavarrig Wetland, Rathorgan Wetland and Walshtownmore Wetland. These areas are identified as semi-natural habitats and are of local biodiversity value. A site inspection noted that the Rathorgan Wetland has been entirely removed due to construction activities by other parties.

11.7.3 The lands within the specific study area are identified and described in the EIS which uses the classification scheme outline in *A Guide to Habitats in Ireland* (Fossit, 2000), with 5 habitats included. The development will result in the loss of some land areas / habitat, but the EIS notes that none are protected. The EIS states that a desktop review and habitat survey was undertaken, to include specific bat and bird surveys. Screening for Appropriate Assessment was undertaken and initially it was determined that a full AA was not required, as the subject site is located at a distance from any designated sites. The findings of the assessment indicate that the proposal will not impact directly on qualifying habitats for designated sites in the vicinity of the subject site.

11.7.4 I have considered all of the information provided, including all reports and assessments, pertaining to the proposed development. I acknowledge the concerns of the County Council's Ecologist with regard to possibility of impact on on-site habitats which have been identified and are noted to support bat species in particular, and I also have had regard to the submissions of the first party and associated experts. In terms of the response to the FI request, I note the details provided in sections 10.3 which relates to the areas of habitat to be removed to accommodate the proposed development and in particular the potential impacts associated with the loss and the bats which use the site. I will discuss this issue further below. I note the concerns arising that there are gaps in the information provided to facilitate the Board in making a decision in relation to the proposed development and notable, in terms of the potential for impact on Natura 2000 sites in the vicinity of the site. It is to be noted that all the proposed turbines are located at least 50m from any streams or watercourses, except for T5 which is located within 45m of a small water body, and no construction (including borrow pits, sub-station and mast) will take place within this buffer zone apart from the proposed water crossings and associated road construction.

11.7.5 A Habitat Map, showing the development layout, was also submitted as part of the EIS, Figure 6.4, supplemented by Figure 10.6 of the response to the FI request. The First Party, through submissions, seeks to provide an evaluation of each habitat type recorded on the site and details of the areas of habitats that will be directly impacted upon due to the development. The information provided suggests that the entire footprint of the development will cover 6.25ha, of a total development site area of 83.42ha, and a study area of 957ha, amounting to 7.49% of the total subject development site area. All of the turbines are proposed to be constructed within the conifer plantation and on improved agricultural grasslands. While I acknowledge the submissions in support of the proposed development, I share the concerns of the Planning Authority, and the Ecologist, in terms of the details relating to the removal of hedge rows and tree lines to accommodate the proposed development. I would concur that clear information and maps should be provided to clearly depict the exact areas of hedgerows and trees to be removed in order to consider the impacts of the development on these habitats, and the species they support.

11.7.6 In terms of mitigation, I acknowledge that the design and layout of the proposed wind farm sought to avoid sensitive habitats identified on the site many of which are of high local importance. While the development will have localised impacts in respect of biodiversity and habitat loss, given the nature of the primary habitats to be affected, I am satisfied that the loss is not so significant as to warrant concern. The environmental benefits derived from the application of a renewable energy source might reasonably be considered to balance any negative impacts on a site, particular having regard to the prevalence of commercial forestry and degraded habitats in the area. In terms of the detail submitted however, I consider that the potential impact on the hedgerow and semi-natural habitats on the site is significant and that the level of information provided is inadequate to fully consider the potential for significant impacts on the species they support.

Impacts on Flora & Fauna

11.7.7 The EIS presents details of a mammal survey and a bat survey where the following species were recorded within study area, fox, rabbit, Irish Hare, Fallow Deer, American Mink, Irish Stoat and red squirrel. The mammal survey also notes that it is possible that Otter may be present due to the proximity of the Dungourney River, but as the scale of the river is small in proximity to the site, it is unlikely to support breeding otters. The EIS does not note rare or threatened mammal species confirmed on the site. In terms of bats, the EIS records the Common Pipistrelle and the Soprano Pipistelle, both of which are listed on the Annex IV of the EU Habitats Directive, were found to be present on the site. Following the submission of the response to the further information request, the Leisler Bat and the Brown Long-Eared bat were noted to be present on the site with a roost identified in proximity to proposed T2. The Board will note that there is no real acknowledgement or discussion in the body of the FI response in this regard, although there is a Bat Survey report provided at appendix M. Mitigation measures are presented as part of this survey and assessment.

11.7.8 Birds: The Birds Survey was carried out over the summer and winter periods, using a combination of on-site surveys and counts, as well as a desktop study. The Board will note that additional surveys were carried out in order to fully respond to the further information request issued by Cork County Council. The County Councils Ecologist advised that concern remained even after the additional surveys and assessment and submits that due to the lack of appropriate information, a full and considered EIA and AA could not be undertaken with regard to the proposed development.

11.7.9 The EIS concluded that of the Bird Watch Ireland red and amber listed species recorded on the site, or indeed the Annex I species, it is unlikely that any breed within or close by the subject site. The EIS concludes that the potential for the wind farm to impact on any bid species is low. The Planning Authority does not appear to accept this view and I refer the Board to the Ecologist Report dated 19/06/201 in this regard. As such, I am inclined to consider that based on the information available in the EIS, it is likely that in principle the development, if permitted, will not so significantly impact upon protected birds species in the area. However, I also acknowledge the expert opinion that additional information would be required to be conclusive in this regard.

11.7.10 Bats: Further to my comments above, I consider that the proposed development has the potential to impact upon the bat population of the area. This is due to the proximity of tree lines and hedgerows where the bat population may congregate, together with the findings of the site survey undertaken. While I would consider that in principle, the nature of the existing coniferous plantation is not generally preferred by bats, I have serious concerns that the EIS and indeed, the response to the further information request, failed to acknowledge the presence of the bat roost in the body of the report. I also note that the Bat survey which was carried out at this time, also noted that the site has potential to support two further rare bat species, Nathusius pipistrelle and Brandt's Bat, with the bat assessor certain that Natterer's Bat and the Whiskered Bat also occur on the site. I also concur with the findings of the Cork Co. Co. Ecologist that mitigation measures identified were not carried into the body of the response to the further information.

11.7.11 As part of the overall assessment, the Board will note that a Bat Survey & Assessment prepared, concluded that the risk to bats have to be acknowledged and that it is possible that some bat mortality may occur due to the proposed development. As such, mitigation measures are recommended to reduce the likelihood of such fatalities. These mitigation measures are detailed in the Bat Survey & Assessment and include acknowledging the presence of the roost in proximity to T2, buffer zones, retention of trees / removal of trees, lighting restrictions and bridges. Overall the report concludes that the favourable conservation status of the Leisler Bat should not be affected and that the development could provide an opportunity to gain baseline data on bat / turbine interaction. The board will note that the appeal documents provide a proposal for the relocation of T2, to a location greater than 150m from the roost. The author of the Bat Assessment report has advised that the relocation of T2 and the curtailment of its use during night hours within the peak period of bat activity during June and July it is now considered that the potential risk to the onsite bat colony will be substantially reduced or negated. Should the Board be minded to grant planning permission in this instance, it is recommended that these mitigation measures are clearly conditioned.

11.7.12 Badgers: No badgers were recorded during the mammal survey which was undertaken at the site although it is acknowledged that it is likely that this species forages in the area. The EIS notes that no setts were recorded during the site survey but notes that areas of the site were inaccessible so it is possible that badger setts are present in those area. Having regard to the information provided, I consider that it is likely that badgers occur at the site, most likely in the grassland habitats in the lower lying areas of the site. Badgers are a protected species under the Wildlife Acts 1976 and 2000. It is an offence to intentionally kill or injure a protected species or to willfully interfere with or destroy the breeding site or resting place of a protected wild animal. Should the Board be minded to grant planning permission in this instance, I consider it appropriate that appropriate conditions be included in the interests of protecting the badger in this area.

11.7.13 Others: The EIS identifies other mammals which are offered protection under the Wildlife Acts including Irish hare and the fox as being confirmed on the site. In addition, rabbit, red squirrel, stoat, fallow deer and American mink are also noted as being present on the site due to the presence of suitable habitat. The red squirrel is likely to be affected by clear felling of trees if these trees are being used by the animals. Any construction impacts on other mammals identified are, likely to be temporary in duration and I am otherwise satisfied that the proposed development would not undermine the habitat of protected species or other fauna in a substantive way, and that the species can adapt to changes where appropriate mitigation is put in place.

11.7.14 Mitigation measures are presented in the EIS with regard to any damage caused to habitats by the proposed development. The appeal submission, in relation to ecology, concludes that overall, the issues raised have been fully addressed. It is submitted that the site is not considered to sustain significant populations of birds of conservation concern and that the development is not considered to pose a risk to birds. In terms of habitats, it is submitted that mitigation measures have been presented to address the loss of 570m of hedgerows and tree lines which will result in the provision of a benefit to the biodiversity of the area post construction. T2 will be relocated in order to avoid the bat roost and restrictions on the timing of operations of this turbine will be applied to minimize the impact on the bat roost. I remain concerned that matters surrounding ecology contain a certain about of gaps in the information provided and as such, I consider it appropriate to err on the side of caution in this instance. I am not satisfied that it can be clearly determined that the development, if permitted will not have a significant impact on habitats, flora and fauna.

11.8 Water Quality & Hydrogeology

11.8.1 In terms of water quality, the EIS provides information regarding ground and surface water features and characteristics on and in the vicinity of the site. The EIS considers that the risk to ground waters is generally negligible and that surface water is the main sensitive receptor. The potential impacts associated with the proposed development in terms of ground water are considered in the document and the risk of pollution from hydrocarbon spills, leakages at borrow pits and from the waste water treatment system are identified as the primary risks. In terms of surface waters, the EIS acknowledges the sensitivity and quality of waters downstream of the site, including the Cork Harbour SPA and the Great Island Channel SAC. Potential risks are identified as surface runoff and the EIS provides an assessment of changes in site runoff volumes. It is concluded that the increase from the site post development will be negligible even before mitigation measures are put in place, providing no risk of flooding down gradient of the site.

11.8.2 The potential impacts on the hydrological and hydrogeological environments during the operational phase are also discussed in the EIS. In order to facilitate the proposed development, new roads, tracks, hard stands and turbine bases will be required which has the potential to affect surface water flow. The EIS concludes that subject to the implementation of mitigation measures, it is considered that the risks to geology and hydrogeology are considered to be negligible.

11.8.3 The development will include the felling of 36.8ha of commercial forestry and as such best practice Forestry Service Guidelines are relevant. Mitigation measures required in these guidelines should be applied to reduce the risk of entrainment of suspended solids and nutrient release in surface watercourses. Finally, the EIS discusses the potential for cumulative impacts associated with the proposed development as well as residual impacts and monitoring. Should the Board be minded to grant planning permission in this instance, I am satisfied that issues relating to water quality protection can be appropriately dealt with by way of condition.

11.9 Adequacy of the EIS

The nature of the development the subject of this planning application requires an EIS to be prepared under the EIA Directive. The EIS has been prepared in support of the planning application and has been advertised in the public notices submitted with the application to Cork County Council. The content of the EIS is summarised above in section 3 of this report, while section 12 below provides an assessment of impacts of the development on the receiving environment.

While I consider that the EIS originally submitted with this application generally presents the potential issues arising from the development and might reasonably be considered as being in accordance with the requirements of Schedule 6 of the Planning & Development Regulations, 2001, I have some reservations as to the lack of information provided with regard to the assessment of the issues and how the conclusions were reached.

The Board will note the extensive further information request that issued from Cork County Council which was responded to on 22nd April, 2014. In addition, I would refer the Board to the comments of Cork County Councils Ecologist who has considered the proposed development and the information provided in support of same but who, even after the receipt of the further information request response, remains of the opinion that 'insufficient information has been provided to complete EIA and screening for Appropriate Assessment.' The Appeal submission provides for additional information which is to be considered.

11.10 Other Issues

11.10.1 Interference with Telecommunications

It is a common submission that wind energy development may have a negative impact on TV reception in the area of such developments. The Frequency Planning and Coverage Department of RTE Transmission Network Ltd requires proposed wind farm applicants to sign a protocol document to ensure remedial measures are implemented to rectify any interference should it arise. It is normal for RTE to monitor such potential interferences and if detected, will investigate and report where necessary to the wind farm operator if it determines that the interference is attributable in whole or in part to the wind farm development. I am satisfied that this is acceptable.

11.10.2 Access to National Grid

The ultimate decision with regard to connection lies with the ESB, who will not usually consider a grid connection offer until permission has been granted for a wind farm. Connections to the grid are usually made through a 20kV or 38kV line. In this instance, the Board will note that the applicant already has secured a Gate 3 grid connection offer to connect the wind farm to the national electricity grid at the existing 110ikV Midleton substation at Carrigogna via an underground cable. The first party has submitted that the precise route of the underground grid connection is not confirmed at this point. The location of the sub-station is not clearly identified in the submitted documentation but the Board is advised that it is located approximately 8km to the south, south west of the site. I'm satisfied that this is acceptable.

11.10.3 Impact on Recreation, Amenity & Tourism

It is a requirement of policy INF 7-4 of the Cork County Development Plan, to have regard to a number of criteria in the consideration of a proposed wind energy project including those which might reasonably be considered as important in relation to the tourism draw of a particular location. Such criteria include:

- *The sensitivity of the landscape and of adjoining landscapes to wind energy projects;*
- *The scale, size and layout of the project, any cumulative effects due to other projects, and the degree to which impacts are highly visible over vast areas;*
- *The visual impact of the project on protected views and prospects, and designated scenic landscapes as well as local visual impacts;*
- *The impact of the project on nature conservation, archaeology and historic structures;*

The EIS notes that the main tourist attractions in the vicinity of the site are an open farm near Dungourney, 4.5km south west of the site and the Jameson Experience in Midleton, approximately 9km to the south of the site. While no key identified tourist attractions pertaining to the site have been identified, the EIS notes that Coillte has an open forest policy which means that their sites are generally accessible for people on foot. The EIS concludes that it is not considered that the proposed development would have an adverse impact on recreation and amenity, including tourism.

While there is no 'obvious' tourist attraction in this area, it is in fact, the area, its local towns and villages, and the landscape that is the draw for many tourists in this area of Cork. It is also to be noted that the issue of wind turbines and their attractiveness is a wholly subjective issue. The Board will also note the distinct lack of turbines in this area of Co. Cork. The applicant seeks to suggest that due to the presence of the distillation plant in the area, together with the maturation warehousing that is currently under construction, there is change to the character of this landscape, which "has been that of low intensity upland rural landscape with some remoteness and tranquillity". It is suggested this is "changing slightly towards a landscape of rural industry" and that "the wind farm will contribute to this change but is more typical of emerging trends in upland rural landscapes than a distillery is." I would not agree with this statement and I refer to my consideration of the visual impacts associated with the development as proposed above in section 11.3 of this report.

12.0 ENVIRONMENTAL IMPACT ASSESSMENT:

12.1 In accordance with the requirements of Article 3 of the European Directive, Directive 85/337/EEC, as amended by Council Directive 97/11/EC of 3rd March 1997, by Directive 2003/35/EC of the European Parliament and of the Council of 26th May 2003, and Section 171A of the Planning & Development Act 2000-2010, the environmental impact statement submitted by the applicant is required to be assessed by An Bord Pleanala, as the competent authority. It is a requirement that the direct and indirect effects of the proposed project are identified, described and assessed in an appropriate manner, in accordance with Articles 4 to 11 of the Environmental Impact Assessment Directive. As indicated above in section 3.0 of this report, the EIS submitted in support of this proposed development is made up of four volumes including a Non-Technical Summary, Main Report, Appendices and Photomontages, where the potential impacts of the proposed development on the environment are detailed.

The Board will note at this point that the information submitted in response to the further information request from the Planning Authority is also considered in my EIA. The following is an assessment of the main impacts identified, and which I consider to be most relevant to the subject site and development and I would advise that I have concerns with regard to a number of issues including noise, visual impact, the water environment and ecology, notably in terms of the information and evidence provided, as well as the conclusions of no significant impacts on the environment contained in the EIS.

12.2 Category 3(i) of schedule 5 of Part 2 of The Planning and Development Regulations 2001, provides that an Environmental Impact Statement shall be prepared in respect of a planning application for the following development:

"Installations for the harnessing of wind power for energy production (wind farms) with more than 5 turbines or having a total output greater than 5 megawatts."

As the application involves a wind farm of 11 turbines with a rated electrical output of approximately 25.3MW, the proposed development is subject to mandatory EIA. Grid connection has been secured for a capacity of 21.6MW.

12.3 The Environmental Impact Statement submitted with the application, dated January 2013 is in 4 volumes as described above and is in the grouped format structure. In general, I consider that the EIS, supplemented by further information response, while providing an appropriate level of detail and scientific evidence with regard to a number of environmental aspects, fails with regard to others. I will discuss these below. I will also have regard to the specialist reports prepared both in support of the proposed development and those from the Planning Authority in this regard.

12.4 I consider that the EIS seeks to compliance with Articles 94 and 111 of the Planning and Development Regulations, 2001, as amended. In this regard, it is notable that the EIS contains the information specified in paragraph 1 of Schedule 6 of the Regulations. The EIS seeks to -

- Describe the proposal, including the site and the development's design and size;
- Describe the measures envisaged to avoid, reduce and, if possible, remedy significant adverse effects;

- Provide the data necessary to identify and assess the main effects the project is likely to have on the environment;
- Outline the main alternatives studied and the main reasons for the choice of site and development, taking into account the effects on the environment.

The EIS, supplemented by the further information response, seeks to provide the relevant information specified in paragraph 2 of Schedule 6 of the Regulations. This includes-

- A description of the physical characteristics of the project and its land use requirements;
- The main characteristics of the wind energy process to be pursued;
- The emissions arising resulting from the operation of the proposed development;
- A description of the aspects of the environment likely to be significantly affected by the proposal;
- A description of the likely significant effects on the environment resulting from the development's existence, the development's use of natural resources, the emission of pollutants and creation of nuisances, and
- A description of the forecasting methods used; and
- Provision of an indication of any difficulties encountered in compiling information.

There is an adequate summary of the EIS in non-technical language, although I would suggest that certain information is lacking in this summary.

12.5 Issues arising with regard to the adequacy of the EIS are detailed in a number of Cork County Council internal engineering reports, notably with regard to noise, the water environment and ecology. I also note the credentials of the consultants who prepared the sections of the EIS in relation to these matters, but I would concur with the Planning Authority that there are a number of concerns arising.

In addition, I note the concerns of the SEP in terms of visual impact and amenity but I accept that the information is provided in order to determine impacts, so in this regard, I consider that the EIS, supplemented with the response to Further Information, is acceptable with regard to the visual impact assessment. I also note the comments of the Senior Planner in terms of EIA Report / NIS, who states that "the EIS is acceptable in relation to the scope of issues addressed having regard to reports on file (Noise, Hydrology / Hydrogeology and Ecological Issues) I conclude that it has not been shown that the proposal would not have a significant negative impact on the Environment. Having regard to the Ecologists / Hydrologists report and Habitats Directive requirements I do not consider that the potential impacts on relevant sites have been screened out and therefore AA screening cannot be completed."

12.6 The EIS considered the main likely significant direct and indirect effects arising from the proposed development. The main likely receptors and effects are presented in the Summary of Interactions of the Main Environmental Effects, Figure 15.1 of EIS as follows:

1.	Ecology	-	**Const. phase**	**Operational**
			Tree felling	Noise
			Traffic	Visual
			Excavation	Energy Output
			Noise	Drainage
				Traffic
				Change in land use
2.	Hydrology & Water Quality	-	**Const. phase**	**Operational**
			Tree felling	Drainage
			Traffic	Traffic
			Excavation	Change in land use
3.	Geology & Hydrogeology	-	**Const. phase**	**Operational**
			Tree felling	Drainage
			Traffic	Geotechnical
			Excavation	Change in land use
4.	Landscape	-	**Const. phase**	**Operational**
			Tree felling	Visual
			Traffic	Change in land use
			Excavation	

			Noise	
5.	Human Environment	-	**Const. phase** Tree felling Traffic Excavation Noise	**Operational** Noise Visual Energy Output Drainage Shadow Flicker Traffic Change in land use
6.	Archaeology & Cultural Heritage	-	**Const. phase** Tree felling Excavation	**Operational** Visual Change in land use
7.	Air & Climate	-	**Const. phase** Tree felling Traffic Excavation	**Operational** Energy Output Traffic Change in land use

12.7 Description of the likely significant effects of the proposed development on the environment:

The likely effects arising from the development proceeding are anticipated to include the following-

12.7.1 Ecology:

<u>Habitats:</u> There are no designated sites located within 3km of the proposed site boundary. The Blackwater River (Cork / Waterford) SAC is located 3.1km to the north of the proposed development site. The Great Island Channel SAC and pNHA and Cork Harbour SPA are located 9.1km to the south of the site. These sites are connected to the subject site as tributaries of the Owenacurra and Dungourney Rivers rise in the site and flow south to the Natura 2000 sites. Impacts on water quality in the surface water bodies and rivers, has the potential to impact upon the designated sites, while impacts on the surface water system at the construction stage due to drainage and peat disturbance. No protected

plant species, rare or protected species were recorded during the habitat and botanical surveys of the site.

Mitigation measures include: Buffer zones around water courses, detailed drainage arrangements; development footprint to be kept to a minimum including tree felling, general pollution protection, Environmental Management Plan;

Fauna: Impacts on birds, mammals and other fauna which use the site and adjoining watercourses. 6 protected species, under the Irish Wildlife Acts (1976-2012) were identified on the site and 4 species of bat with a Brown Long-eared bat roost was identified. In terms of birds, Annex I species Golden Plover and BWI red listed species Meadow Pipit were recorded within the proposed development site. In addition, there were recorded sightings of Kestrel, Buzzard and Snipe, but it is submitted that there is no indication that these species are breeding at the site and it is unlikely that the site is of importance to such species. Mitigation measures with regard to birds include the carrying out of works outside the breeding season and the planting of additional treesl and hedgerows along existing gaps

12.7.2 Human Environment:

Employment: 20 Short-term jobs at the construction stage, with no clear indication of the number of maintenance jobs during the operational phase.

Visual Impacts: This issue while acknowledged in the EIS is understated in my opinion.

Tourism: Visual and landscape impact distorting the natural tourism product. However, no significant negative impacts because of a generally positive attitude to wind energy and existing wind farms in the area.

Shadow Flicker: Shadow flicker may be cast on neighbouring residential properties. Shadow flicker was assessed in the EIS in relation to residential properties in the vicinity of the site and included total of 45 houses. The assessment concluded that shadow flicker is predicted to occur at 27 of the 45 houses and that DoEHLG guideline total values could be exceeded at 22 houses as a worst case scenario. When the regional sunshine data is considered, 3 houses are potentially affected, all of which belong to participating landowners.

Noise: Noise associated with the proposed operation of turbines is in two forms, the noise from the generator itself and the 'swoosh' noise as the blades move through the air. The submitted EIS figures would suggest that there will be an exceedence at one location but concludes that the proposed development can be designed so as to meet noise criteria for residential properties in the area, including the draft guideline of 40dB $_{LA90, T}$. Mitigation measures are advised in relation to construction noise, in line with best practice measures.

Traffic: Short term local community impact associated mainly with the construction phase of the development and the transportation of turbine elements and construction materials.

12.7.3 Soils, Hydrogeology and slope stability:

Peat stability: Potential of a peat slide from stored or disturbed peat is considered negligible.

Extraction of rock: Three borrow pits for rock extraction are proposed in order to provide for construction purposes.

Hydrogeology: Impact associated with the proposed necessary water crossings

12.7.4 Hydrology & Water Quality:

Effect on water quality: Changes in site run-off volumes, impacting on water chemistry for fish, siltation in streams.

Effect on important habitats located on site and downstream from the site.

12.7.5 Air & Climate:

Climate Change: Role of renewable energy and climate change.

Noise disturbance: Mechanical and aerodynamic noise impacts on residents.

Vibration

12.7.6 Landscape and Visual Impact:

Scale and height and extent of visibility: Intrusive visual effects on the wider area beyond the site.

Impact on landscape character: Distortion of the natural landscape character.

Impact on views: Potential incongruity with views into, across and beyond the site, notably from designated scenic route to the north.

12.7.7 Archaeology & Cultural Heritage:

Archaeology: Disturbance to or potential destruction of on-site archaeology, including newly discovered archaeology.

Cultural Heritage: visual impacts associated with development on protected structures.

12.7.8 Material Assets:

Road Network: The transportation of materials will have certain consequences for the structure and carrying capacity of the existing local roads at certain points along the proposed delivery route.

Telecommunications: Electromagnetic interference with telecommunications signals may occur.

Forestry: Clear-felling of commercial plantation to be undertaken on the site to facilitate the siting of the turbines and the provision of internal roads.

12.7.9 Interactions:

The effects of the interactions between humans and air quality, the visual landscape, flora & fauna and water and soils; and landscape and the natural environment are implicit in the range of preceding issues listed.

12.8 Assessment of the Likely Significant Effects Identified, having regard to the mitigation measures proposed:

The assessment contained in this report fully considers the range of relevant likely significant effects having regard to the information submitted with the planning application, together with all the comments and submissions made in relation to the proposed development. Mitigation measures proposed to be applied if the proposed development proceeds will be fully integrated to that assessment. Some of the more important mitigation measures proposed to be employed which are considered necessary to address the range of potential significant impacts arising from the proposed development include as follows:

12.8.1 Human Environment:

Shadow flicker: The EIS assessment concluded that shadow flicker is predicted to occur at 27 of the 45 houses and that DoEHLG guideline total values could be exceeded at 22 houses. When the regional sunshine data is taken into account, and assumes 40% sunshine, this number is reduced to 3 houses being affected per year, H44, H45 and H46, all of which belong to participating landowners. Mitigation is not explicitly proposed and the EIS suggests that where an issue arises, mitigation requirements will be assessed by way of a procedure of evaluation of the existing screening, window orientation and the periods of shadow flicker actually occurring and will be carried out in consultation with the relevant landowner. The wind turbine control system could include the shutting down of particular turbines at specific times of specific days of the year.

Noise: Noise mitigation measures were indicated as having been included as part of the overall design and layout of the proposed development. The EIS considers that the impact associated with noise is considered to be within the established parameters and guideline limits. I have advised my concerns in relation to noise associated with the proposed development and the potential impacts on the human environment in the vicinity of the site.

12.8.2 Flora & Fauna

Designated sites: Impacts on water quality in surface water bodies which feed Great Island Channel SAC and pNHA and Cork Harbour SPA are located 9.1km to the south of the site. These sites are connected to the subject site as tributaries of the Owenacurra and Dungourney Rivers rise in the site and flow south to the Natura 2000 sites.

Impacts on on-site habitats: Minimal loss of habitat

Species: Minimal reducing in the diversity of species.

Avifauna: Minimal impact for conservation species. I have advised my concerns in relation to the potential impacts on the birds using and in the vicinity of the site.

6.25ha (about 7.5%) of the entire site will be subject to development works. The amount of soil or rock to be disturbed is relatively limited.

The mitigation measures designed to limit silt/hydrocarbons moving into and down-stream/river systems are adequate.

The areas to be subject to construction works – existing roads/conifer plantations are not significant habitats for birds of conservation value and the proposed development will not negatively impact on species.

12.8.3 Soils & Hydrogeology

It is unlikely that the proposal will give rise to peat slides.

12.8.4 Hydrology & Water Quality

Water quality: Minimising run-off volumes, drainage design and control, Best practice methods during construction phase.

Natural water system: Maintaining routes of natural watercourses, avoiding natural watercourse crossings where possible.

Important habitats: It is suggested that there will be no direct discharge to any water body arising due to the proposed development.

The spatially limited extend of the works within the site, together with the mitigation measures proposed in the EIS and additional submissions to the planning authority and the Board should ensure against deterioration in water quality status.

12.8.5 Air, Climate

The proposed development will contribute to limiting CO_2 emissions.

12.8.6 Landscape and Visual Impact

Landscape character and important views: Separation distance from the public realm.

Cumulative impact: Not relevant.

The EIS submits that there will be minor and on-going visual intrusion from the proposed development but not sufficient as to seriously negatively impact on areas of special landscape importance or views or prospects which it is necessary to preserve. The matter of localised visual impact is considered in terms of residential amenity, which I consider to be significant and understated in the EIS.

12.8.7 Archaeology & Cultural Heritage

Archaeology: The identified archaeological remains on will be protected during construction by means of the application of buffer zones, and archaeological monitoring will be undertaken during the site preparation and construction phases.

Cultural Heritage: subject to the implementation of mitigation measures and appropriate conditions, the proposed development can be considered acceptable.

12.8.8 Material Assets

Road network: Heavy materials delivery and plant transportation with access junction improvements where necessary. The impacts on the local road network will be limited to the construction phase and will not permanently negatively impact on the local road network.

Telecommunications: Careful siting of turbines to minimise interference with existing telecommunications infrastructure. Adherence to protocol.

Aviation: Warning lights affixed to turbines. The impact on air navigation is not raised as a significant issue of concern.

12.9 Conclusions Regarding the Acceptability or Otherwise of the Likely Residual Effects Identified

The conclusions regarding the acceptability of the likely main residual effects of this proposal are clearly addressed under the various headings of the main assessment above. The principal areas of concern, in my opinion, focus on residential amenity, visual impacts, noise and ecology issues. In terms of the comments of the PA in relation to EIA, I do accept that there is somewhat limited information and assessment provided in support of the proposed development where there are outstanding issues particularly with regard to residential amenity and ecology which preclude me from determining that there will not be a significant environmental impact associated with the proposed development.

13.0 APPROPRIATE ASSESSMENT:

13.1 The obligation to undertake appropriate assessment derives from Article 6(3) and 6(4) of the Habitats Directive. Essentially it involves a case by case examination for Natura 2000 site and its conservation objectives. Appropriate Assessment involves consideration of whether the plan or project alone or in combination with other projects or plans will adversely affect the integrity of a European site in view of the site's conservation objectives and includes consideration of any mitigation measures to avoid reduce or offset negative effects. This determination must be carried out before a decision is made or consent given for the proposed plan or project. Consent can only be given after having determined that the proposed development would not adversely affect the integrity of a European Site in view of its conservation objectives.

13.2 The submitted EIS at Appendix D3, provides a Screening Report for AA prepared by Fehily Timoney & Company. This report identified three Natura 2000 sites within 10km of the subject site including

- Blackwater River (Cork / Waterford) SAC (Site Code 002170)
- Great Island Channel SAC (Site Code 001058)
- Cork Harbour SPA (Site Code 004030)

13.3 The Blackwater River (Cork / Waterford) SAC (Site Code 002170) is located 3.1km to the north of the site but it is submitted that it is not hydrologically connected to the proposed development site and is therefore not potentially impacted upon by the proposed development. The report seeks to address the other identified Natura 2000 sites and identifies the qualifying interests associated with the sites as well as the conservation objectives afforded to same. The report submits that there will be no direct impacts on the Natura 2000 sites. It is not considered likely that there will be any indirect impacts on the Natura 2000 sites during the construction of the wind farm project or in conjunction with the development at the adjacent Distillery Storage house, due to the distance of the proposed development from Cork Harbour.

13.4 The Great Island Channel SAC (Site Code 001058) is located approximately 9km to the south of the subject site. This SAC is so designated for the following qualifying interests:

Estuaries [1130]
Mudflats and sandflats not covered by seawater at low tide [1140]
Spartina swards (Spartinion maritimae) [1320]
Atlantic salt meadows (Glauco-Puccinellietalia maritimae) [1330]

13.5 The Cork Harbour SPA is located approximately 9km to the south of the subject site. This SPA is so designated for the following qualifying interests:

Little Grebe (*Tachybaptus ruficollis*) [A004]
Great Crested Grebe (*Podiceps cristatus*) [A005]
Cormorant (*Phalacrocorax carbo*) [A017]
Grey Heron (*Ardea cinerea*) [A028]
Shelduck (*Tadorna tadorna*) [A048]
Wigeon (*Anas penelope*) [A050]
Teal (*Anas crecca*) [A052]
Pintail (*Anas acuta*) [A054]
Shoveler (*Anas clypeata*) [A056]
Red-breasted Merganser (*Mergus serrator*) [A069]
Oystercatcher (*Haematopus ostralegus*) [A130]
Golden Plover (*Pluvialis apricaria*) [A140]

Grey Plover (*Pluvialis squatarola*) [A141]
Lapwing (*Vanellus vanellus*) [A142]
Dunlin (*Calidris alpina*) [A149]
Black-tailed Godwit (*Limosa limosa*) [A156]
Bar-tailed Godwit (*Limosa lapponica*) [A157]
Curlew (*Numenius arquata*) [A160]
Redshank (*Tringa totanus*) [A162]
Black-headed Gull (*Chroicocephalus ridibundus*) [A179]
Common Gull (*Larus canus*) [A182]
Lesser Black-backed Gull (*Larus fuscus*) [A183]
Common Tern (*Sterna hirundo*) [A193]
Wetlands & Waterbirds [A999]

In terms of the above, the Board will note that the Golden Plover has been identified as frequenting the subject site.

13.6 In addition to the above identified Natura 2000 sites, the Board will note that the Blackwater Callows SPA is located approximately 11km to the north of the site. This SPA is so designated for the following qualifying interests

Whooper Swan (*Cygnus cygnus*) [A038]
Wigeon (*Anas penelope*) [A050]
Teal (*Anas crecca*) [A052]
Black-tailed Godwit (*Limosa limosa*) [A156]
Wetlands & Waterbirds [A999]

It is the stated objective to maintain or restore the favourable conservation condition of the bird species listed as Special Conservation Interests for the two identified SPAs. The AA Screening report submitted in support of the proposed development noted that the subject site may affect the flight path of a number of bird species travelling between the Cork Harbour SPA and the Blackwater Callows.

13.7 The site the subject of this appeal itself can be considered a commercial forest. However, given that there are Natura 2000 sites located within 15km of the site, the Board will be required to consider the potential effects of the proposed development on the identified SPAs and SACs.

The site must be subject to AA regarding its implications for the Natura 2000 site in view of the site's conservation objectives *"if it cannot be excluded, on the basis of objective information, that it will have a significant effect on that site, either individually or in combination with other plans or projects"* (EC, 2006). In other words, where doubt exists about the risk of a significant effect, an Appropriate Assessment must be carried out.

13.8 Having considered a number of potential significance indicators which have regard to any potential or likely effects of the proposed development on the on-site habitats, together with the habitats so protected under the designated SACs within 15km of the subject site, it is clear that the potential impact associated with the proposed development relates to the deterioration of water quality, which could have an indirect effect on the species and habitats that occur within the SACs. That said, I consider that, given the scale of the proposed development, together with the distance between the site and the SACs and the mitigation measures proposed in the EIS, the proposed development is unlikely to have an impact on the Natura 2000 sites within the 15km of the site. I am of the opinion therefore, that the development, if permitted, is likely to have little or no impact on the proximate Natura 2000 site. Invoking Article 28 and seeking the comments of the NPWS, is unnecessary in my opinion.

13.9 The EIS determined that a full AA was not required, as the subject site is located at a distance from any designated sites and that no significant impact on designated habitats is expected to occur. The Planning Authority have considered that due to inadequate information pertaining to protected species supported by the Natura 2000 sites, which were identified within the study area, AA could not be completed in this instance. The Board will note that a number of protected bird species were noted on and off site during the surveys, many of which are qualifying species associated with the Cork Harbour and Blackwater Callows SPAs.

13.10 The safeguards set out in Article 6(3) and (4) of the Habitats Directive are triggered not by certainty but by the possibility of significant effects. Thus, in line with the precautionary principle, it is unacceptable to fail to undertake an appropriate assessment on the basis that it is not certain that there are significant effects. Having regard to information provided, and in terms of screening for AA, I concur with the findings of the County Council Ecologist and suggest that there is no certainty that there will not be an impact associated with the proposed development on the protected bird species, supported by the Natura 2000 sites and which are known to frequent in and around the subject site. It is therefore, not appropriate to 'screen out' the potential for significant impacts affecting said species.

14.0 CONCLUSION & RECOMMENDATION

14.1 Conclusion:

14.1.1 Having regard to the information submitted in support of the application together with all reports and third party submissions, and the requirements of the Cork County Development Plan 2009-2015 and in particular, as it relates to the provision of wind energy projects, the Board will note that while the subject site is not located within a 'strategic search area', neither is it located within a 'strategically unsuitable area'.

14.1.2 As such, it is reasonable to consider the potential for the site with regards suitability for the proposed development of a wind energy project in terms of the criteria stipulated in objective INF 7-4 of the Plan which deals specifically with Wind Energy Projects, and in particular part (c) of same. In this regard, I am satisfied that, subject to the normal planning criteria identified, in principle, it can be considered that the subject proposed site is suitable for the proposed development, and as such, a grant of planning permission would not, in principle, constitute a material contravention of the Development Plan, contrary to the indication of same by the Planning Authority in its reasons for refusal.

14.1.3 In relation to the roads and traffic issues, I consider that at minimum, a schedule of traffic and potential movements, including possible routes through the area, should be provided for consideration. Given the nature of the proposed development, these proposals should also be considered by the Roads Section of the County Council for comment and recommendation of conditions. However, I do not consider that the long term impacts of the development on the local road network is so significant as to warrant refusal of planning permission in this instance.

14.1.4 I further consider that the proposed development, subject to the mitigation measures indicated, will not so significantly impact upon archaeology, water quality, geology and hydrogeology of the site or the immediate vicinity of the site, as to warrant refusal of planning permission.

14.1.5 Notwithstanding the above, I do have a real concern regarding the scale of the proposed wind energy project which would exist on this site given its rural, but well-populated, low lying location, particularly in terms of visual impact and certain residential amenity impacts. I consider that the development as proposed will give rise to significant impacts on existing residential amenity. I consider that the development of turbines which are 156.5m high would substantially dominate the surrounding landscape and in my opinion, would be contrary to the provisions of The Department of Environment Heritage and Local Government Planning Guidelines for Wind Energy (June 2006). In this regard, I consider that the proposed provision of 11 turbines of the height propose at this location would adversely impact upon the visual amenities of the area, warranting refusal.

14.1.6 I have also indicated concern regarding the potential impact of the development on the residential amenities of a significant number for of residences in the immediate vicinity of the subject site, notably in terms of visual impact arising from the development.

14.1.7 Further to the above, I have considered the potential impact of the development on the ecology of the site. As part of my EIA, I have concluded that inadequate information has been provided to determine that the development, if permitted, will not have a significant and negative impact on habitats and flora fauna on the site, notably with regard to birds and bats and the loss of extensive areas of hedgerows and tree lines. I would concede to the findings of the County Council Ecologist in this regard.

14.1.8 In relation to Appropriate Assessment (AA), should the Board be minded to grant planning permission for the proposed development, then full screening for AA would have to be carried out as part of that consideration.

14.2 Recommendation:

Having considered the contents of the application including the Environmental Impact Assessment and all specialist reports contained therein, the decision of the planning authority, the provisions of the Cork County Development Plan, the provisions of the Wind Energy Development Guidelines (DOEHLG 2006) the grounds of appeal and the responses thereto, the observations made to the Board, my site inspection and my assessment of the planning issues, I recommend that permission be refused for the reasons set out hereunder:

REASONS AND CONSIDERATIONS

1 Having regard to the information submissions made in connection with the application by reference to ecological and noise impacts (which is considered deficient) the planning authority are not satisfied that the proposed development would not have a significant and adverse impact on the amenities and environment of the area including significant adverse impacts on:

- Noise sensitive locations in the vicinity, and
- Ecology of the area including protected species and sites.

The proposed development would therefore be contrary to the provisions of The Wind Energy Guidelines for Planning Authorities issued by the DoEHLG in June 2006 and would be contrary to the proper planning and development of the area.

2. Having regard to the number, scale and height of the proposed turbines, the proximity of the proposed turbines to a number of residential properties in the vicinity and notwithstanding the proposed mitigation measures contained in the submitted EIS, it is considered that that the proposed wind energy development, if permitted, would significantly and adversely impact upon the existing residential amenities of a number of houses in the vicinity by reason of visual impact and overbearing and noise impacts associated with the turbines considering the baseline noise levels identified in the EIS and supplementary documentation provided in

support of the proposed development. The development therefore, would seriously injure the existing residential amenities of the area and would be contrary to the proper planning and sustainable development of the area.

3. It is the stated objective of the current Cork County Development Plan, 2009, Objective INF 7-4, to consider the scale, size and layout of the wind farm and consider cumulative effects as well as local visual impacts. Having regard to the nature of the receiving low lying landscape and the open nature of the adjoining lands, it is considered that a wind farm development of the scale proposed would create a significant visual intrusion in this landscape by reason of the height and spatial extent of the proposed turbines which would be excessively dominant and visually obtrusive in the receiving landscape and when viewed from the surrounding countryside and villages. The proposed wind energy development would, therefore, seriously injure the visual amenities of the area, would be contrary to the provisions of The Department of Environment Heritage and Local Government Planning Guidelines for Wind Energy (June 2006), the objectives of the County Development Plan, 2009 and would be contrary to the proper planning and sustainable development of the area.

A. Considine,
Planning Inspector.
21st October 2014.

◀ P54

and velocity, v(f) and * signifies the complex conjugate. It is plotted in dB in figure 5 along with the two idealised lumped-parameter impedances of $i\omega m$ and $\rho c_L S$. It can be seen that while peaks in the spectrum reach the upper $i\omega m$ curve, at most frequencies the curve is closer to the lower $\rho c_L S$.

Figure 6 shows the velocity transmissibility of the bearings along with the SDOF transmissibility curve. Figure 6 shows, in 1/3 octave bands, the velocity transmissibility relative to the base velocity of the building with the bearings in place, and Figure 7 is the velocity transmissibility relative to the base velocity of the building with rigid support so that it takes account of the effect of the bearings on the source below as well as the structure above. Of particular note is the absence of a peak at the SDOF bearing natural frequency, and the presence of two coupled peaks, one above and the other below the SDOF natural frequency, resulting from the coupling between the structure above the bearings and the foundations below. Comparison of Figure 7 with Figure 6 shows that when the change in the foundation velocity is taken into account, the actual transmissibility more closely resembles that predicted using the driving point impedance of an infinite column than a lumped mass.

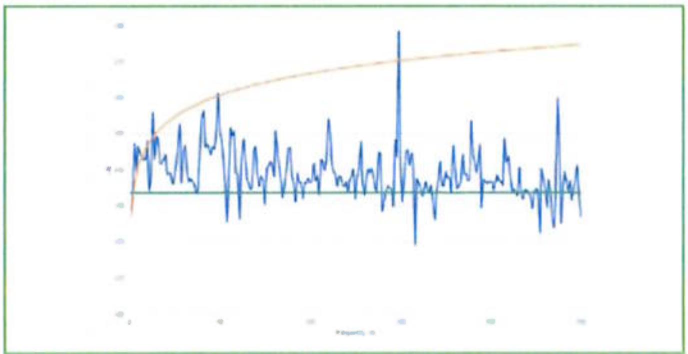


Figure 5. Driving point impedance of (1) column above bearing (middle curve) together with (2) an equivalent lumped mass (upper curve) and (3) an infinite column

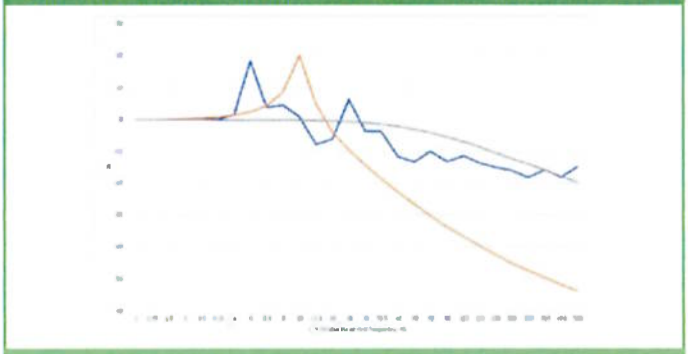


Figure 6. Velocity transmissibility of the 10Hz bearings (1) from the FDTD model (middle curve) together with (2) an equivalent lumped mass (lower curve) and (3) an infinite column (upper curve)

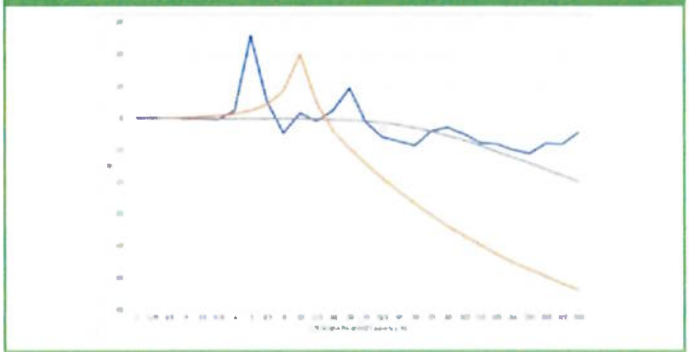


Figure 7. Velocity transmissibility of the 10Hz bearings relative to the base in the unisolated building(1) from the FDTD model (middle curve) together with (2) an equivalent lumped mass (lower curve) and (3) an infinite column (upper curve)

Conclusions

It can be concluded the predicting the performance of a base-isolation system over the frequency range relevant to the reduction of groundborne noise using a SDOF model is likely to lead to an over-optimistic result is the base of large, tall or complex buildings. The reasons for this have been discussed and primarily relate to the dynamic response of such buildings which will limit the driving point impedance of the structure "seen" by the top of the bearings. The additional degrees of freedom of a lumped mass are only a partial explanation. Additionally, the use of a simple velocity transmissibility equation can be misleading, as the velocity of the base is affected by the insertion of the bearings. The SDOF model also fails to allow for coupling between the mass-on-a-spring of the building and its bearings and the mass and spring system which exists in the foundation.

Numerical modelling is capable of taking all these matters into account, and provides the most detailed method of predicting the performance of base isolation systems. ◘

__Rupert Thornely-Taylor__ began working in acoustics in 1964 and has run his own practice since 1968. A former member of the Noise Advisory Council, he was also a member of the Scott Committee which drafted the basis of the noise section of the Control of Pollution Act 1974.

References are available from the Editor at **ioa@ioa.org.uk**

A planning condition for wind turbines

This article has been contributed to by Andy McKenzie, Matthew Cand, Dick Bowdler, Mark Jiggins, Gavin Irvine, Michael Reid, Richard Perkins, Michael Lotinga, Malcolm Hayes and Andrew Bullmore

Introduction

This article sets out a proposed wording for a planning condition on noise for wind farms or individual wind turbines.

Whilst local authorities and developers have waited for a planning condition that could be applied to newly consented wind farms, or to those already consented but with a suspensive condition, the report Wind Turbine AM Review (WTAMR) by WSP/Parsons Brinckerhoff for DECC arguably did not provide that. In addition there have been a number of comments on WTAMR that we consider should be addressed. The introductory sections and the conditions text represent the broad consensus view of those whose names appear below, following a period of discussion, compromise and agreement. This approach is proposed based on the current state of understanding, but may be subject to modification in light of new research and further robust information.

Copies of the condition only in Word format are available from the following websites:

- **www.hayesmckenzie.co.uk/uploads/A_Planning_Condition_for_Wind_Turbines_Sept_2017.docx**
- **www.dickbowdler.co.uk/content/publications/**

Proposed wording condition

The annex contains the condition wording which takes fairly typical wording for a planning condition on wind farm noise, including adjustments for tonal penalties if relevant, and adds a mechanism for adding a penalty for AM. Consistent with the recommendations of the WTAMR, the AM penalty is applied in addition to the tonality penalty. But how to calculate an AM penalty in practice is not clear from the WTAMR report.

WSP researchers in their subsequent *Acoustic Bulletin* article have discussed this aspect further: the penalty "should be applied to each

P58 ▶

◄ P56

individual 10-minute period assessed, and the rated levels separated into wind speed integer 'bins' for the purposes of comparison with the condition limits". They explain that to "aggregate the AM penalty" values would give an equivalent result to adding the penalty to each 10 minute period and then averaging the resulting "rated" levels, which is our experience in practice. In contrast, as they note, averaging the AM ratings and deriving an AM penalty on that basis would in many cases lead to different results.

The proposed condition has therefore been drafted on the basis of aggregating the AM penalties obtained, and applying this to the overall noise levels. This is considered to be a pragmatic way to represent the frequency/intensity of AM typically observed in relevant weather conditions. The condition explains that this averaging should only be done in relevant subsets of conditions which are determined in each case based on the observed complaints (if relevant), data analysis results or practitioner judgment. Analysis in wind direction bins, or plotting the amplitude modulation as a polar plot may be important in determining the appropriate subset. An example is shown in Fig 1 which is a polar plot of AM values as a function of wind direction and speed.

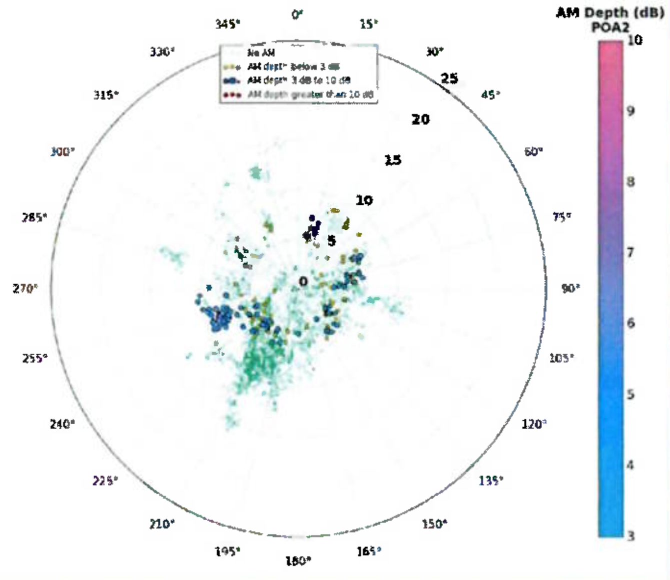


Fig 1 - plot of calculated AM ratings (dots) as a function of wind direction (circular direction) and wind speed (radial direction).

AM penalty – general aspects

As various people before us have discovered, the derivation of a penalty is not easy. There is not sufficient reliable research to be confident that a penalty system would always provide a fair indication of the impact of AM. However, to do nothing would be unfair on those wind farm neighbours adversely affected by AM and, in any case, there seems to be general agreement amongst many stakeholders on all sides of the debate that a robust condition including AM is required.

There are a significant number of people who have reservations about the penalty scheme proposed in the WTAMR report and this has been discussed in some detail by interested parties. The conclusion is that the penalty graph needs further research to establish whether it should be amended to take account of rotational speed and the difference between Leq and L90 (which increases as AM increases) and that this should be progressed as soon as possible. Meanwhile we have included the WTAMR graph in this condition. It is intended for medium to large scale turbines with a rotational speed up to 32 rpm.

A note on the night time limit

There has been criticism from some quarters of the method the WTAMR report proposed for an additional penalty to be applied at night to take account of the difference between the night-time and day-time limits; specifically where the night-time limits are higher. With a few exceptions (where suspensive conditions for AM have been applied, typically as a scheme to be agreed) the condition we are discussing here applies only to new consents. That means that, in the majority of cases, it will be applied as part of a complete set of noise limits. In such cases, the night-time and day-time limits can be set appropriately in accordance with the circumstances of the case. It should be noted that, if the night time limit is higher than the day time limit this could mean that an AM penalty would take the wind farm over the limit during the day but not at night. Where a suspensive condition for AM has been applied, the AM penalty would have to be tailored to the individual case unless an application were made to amend the conditions as a whole.

Annex

Proposed planning conditions on noise for ** Wind Farm**

The rating level of noise immissions from the combined effects of the wind turbines hereby permitted (including the application of any tonal penalty and amplitude modulation (AM) penalty), when determined in accordance with the attached guidance notes, shall not exceed the values for the relevant integer wind speed set out in or derived from Table 1 attached to these conditions and:

A) Within 21 days from receipt of a written request of the planning authority, following a complaint to it alleging noise disturbance at a dwelling, the wind farm operator shall, at its expense, employ an independent consultant and provide a written protocol to be approved by the planning authority. The protocol shall describe the procedure to assess the level and character of noise immissions from the wind farm at the complainant's property in accordance with the procedures described in the attached guidance notes. The written request from the planning authority shall set out as far as possible the time or meteorological conditions to which the complaint relates and time or conditions relating to tonal noise or AM if applicable. Measurements to assess compliance with the noise limits shall be undertaken in accordance with the assessment protocol which shall be approved in writing by the planning authority.

B) The wind farm operator shall provide to the planning authority the independent consultant's assessment of the rating level of noise immissions undertaken in accordance with the protocol within two months of the date of the approval of the protocol by the local authority unless otherwise agreed by the planning authority. The assessment shall include all data collected for the purposes of undertaking the compliance measurements and analysis, such data to be provided in a format to be agreed with the planning authority. Certificates of calibration of the equipment shall be submitted to the planning authority with the report.

C) Where a further assessment of the rating level of noise immissions from the wind farm is required pursuant to Guidance Note 5 of the attached Guidance Notes, the wind farm operator shall submit a copy of the further assessment within 21 days of submission of the independent consultant's initial assessment unless otherwise agreed by the Planning Authority.

[It is acknowledged that there may be other parts of the current IOAGPG conditions which require inclusion here, such as the clause discussing limits which apply at non named locations etc. The text included above aims to show how rating of AM scheme fits within the normal WF compliance approach.]

(Insert here the table or tables relevant to the specific planning condition)

Guidance notes for noise condition

These notes are to be read with and form part of the planning condition on noise. The measured data is to be split into bins as described below. The rating level in each bin is the arithmetic sum of the wind farm noise level, any tonal penalty applied in accordance with Note 3 and any AM penalty applied in accordance with Note 4. Reference to ETSU-R-97 refers to the publication entitled "The Assessment and Rating of Noise from Wind Farms" (1997) published by the Energy Technology Support unit (ETSU) for the Department of Trade and Industry (DTI). IOAGPG is "A Good Practice Guide to the Application of ETSU-R-97 for the Assessment and Rating of Wind Turbine Noise" or any update of that report current at the time of measurement. The IOA Metric is "A Method for Rating Amplitude Modulation in Wind Turbine Noise" dated 9th August 2016 or any update of that current at the time of measurement.

P60 ►

◄P58

Note 1 – Data collection

A) Values of the LA90,10-minute noise index should be measured in accordance with the IOAGPG. Measurements shall be undertaken in such a manner to enable a tonal penalty to be calculated and to allow an AM penalty to be calculated for selected periods where a tonal or AM assessment is required.

B) To enable compliance with the conditions to be evaluated, the wind farm operator shall continuously log arithmetic mean wind speed in metres per second (m/s) and arithmetic mean wind direction in degrees from north in each successive 10-minutes period in a manner to be agreed in writing with the planning authority. The wind speed at turbine hub height shall be "standardised" to a reference height of 10 metres as described in ETSU-R-97 at page 120 using a reference roughness length of 0.05 metres. It is this standardised 10 metre height wind speed data which are correlated with the noise measurements determined as valid. The wind farm operator shall continuously log arithmetic mean nacelle anemometer wind speed, arithmetic mean nacelle orientation, arithmetic mean wind direction as measured at the nacelle, arithmetic mean rotor RPM and whether each wind turbine is running normally during each successive 10-minutes period for each wind turbine on the wind farm. All 10-minute periods shall commence on the hour and in 10-minute increments thereafter synchronised with Universal Time (UT).

Note 2 – Data analysis

A) The independent consultant shall identify a sub set of data having had regard to:-
- the conditions (including time of day and corresponding wind directions and speeds) at times in which complaints were recorded;
- the nature/description recorded in the complaints if available;
- information contained in the written request from the local planning authority;
- likely propagation effects (downwind conditions or otherwise);
- the results of the tonality/AM analysis where relevant.

In cases where it is possible to identify patterns of clearly different conditions in which complaints have arisen additional sub sets may be considered provided this does not introduce unreasonable complexity in the analysis and can be justified by the independent consultant.

B) Within each of the sub set(s) of data identified, data shall be placed into separate 1 m/s wide wind speed bins.

Note 3 – Tonal penalty

A) Where, in accordance with the protocol, the noise contains or is likely to contain a tonal component, a tonal audibility shall be calculated for each ten-minute period using the following procedure.

B) For each 10-minute period for which a tonal assessment is required this shall be performed on noise immissions during two minutes of each 10-minute period. The two-minute periods should be spaced at 10-minute intervals provided that uninterrupted uncorrupted data are available ("the standard procedure").

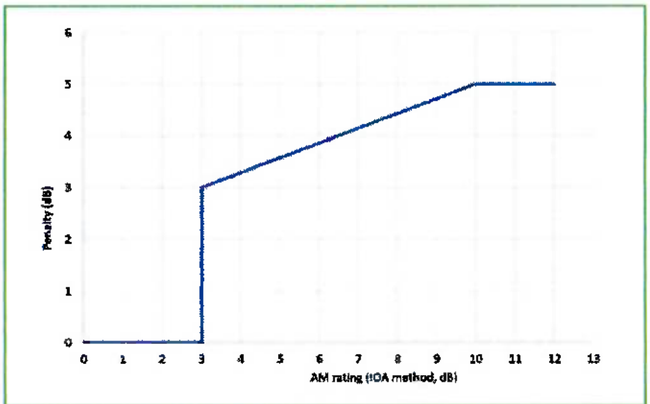
C) For each of the two-minute samples the tone level above audibility shall be calculated by comparison with the audibility criterion given in Section 2.1 on pages 104 -109 of ETSU-R-97. Samples for which the tones were below the audibility criterion or no tone was identified, a value of zero audibility shall be substituted. Where data for a ten-minute period are corrupted, that period shall be removed from the tonal analysis.

D) The tone level above audibility for each 10-minute period shall be placed in the appropriate data sub set and wind speed bin.

Note 4 – AM penalty

A) Where, in accordance with the protocol, the noise contains or is likely to contain AM, an AM penalty shall be calculated for each ten-minute period using the following procedure.

B) For each 10-minute interval for which an AM assessment is required this shall be performed in accordance with the IOA Metric. The value of AM for each ten-minute period shall be converted to a penalty in decibels in accordance with the graph below and the penalty shall be placed in the appropriate data sub set and wind speed bin. Where a penalty is zero it should be placed in the bin in the same way.



Penalty graph

Note 5 – Calculation of rating level

A) The LA90 sound pressure level for each data sub set and wind speed bin is the arithmetic mean of all the 10 minute sound pressure levels within that data sub set and wind speed bin except where data has been excluded for reasons which should be clearly identified by the independent consultant. The tonal penalty for each bin is the arithmetic mean of the separate 10 minute tonal audibility levels in the bin converted to a penalty in accordance with Fig 17 on page 104 of ETSU-R-97. The AM penalty for each bin is the arithmetic mean of the AM penalties in the bin. The assessment level in each bin is normally the arithmetic sum of the bin LA90, the bin tonal penalty and the bin AM penalty except where the AM penalty and the tonal penalty relate to the same characteristic (e.g. amplitude modulated tones) when the sum of both penalties may overly penalise the characteristics of the noise. Such cases should be identified and only the larger of the AM or tonal penalty should be applied.

B) If the assessment level in every bin lies at or below the values set out in the table(s) attached to the conditions then no further action is necessary. In the event that the assessment level is above the limit(s) set out in the tables attached to the noise conditions in any bin, the independent consultant shall undertake a further assessment of the rating level to correct for background noise so that the rating level relates to wind turbine noise immission only. Correction for background noise need only be undertaken for those wind speed bins where the assessment level is above the limit.

C) The wind farm operator shall ensure that all the wind turbines in the development are turned off for such periods as the independent consultant requires to undertake the further assessment. The further assessment shall be undertaken in accordance with the following steps:-

i. Repeating the steps in Note 1, with the wind farm switched off, and determining the background noise (L_3) in each bin as required in the protocol. At the discretion of the consultant and provided there is no reason to believe background noise would vary with wind direction, background noise in bins where there is insufficient data can be assumed to be the same as that in other bins at the same wind speed.

ii. The wind farm noise (L_1) in each bin shall then be calculated as follows where L_2 is the measured level with turbines running but without the addition of any tonal nor AM penalty:

$$L_1 = 10\log\left[10^{L_2/10} - 10^{L_3/10}\right]$$

iii. The rating level shall be calculated by adding the tonal and AM penalties to the derived wind farm noise L1 in that bin.

iv. If the rating level after adjustment for background noise contribution and adjustment for tonal and AM penalties in every bin lies at or below the values set out in the Tables attached to the condition at all wind speeds then no further action is necessary. If the rating level at any integer wind speed exceeds the values set out in the Table(s) attached to the condition then the development fails to comply with the planning condition in the circumstances represented by that bin. ◘

INCEEUROPE

6th International Conference on Wind Turbine Noise

Glasgow, 20 - 23 April 2015

Overall Programme

Sunday 19th April	14:00 to 17:00	Registration
Monday 20th April	09:00	Registration and Refreshments
	11:00	Conference Opens - Oral Presentations
	17:00	Drinks Reception and Poster Inauguration
	19:00	Free Evening
Tuesday 21st April	08:00	Refreshments
	08:30	Oral Presentations
	16:50	Workshop - Experience with the implementation of IEC 61400-11 (Edition 3) - Contact Sylvia Broneske
	18:15	Whisky Tasting
	19:45	Free Evening
Wednesday 22nd April	08:00	Refreshments
	08:30	Oral Presentations
	17:30	Workshop - Measuring Modulation from Wind Turbines - Contact Matthew Cand
	19:30	Conference Dinner
Thursday 23rd April	08:00	Refreshments
	08:15	Oral Presentations
	16:00	Conference Ends

Please note that some of these times may change slightly

6th International Conference on Wind Turbine Noise

Poster Presentations

Group	Title	Author 1
A - Source Noise - Localisation	The DTU Wind Energy WTN Test Facility	Bradley
	Doppler analysis and processing for the localization of low frequency tonal sound sources on blades: An experimental approach	Falourd
	Observation of vibration velocity at many parts of wind turbine and relational analysis with propagated sound to surroundings	Iwase
	Sound source localization on wind turbines using a single acoustic vector sensor	Serraris

B - Source Noise - Measurement	Small Wind Turbines – Comparison of Acoustic Noise Measurements in Accordance with IEC 61400-11 Ed. 3 to BWEA Small Wind Turbine Guideline	Broneske
	A new method for determining the wind turbine noise based on the constant divergence of sound pressure level	Buzduga
	Field comparison of IEC 61400-11 Wind turbines - Part11: Acoustic noise measurement techniques: Edition 3.0 and Edition 2.1	Joswiak

C - Receiver - Sensitivity	Relationship between exposure to wind turbine noise and subjective and objective sleep disorder in southern part in Japan	Morimatsu
	Wind turbines - A changed environment	Palmer
	Experimental study of relationship between amplitude modulation and detection threshold of wind turbine noise	Yoon

D – Receiver - Monitoring	Study of secondary wind shield performance in the field	Adcock
	Wind noise estimation functions for low frequency sound measurment in natural wind at different topography types	Kamiakito
	Investigation into the influence of windscreens during sound emission measurements in accordance with IEC 61400-11 ed. 3.0	Kaufmann
	Background noise assessment in Utrecht	Balkema
	Automated wind farm noise measurement systems with feature analysis	Jiggins

E - Low Frequency and Infrasound	A system for measuring wind turbine infrasound emissions	Annan
	Stationary wind turbine infrasound emissions and propagation loss measurements	Huson (1)
	Constraints imposed by and limitations of IEC 61672 for the measurement of wind farm sound emissions	Huson (2)
	Environmental Impact Assessment and Management Plan on Wind Turbine Noise in South Korea	Park
	Direct experience of low frequency noise and infrasound within a windfarm community	Swinbanks
	Measuring wind turbine coherent infrasound	Vanderkooy

6th International Conference on Wind Turbine Noise

Monday 20th April 2015 - Oral Presentations		
11:00	Opening	
	Sound Propagation 1 - Geoff Leventhall	
11:05	**PLENARY** - Wind turbine noise propagation - results of numerical modelling techniques to investigate specific scenarios	Sims
11:35	Modeling of ground and atmospheric effects on wind turbine noise	Tian
11:55	Metrological validation of the DIN ISO 9613-2 propagation model concerning wind turbine noise	Engelen
12:15	Prediction of variability in wind turbine noise calculations	Cotte
12:35	Discussion	
13:00	Lunch	
	Sound Propagation 2 - Sylvia Broneske	
14:00	Directivity noise attenuation values for large wind turbines - Research based on long term measurements	Coulon
14:20	Propagation of noise from wind farms according to the Institute of Acoustics' Good Practice Guide - a sensitivity analysis	Birchby
14:40	Low-Frequency acoustic near-field of wind-turbines	Richarz
15:00	Prediction of infrasound and low frequency noise propagation for modern wind turbines, a proposed supplement to ISO9613-2	Hansen
15:20	Discussion	
15:40	Break	
	Sound Propagation 3 - Dick Bowdler	
16:00	Influence of vertical temperature gradient on background noise and on long-range noise propagation from wind turbines	Bigot
16:20	Effects of built environment morphology in residential areas on resisting wind turbine noise on building façades	Qu
16:40	Discussion	
16:50	Session ends	

6th International Conference on Wind Turbine Noise

Tuesday 21st April 2015 - Oral Presentations		
	Health Effects and Annoyance - Matthew Cand	
08:30	**PLENARY** – Wind Turbine Noise and Health Study: Summary of Results	Michaud
09:10	Findings of the Council of Canadian Academies Expert Panel on Wind Turbine Noise and Human Health	Howe
09:30	Impact of windturbine noise on local residents in mountainous terrain at Lista Windfarm, South Norway	Vagene
09:50	Compliance isn't everything	Large
10:10	Noise from wind turbines and health effects - Investigation of wind turbine noise spectra	Sondergaard
10:30	Discussion	
10:50	Break	
	Regulations 1 - David Colby	
11:10	Comparative analysis of wind turbine noise assessment and rating procedures in the UK, France and the Netherlands	Goeme
11:30	The use of cumulative wind turbine noise related planning conditions	Mackay
11:50	State of the art and new perspectives for the development of noise regulation of wind farms	Schild
12:10	A history of wind turbine noise regulations in the Netherlands	van den Berg (GP)
12:30	Discussion	
12:55	Lunch	
	Receiving Environment - TBA	
13:55	From good practice guidance to solving amplitude modulation for wind turbine noise assessment in the UK	Perkins
14:15	Wind turbines - A changed environment	Palmer
14:35	Modelling of house filter for wind turbine noise	Tachibana
14:55	Discussion	
15:10	Break	
	Tonal noise - Jean Tourret	
15:30	Assessment of tonal components contained in wind turbine noise in immission areas	Kobayashi
15:50	Tonal noise from wind turbines	Evans
16:10	Reduction of tonalities in wind turbines by means of active vibration absorbers	Engelhardt
16:30	Discussion	
16:45	Presentations end	

6th International Conference on Wind Turbine Noise

Wednesday 22nd April 2015 - Oral Presentations - Hall 1		
	Aeroacoustic Noise Source 1 - Helge Madsen	
08:30	**PLENARY** - Basic principles and evidences of wind turbine noise generation mechanisms	Bertagnolio
09:05	**PLENARY** - Impact on flow topology of solid and permeable trailing edge serrations at incidence on cambered and symmetric airfoils	Arce
09:25	Aeroacoustic simulation of an airfoil in turbulent inflow	Illg
09:45	Displacement thickness evaluation for BPM-Type Airfoil-TE noise prediction model	Saab
10:05	Simulation of broadband trailing-edge noise - Influence of airfoil shape and flow characteristics	Rautmann
10:25	Discussion	
10:45	Break	
	Aeroacoustic Noise Source 2 - Brian Howe	
11:05	Numerical simulation of airfoil trailing edge serration noise	Zhu
11:25	On the measurement and prediction of wind-turbine trailing-edge noise	Stalnov
11:45	Development of a high-fidelity noise prediction and propagation model for noise generated from wind turbines	Debertshauser
12:05	On predicting wind turbine noise and amplitude modulation using Amiet's theory	Sinayako
12:25	Discussion	
12:45	Lunch	
	Aeroacoustic Noise Source 3 - Sabine von Hunerbein	
13:45	On the noise prediction of a serrated DU96 airfoil using the Lattice Boltzmann Method	van der Velden
14:05	An experimental and numerical parameter study on trailing edge blowing for reduced trailing edge noise	Gerhard
14:25	Aeroacoustic wind tunnel experiment for serration design optimisation and its application to a wind turbine rotor	Hurault
14:45	Icing of wind turbines and the effect on noise - Long-term measurements	Appelqvist
15:05	Experimental characterization of stall noise toward its modelling	Bertagnolio
15:25	Discussion	
15:50	Break	
	Small Turbines - Christophe Delaire	
16:10	Noise reduction for small wind turbine by trailing edge modification	Yamagata
16:30	Noise directivity from a vertical axis wind turbine	Mollerstrom
16:50	Numerical investigation of the aeroacoustics of small vertical axis wind turbines	Weber
17:10	Discussion	
17:25	Presentations End	

6th International Conference on Wind Turbine Noise

Wednesday 22nd April 2015 - Oral Presentations - Hall 2		
08:30	See Hall 1	
	Background and Turbine Noise at Receivers -1 - Payam Ashtiani	
09:25	Background noise map creation through a CFD wind model	Bartolazzi
09:45	Methods for assessing background sound levels during post-construction compliance monitoring within a community	Duncan
10:05	Practical measurement method of wind turbine noise	Fukushima
10:25	Discussion	
10:45	Break	
	Background and Turbine Noise at Receivers -2 - Norm Broner	
11:05	Spectral discrete probability density function of measured wind turbine noise in the far field	Ashtiani
11:25	Research into a continuous wind farm noise monitoring system	Delaire
11:45	Noise optimized wind park operation	Petitjean
12:05	Wind Farm Noise Optimisation Tool	Fotheringham
12:25	Discussion	
12:45	Lunch	
	Infrasound - Sarah Large	
13:45	Progress report on synthesis of wind turbine noise and infrasound	Walker
14:05	Response to simulated wind farm infrasound including effect of expectation	Tonin
14:25	Perception and annoyance of low frequency noise versus infrasound in the context of wind turbine noise	Hansen
14:45	On the overlap region between wind turbine infrasound and infrasound from other sources and its relation to criteria	Leventhall
15:05	Health-based audible noise guidelines account for infrasound and low frequency noise produced by wind turbines	Berger
15:25	Discussion	
15:50	Break	
	Regulations 2 - Jean Tourret	
16:10	Noise protection regulations for wind turbines in Germany	Bauerdorff
16:30	Sensitivity analysis test on the Italian ISPRA-ARPAT methodology to assess noise impact of operational wind farms	Fredianelli
16:50	Parsimonius regulations for wind turbine noise	van den Berg (M)
17:10	Discussion	
17:25	Presentations End	

6th International Conference on Wind Turbine Noise

Thursday 23rd April 2015 - Oral Presentations		
	Amplitude Modulation 1 - Sabine von Hunerbein	
08:15	**PLENARY** - An overview of recent research on AM and OAM of wind turbine noise	Madsen
08:45	The Institute of Acoustics' Working Group on Amplitude Modulation - Progress towards an agreed rating and assessment metric	Irvine
09:05	Measurements demonstrating mitigation of far-field AM from wind turbines	Cand
09:25	Addressing the issue of enhanced amplitude modulation: A developer's perspective	Cassidy
09:45	On the Measurement and Prediction of Wind-Turbine Swishing Noise	Cheong
10:05	Discussion	
10:30	Break	
	Amplitude Modulation 2 - Mark Bastasch	
10:50	Current challenges of assessing excess amplitude modulation character in wind turbine noise during EIA/planning phase	di Napoli
11:10	Can we really predict wind turbine noise with only one point source?	Ecotiere
11:30	Time-dependent interference: The Mechanism Causing Amplitude Modulation Noise?	Bradley
11:50	Low frequency amplitude modulation related to Doppler frequency shift: An experimental study of a 101m diameter wind turbine in a Swiss valley	Falourd
12:10	Detection of amplitude modulation in Southern Ontario wind farms	Halstead
12:30	Discussion	
12:50	Lunch	
	Amplitude Modulation 3 - Frits van den Berg	
13:50	Cotton Farm Wind Farm - long term community noise monitoring project - 2 years on	Stigwood
14:10	Affective response to amplitude modulated wind turbine sound	Von Hunerbein
14:30	Subjective experiments on the auditory impression of the amplitude modulation sound contained in wind turbine noise	Yokoyama
14:50	Indoor simulation of wind turbine amplitude modulated noise	Fernandez
15:10	Overview of IEEE standard development on amplitude modulation noise measurement	Xue
15:30	Discussion	
15:55	Closing	
16:00	Conference Ends	

MARSHALL DAY
Acoustics

EXAMINATION OF THE SIGNIFICANCE OF NOISE IN RELATION TO ONSHORE WIND FARMS

Commissioned by Sustainable Energy Authority of Ireland (SEAI)

MARSHALL DAY Acoustics

7 Osborne Promenade
Warrenpoint
Co.Down BT34 3NQ
T: (UK) +44 28 308 98009
T: (RoI) +353 1 440 4383
C.R.N. NI069050
www.marshallday.com

Project: **EXAMINATION OF THE SIGNIFICANCE OF NOISE IN RELATION TO ONSHORE WIND FARMS**

Prepared for: **SEAI**
Wilton Park House
Wilton Place
Dublin

Prepared by: **Marshall Day Acoustics**

Date: **29 November 2013**

TABLE OF CONTENTS

1.0 INTRODUCTION

The Department of Environment, Community and Local Government (DECLG) and the Department of Communications Energy and Natural Resources (DCENR) have commenced a technical update of the guidance on noise in the Wind Energy Development Guidelines 2006[1] (WEDG06).

The review is taking place in the context of Ireland's targets under Directive 2009/28/EC on the promotion of the use of energy from renewable sources. Ireland's National Renewable Energy Action Plan (NREAP) sets out how Ireland intends to achieve its individually binding national renewable energy (RE) target of 16% of energy demand by 2020: through 40% of electricity consumption, 10% of transport energy and 12% of heat energy being obtained from renewable sources.

The Sustainable Energy Authority of Ireland (SEAI) are assisting with the review and have commissioned a desk based study to review, and provide advice on, international best practice in relation to onshore wind farm noise which will be a key input into the review of WEDG06.

WEDG06 was issued under Section 28 of the Planning and Development Act, 2000, which requires both planning authorities and An Bord Pleanála to have regard to them in the performance of their functions. WEDG06 offers advice to planning authorities on planning for wind energy through the development plan process and in determining applications for planning permission.

The SEAI's stated objective for the desktop study of onshore wind farm noise is to:

> *"...obtain evidence upon which to evaluate the appropriateness of the Wind Energy Development Guidelines in relation to noise impacts and if considered necessary suggest changes."*

This report summarises the findings of a desktop study and concludes with comments about the effectiveness of WEDG06 for wind farm noise assessment with an emphasis on commercial scale wind farm developments. In particular, the effectiveness of WEDG06 is reviewed in light of the development and research that has occurred in the seven years since its publication. Recommendations are also provided for consideration as part of any subsequent update of WEDG06.

A key objective of all wind farm noise policies is to appropriately balance the protection of amenity for communities neighbouring wind farm developments with the wider interests of national infrastructure development which, in the Irish context, includes requirements to meet statutory wind energy targets.

---

[1] Available on the DECLG website at www.environ.ie

The appropriate balance will always be dependent on contextual factors that are specific to each county, country or region. Key examples of these factors include:

- The relative importance of onshore wind energy to the overall renewable energy strategy of a country or region
- Expectations and attitudes of the communities around the locations where wind farms are likely to be considered
- The scale of available development sites with suitable wind resources and compatible infrastructure.

This region-specific balance is an essential consideration when reviewing international guidelines and policy options.

The report comprises the following key sections:

Report Section	Content	Related Work Package
2	Scoping discussions	-
3	High level review of wind turbine noise	Package 1
4	International benchmarking: Introduction to Sections 5, 6 & 7	-
5	International benchmarking of wind farm noise control methods including consideration of cumulative noise and special audible characteristic	Package 2
6	International benchmarking of noise considerations during the planning stage for a wind farm	Package 2
7	International benchmarking of noise issues for operational wind farms noise control	Package 2
8	Review of current wind farm noise assessment practices in the Republic of Ireland	Package 3
9	Conclusions of desktop study	Package 4
10	Recommendations	Package 4
	Appendices addressing acoustic terminology, a literature review summary and bibliography.	-

2.0 SCOPING DISCUSSION

This section briefly outlines concepts of sound and how it can be measured as well as discussing the background for the current study and recent developments in wind farm noise assessment.

2.1 Acoustic basics

2.1.1 Sound and noise

Sound can generally be considered as what we hear with our ears. Noise, in particular, is unwanted sound.

That is, noise is a subset of sound, which is unwanted by a listener or group of listeners. Noise is therefore subjective. While noise is not technically a synonym for sound in day to day use, particularly in the field of acoustic consulting and noise impact assessments, the two terms are often used interchangeably.

Evaluation of sound involves several key concepts:

Frequency (pitch)

Sound can occur over a range of frequencies extending from the very low, such as the rumble of thunder, up to the very high such as the crash of cymbals. Sound is generally described over the frequency range from about 63 Hz up to 4000 Hz (4 kHz). This is roughly equal to the range of frequencies on a piano. The audible range of frequencies for humans is generally considered to span from about 20 Hz up to about 20,000 Hz. Frequencies below 20 Hz can also be audible if levels are sufficiently high.

Sound level (magnitude)

Decibel is the unit of sound level and is commonly denoted as dB. Adjusting the volume dial on a home stereo adjusts the sound level. The audible range of sound levels for humans is generally considered to span from 0 dB, the hearing threshold, up to 120+dB, where such high levels of sound can cause pain to listeners.

Changes in sound level

The decibel scale is logarithmic, not linear. This means that, for example, if two instances of the same sound occur at the same time, and each has a sound level of 30 dB, their combined level will be 33 dB. The combined level is not 60 dB.

Perceived changes in sound level

A perceived doubling in the loudness of a sound generally corresponds to a 10 dB increase in sound level[2]. That is, when listening to a sound that is 40 dB, increasing the sound level to 50 dB would subjectively be heard as a doubling in loudness. Increasing the sound level again, to 60 dB, would feel like a further doubling in loudness. Conversely, increasing the level of a given sound by 1-3 dB can often be imperceptible or only just perceptible while a 5 dB increase in sound level can be described as clearly noticeable[2].

---

[2] (Department of Health (Victoria), 2013)

Care should be taken, however, in applying these rules-of-thumb to noise measurements and noise limits. For example, wind farm noise is often measured for a period of weeks to collect data across a broad range of weather conditions. Often, this large set of data is effectively averaged[3] to compare levels with applicable noise limits. Due to the data-averaging, a 3 dB change in sound level could be caused by a 3 dB increase in level during the entire assessment period or, alternatively, a much larger increase in sound level for only a portion of the assessment period. Typical subjective impressions of sound level could vary greatly between these two cases even though the average change in sound level is the same.

2.1.2 Sound indices

Changes in sound level with time

Sound is often not steady. The sound from traffic, music and the barking of dogs are all examples of sounds that vary over time. When such sounds are measured, the sound level can be expressed as an average level, or as a percentile measure, such as the level exceeded for 90% of the time. Commonly used sound indices are L_{min}, L_{90}, L_{eq}, L_{10} and L_{max}. Figure 1 provides a time history plot demonstrating some examples of common sound indices as determined for a 30 minute measurement interval.

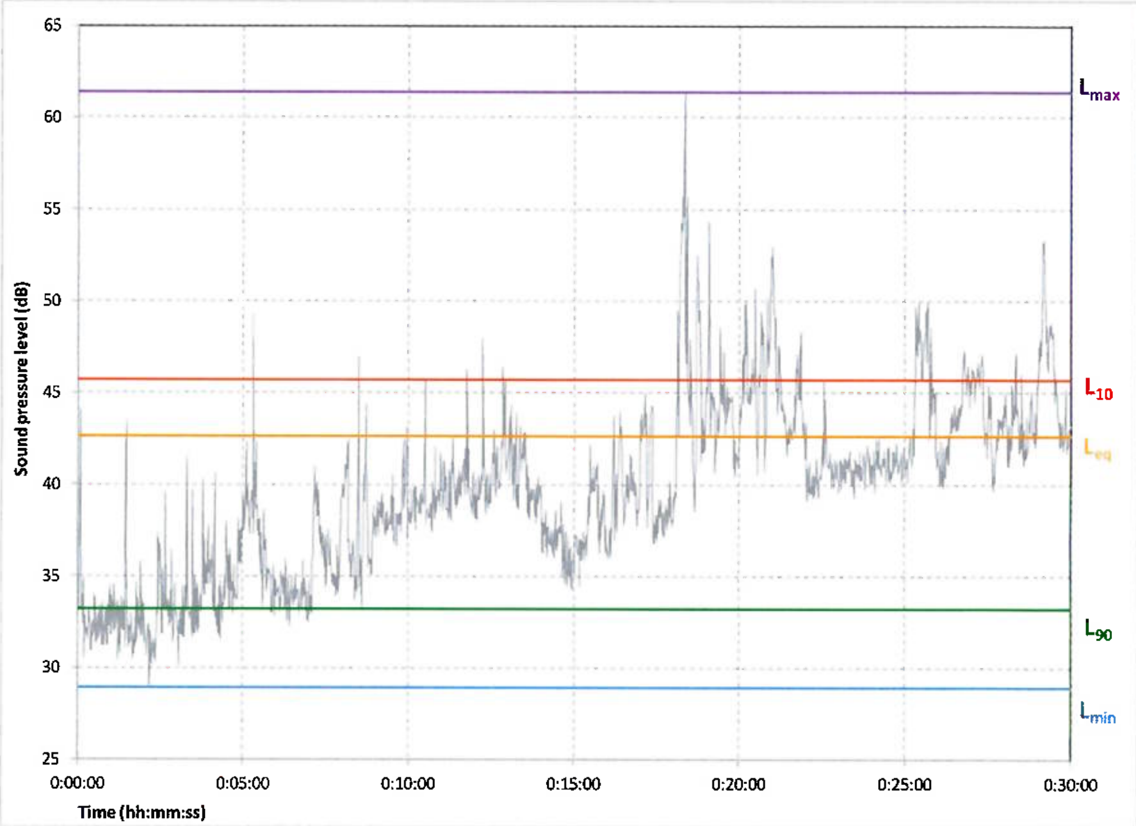


Figure 1: Example of noise indices that may be used to measure a time-varying sound level

[3] Typically using a regression analysis. Refer to Section 3.3 for details.

Frequency weightings

Where A-weighted decibels are used, the A-weighting approximates the response of the human ear over a range of frequencies. The A-weighting is one of many types of weightings and indices which adjust sound levels based on frequency content. Other examples include B, C and G weightings (see Appendix A for example weighting curves).

Example sound levels

Examples of typical noise levels experienced across a range of situations are presented in Figure 2 and Figure 3. Is it important to note however, that the levels presented are only indicative and appropriate as a 'rule of thumb' guide. Levels encountered in practice for a given activity could readily vary by ±10 decibels or more.

Sound	Noise Level (dB)	Effect
Boom Cars	145	
Jet Engines (near)	140	
Shotgun Firing Jet Takeoff (100–200 ft.)	130	
Rock Concerts (varies)	110–140	Threshold of pain begins around 125 dB
Oxygen Torch	121	
Discotheque/Boom Box Thunderclap (near)	120	Threshold of sensation begins around 120 dB
Stereos (over 100 watts)	110–125	
Symphony Orchestra Power Saw (chainsaw) Pneumatic Drill/Jackhammer	110	Regular exposure to sound over 100 dB of more than one minute risks permanent hearing loss
Snowmobile	105	
Jet Flyover (1000 ft.)	103	
Electric Furnace Area Garbage Truck/Cement Mixer	100	No more than 15 minutes of unprotected exposure recommended for sounds between 90–100 dB
Farm Tractor	98	
Newspaper Press	97	
Subway, Motorcycle (25 ft.)	88	Very annoying
Lawnmower, Food Blender Recreational Vehicles, TV	85–90 70–90	85 dB is the level at which hearing damage (8 hrs.) begins
Diesel Truck (40 mph, 50 ft.)	84	
Average City Traffic Garbage Disposal	80	Annoying; interferes with conversation; constant exposure may cause damage
Washing Machine	78	
Dishwasher	75	
Vacuum Cleaner, Hair Dryer	70	Intrusive; interferes with telephone conversation
Normal Conversation	50–65	
Quiet Office	50–60	Comfortable hearing levels are under 60 dB
Refrigerator Humming	40	
Whisper	30	Very quiet
Broadcasting Studio	30	
Rustling Leaves	20	Just audible
Normal Breathing	10	
		The threshold of normal hearing starts at about 1000 to 4000kHz.

Figure 2: Example A-weighted noise levels for a range of common activities [4]

[4] (National Institute of Deafness and other Communication Disorders (USA))

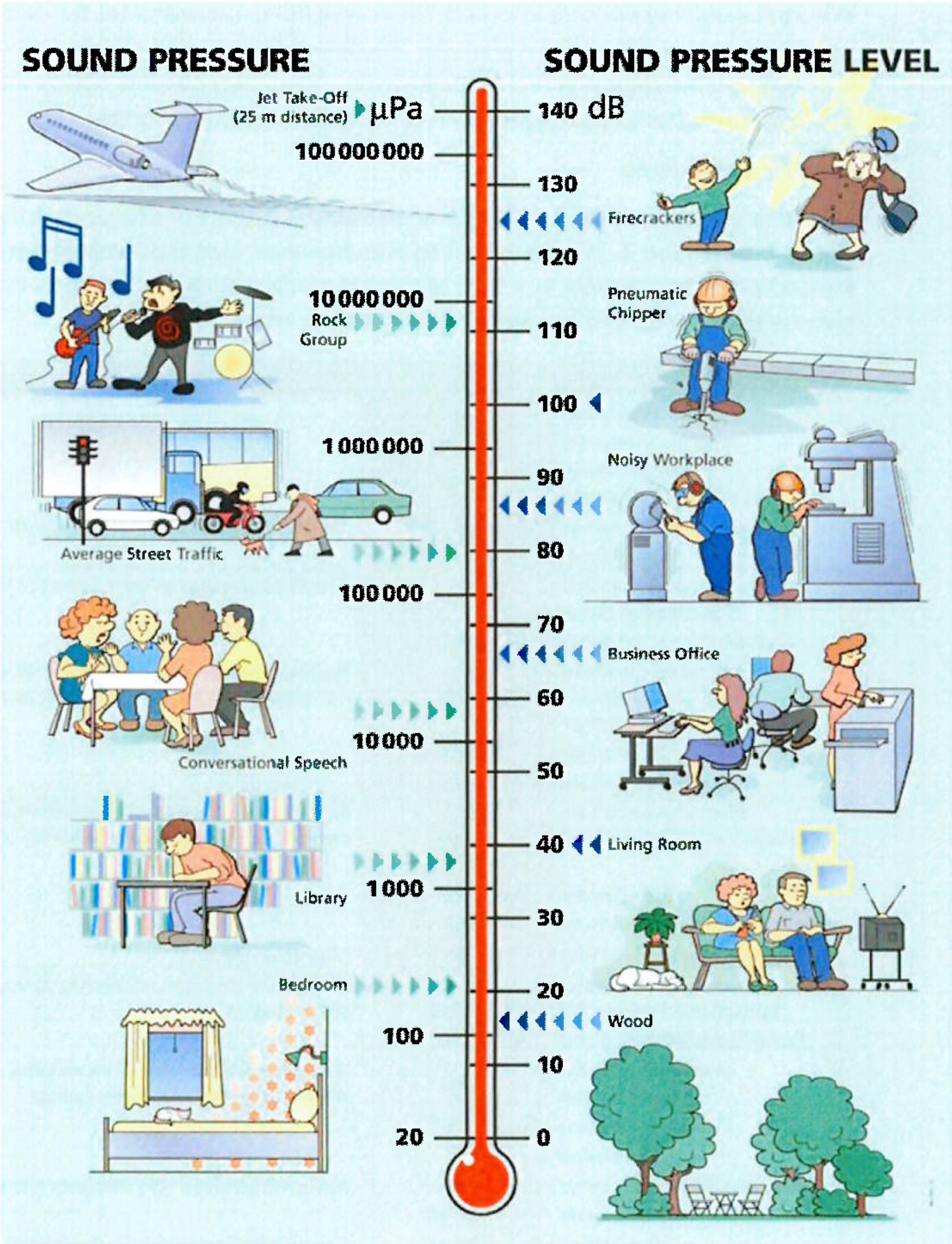


Figure 3: Example A-weighted noise levels for a range of common activities[5]

Additional indicative 'rule of thumb' levels are presented in Figure 4, an extract from the State Government of Victorian (Australia) Department of Health document *Wind farms, sound and health - Technical information*[6], including a reported level range for a typical wind farm operating at a moderate speed at a distance in the range 500m to 1000m.

[5] (Bruel & Kjaer)

[6] (Department of Health (Victoria), 2013)

Table 3: Typical A-weighted sound levels for different sources (adapted from[4, 16])

Noise source	Sound level (dBA)
Quiet bedroom	20–25
Rural night-time background	20–40
Typical wind farm (at moderate wind speed 7 m/s)	**35–45***
Car at 64 km/h at 100 m	55
Busy general office	60
Pneumatic drill at 15 m	95
Jet aircraft at 50 m	105
Threshold of pain	130

* Based on sound level measurements taken from multiple resident locations near two Victorian wind farms, at distances 500–1,000 m from the nearest turbine

Figure 4: Example A-weighted noise levels for a range of common activities[7]

2.2 Project background

Since the publication of the Renewable Energy Directive (2009/28/EC) mandatory targets have been set for all European states, with the overall target of 20% of all energy to come from renewable sources by 2020. In their contribution to this the Republic of Ireland has an overall renewable target of 16% of total final consumption from renewable by 2020, with a 40% contribution from renewable to the gross electricity consumption[8].

This puts legal requirements on the Government to increase the capacity for renewable energy. Whilst wind is an established renewable source of energy, an increased requirement for wind energy is likely to increase the number of potential wind farm neighbours, with associated potential noise impacts.

The Department of the Environment, Community and Local Government (DECLG) together with the Department of Communications Energy and Natural Resources (DCENR) have commenced a technical update of the guidance on noise in the *Wind Energy Development Guidelines 2006* (WEDG06), which superseded the original guidelines issued in September 1996.

With the agreement of the Minister for Housing and Planning, the Minister for Communications, Energy & Natural Resources asked the Sustainable Energy Authority of Ireland (SEAI) to assist DCELG and DCENR in their work to update WEDG06. It was agreed that SEAI would, with guidance from an interdepartmental group, commission a desk based study to review, and provide advice on, international best practice in relation to informing the guidelines on onshore wind farm noise. It was also agreed that this would form a key input into the review of the statutory guidelines.

[7] (Department of Health (Victoria), 2013)

[8] See http://www.seai.ie/Publications/Statistics_Publications/Statistics_FAQ/Energy_Targets_FAQ/#What_are_Irelands

In common with other types of environmental noise sources, wind farms require a range of dedicated assessment techniques to deal with the issues specific to wind farms. The primary issue addressed by most wind farm noise guidance documents is considering how wind turbine or wind farm sound varies with changes in wind speed.

WEDG06 identifies noise as a relevant consideration for new wind farm developments and provides assessment guidance tailored to wind farms including broad guidance on noise limits and separation distances relevant for assessing new and cumulative proposals.

WEDG06 requires a noise assessment of proposed new developments, and requires both local planning authorities and An Bord Pleanála to have regard to WEDG06 in the performance of their functions under the Planning and Development Act, 2000. In common with previous versions of the guidelines, the current version seeks to strike a balance between the need to protect amenity of dwellings and other noise sensitive locations in rural areas where wind farms are often located, and the need to provide a viable framework for the expansion of wind powered renewable energy.

The technical update of WEDG06 presents an opportunity to review the suitability of existing wind farm noise assessment guidance and to consider provision of additional guidance that may support the application of the Wind Energy Development Guidelines to all phases of wind farm development to enable more consistent, reliable and transparent assessment processes for wind farm developments. Given the sensitivities associated with wind farm developments and noise related issues, it is envisaged that this would assist planning authorities in making more informed decisions, in turn benefiting community perception and understanding of the assessment process.

Delivering clear and robust noise assessment guidance is particularly relevant for wind farm developments as wind farms offer comparatively fewer methods of reducing or attenuating noise. For example, reducing noise from an operational wind farm typically requires operating turbines in reduced power modes, turning off turbines in some weather conditions or improving the sound insulation performance of dwelling façades. A number of conventional noise reduction methods that can work well with general noise sources, such as motorway barriers or acoustic enclosures for industrial equipment, are not practicable for reducing wind farm noise.

2.3 Developments in wind farm noise since 2006

WEDG06 was published in 2006. In many respects, key elements of wind farm noise assessment have remained fundamentally unchanged during the intervening period. For example, the 1996 document *The assessment and rating of noise from wind farms* (ETSU-R-97) still remains a widely used assessment tool in Ireland and correspondingly wind farm noise is largely assessed using A-weighted noise levels, with limits that have regard for the nature of the ambient noise environment at the receptor locations.

Since 2006 the public profile of wind farm noise issues has, however, arguably been heightened through a range of mechanisms including greater media exposure, the advent of social media and activity from lobby groups both opposing and supporting wind farm development. Public profile is also likely to continue changing over time. As more wind farm developments are completed a greater portion of the general population will acquire firsthand experience in viewing and hearing operational wind farms.

Whilst recent developments in the topic of onshore wind farm noise are implicitly incorporated into the body of this report, a broad snapshot of some key issues is outlined here to provide a more concise overview of topical issues. Notwithstanding this, it is recommended that the reader refer to the appropriate sections of this report for a detailed discussion of any particular issue.

Wind turbines have continued to increase in size and generating capacity since 2006, with capacities of up to 10MW reported to have been developed[9]. Changes in turbine design have the ability to contribute to reducing sound emission, through improved design. Conversely, increased turbine size could lead to higher sound emission and may alter the character of the sound[9].

Mechanisms for wind turbine sound generation have arguably become better understood since 2006, including advancements in understanding aerodynamic noise[10]. However, issues such as the prevalence, significance and onset of excessive amplitude modulation[11] are still not fully understood and are the subject on ongoing investigation[12].

A significant amount of institutional wind farm noise research has been carried out since the issue of WEDG06. This is likely due, in part, to the increasing number of wind farms in operation which are available to be researched and, in part, as a response to the increased public profile of wind farm noise issues. Examples of research projects include:

[9] (Bolin, Bluhm, Eriksson, & Nilsson, 2011)

[10] (Oerlemans, Detection of aeroacoustic sound sources on aircraft and wind turbines, 2009)

[11] Refer to Section 3.4 for descriptions of amplitude modulation.

[12] (Bass, Bowdler, McCaffery, & Grimes, 2011)

- Social surveys of annoyance (Pedersen, 2008[13])
- Review of low frequency noise content in wind turbine sound (Madsen et al, 2010[14])
- Research into perception of wind turbine sound (Hunerbein et al, 2010[15]).
- Differences in expectations of wind turbine noise leading to differences in reporting symptoms (Crichton et al, 2013[16])

Indeed at present there are several potentially significant studies in progress across various wind farm noise related disciplines, including:

- University of Adelaide *Resolving the mechanics of wind turbine noise production*[17]
- Health Canada *Wind turbine noise and health study*[18]
- RenewableUK *Fundamental research in amplitude modulation*[19]

Complaints and discussion of wind farm noise annoyance and potential wind farm noise related health effects have also heightened since 2006. Reports range from anecdotal accounts of annoyance and health effects by some wind farm neighbours to web content from lobby groups such as landscape guardian organisations and papers and reports from doctors and academics. Particular attention has been paid to potential special audible characteristics of wind turbine noise such as low frequency noise, infrasound and amplitude modulation[20]. Topical examples of reports and critiques include:

- A book titled *Wind Turbine Syndrome*[21] which investigates health complaints reported by a set of 37 wind farm neighbours.
- Work by Salt et al[22] concerning the sensitivity of the ear to infrasound
- Work by Nissenbaum et al[23] concerning effects of wind turbine noise on sleep disturbance and health.

Such documents have proven controversial and in some cases their findings are disputed. For example, a 2009 report prepared for the American and Canadian wind energy associations made the following comments about a 2009 pre-publication of the Wind Turbine Syndrome book:

[13] (Pedersen & Larsman, The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines, 2008) (Pedersen, van den Berg, Bakker, & Bouma, 2009)

[14] (Madsen & Pedersen, 2010)

[15] (Hunerbein, King, Hargreaves, Moorhouse, & Plack, 2010)

[16] (Crichton, Dodd, Schmid, Gamble, & Petrie, 2013)

[17] See: http://www.adelaide.edu.au/news/news58021.html

[18] See: http://www.hc-sc.gc.ca/ewh-semt/consult/_2013/wind_turbine-eoliennes/index-eng.php

[19] (Bass, Bowdler, McCaffery, & Grimes, 2011)

[20] Refer to Section 3.4 for a discussion of special audible characteristics

[21] (Pierpont, 2010)

[22] (Salt & Lichtenhan, 2011)

[23] (Nissenbaum, Aramini, & Hanning, 2012)

> *[...] the panel considered "wind turbine syndrome" and vibroacoustic disease, which have been claimed as causes of adverse health effects. The evidence indicates that "wind turbine syndrome" is based on misinterpretation of physiologic data and that the features of the so-called syndrome are merely a subset of annoyance reactions. The evidence for vibroacoustic disease (tissue inflammation and fibrosis associated with sound exposure) is extremely dubious at levels of sound associated with wind turbines.*

Other cases, such as the sensitivity of the ear to infrasound, are the subject of ongoing debate[24].

Concurrently, a number of government agencies have prepared statements regarding potential association between wind farm noise and health effects. Examples include the Australian National Health and Medical Research Council (NHMRC) public statement dated July 2010[25] which states that:

> *There is currently no published scientific evidence to positively link wind turbines with adverse health effects.*

Several notable guidance documents for wind farm noise assessment were developed during the 1990s and the early part of the 2000s when the potential for larger scale development of wind energy increased. The intervening period since the issue of WEDG06 has seen some of these documents revised, such as:

- New Zealand Standard 6808: 1998 *Acoustics - the assessment and measurement of sound from wind turbine generators*[26] which has been superseded by a 2010 version of the standard[27]
- International Electrotechnical Commission Standard 61400-11:2006 *Wind turbine generator systems - Part 11: Acoustic noise measurement techniques*[28], the international standard prescribing methods for measuring sound power levels from a turbine which was updated to Version 3.0[29] in December 2012
- The South Australian Wind Farm Guidelines 2003 which has been superseded by the document *Wind farms: Environmental noise guidelines* (July 2009)[30]

These revised documents generally detail refined versions of methodologies from the documents they supersede, as opposed to any fundamental shift in approach or methodology. This is consistent with some examples of recently developed guideline documents such as the Ontario Ministry of Environment *Noise Guidelines for Wind Farms*[31] produced in 2008 in the Canadian province of Ontario.

---

[24] (Leventhall, Concerns about infrasound from wind turbines, 2013)

[25] (National Health and Medical Research Council, 2010)

[26] (Standards New Zealand, 1998)

[27] (Standards New Zealand, 2010)

[28] (International Electrotechnical Commission, 2006)

[29] (International Electrotechnical Commission, 2012)

[30] (South Australia Environment Protection Authority, 2009)

[31] (Ontario Ministry of Environment, 2008)

While WEDG06 provides high level guidance on wind farm noise assessment, general practice in Ireland is to reference ETSU-R-97 for detailed guidance on assessment methodologies and measurement practices. In this context, the recently published Institute of Acoustics UK document *A good practice guide to the application of ETSU-R-97 for the assessment and rating of wind turbine noise*[32] (IOA GPG) published in May 2013 represents one of the most significant recent publications on wind farm noise in the Irish context, particularly in light of its endorsements by the English, Welsh & Scottish governments[33].

The IOA GPG was prepared to reflect current UK industry practice for wind farm noise assessments, where common and generally agreed practices have evolved from the application of ETSU-R-97 to new wind farm developments. Given the use of ETSU-R-97 in the context of WEDG06 and Irish wind farm developments, many of the IOA GPG comments and recommendations are, currently, as applicable to Irish wind farm developments as they are to UK projects.

2.4 Definitions and reference documents

There are a number of key terms and reference documents that are referred to regularly throughout this report. For clarity, details of the common references are provided here.

2.4.1 Definitions

Sound	**What we hear**
Noise	Unwanted sound
Wind farm neighbours	Property uses near a proposed or built wind farm that may be potentially impacted by wind farm noise. Associated terms include noise sensitive locations, dwellings, receptors and receivers[34].
Ambient noise	The total sound at a given position in the absence of the specific sound(s) being considered. At wind farm neighbours, ambient noise will typically refer to the noise or sound environment at the property excluding wind farm noise.
Background noise level	A type of measured sound level, commonly described in dB L_{A90}, being the level exceeded for 90% of the measurement period.

A complete list of acoustic terms used throughout this report is provided in Appendix A.

[32] (Cand, Davis, Jordan, Hayes, & Perkins, 2013)

[33] See: http://www.ioa.org.uk/about-us/news-article.asp?id=272

[34] A discussion of the types of properties classified as wind farm neighbours is provided in Section 3.3

2.4.2 Reference documents

Documents relevant to Irish wind farm noise assessments	
WEDG06	*Wind Energy Development Guidelines* Irish Department of Environment, Heritage and Local Government, 2006
ETSU-R-97	*ETSU-R-97 The assessment and rating of noise from wind farms,* Noise Working Group 1996, United Kingdom (Commissioned by the Department of Trade and Industry, UK)
NG3	*Guidance Note on Noise Assessment of Wind Turbine Operations at EPA Licensed Sites,* (EPA Ireland, Office of Environmental Enforcement)
Other wind farm noise assessment documents commonly referred to herein	
AS4595:2010	Standards Australia 4959:2010 *Acoustics – Measurement, prediction and assessment of noise from wind turbine generators*
DSO1284	Danish EPA document *Statutory Order on Noise from Wind Turbines (Translation of Statutory Order no. 1284 of 15 December 2011)*
IOA GPG	*A Good Practice Guide To The Application Of ETSU-R-97 For The Assessment And Rating Of Wind Turbine Noise* Institute of Acoustics UK, 2013, produced at the request of the UK Department of Energy and Climate Change (DECC)
IOA JS2009	Leventhall, G, Bullmore, A, Jiggins, M, Hayes, M, McKenzie, A, Bowdler, D & Davis, B 2009, 'Prediction and assessment of wind turbine noise – Agreement about relevant factors for noise assessment from wind energy projects', *Acoustics Bulletin*, March-April 2009, pp35-37.
NZS6808:2010	New Zealand Standard NZS 6808:2010 *Acoustics – Wind farm noise*
ONG2008	Ministry of the Environment (Province of Ontario, Canada), *Noise Guidelines for Wind Farms Interpretation for Applying MOE NPC Publications to Wind Power Generation Facilities* (October 2008)
SAG2009	Environment Protection Authority (State of South Australia, Australia) 2009, *Wind farms: Environmental noise guidelines* (July 2009)

A full list of referenced documents in provided in Appendix H.

2.5 Scope limitations and exclusions

Limitations

Deciding on the most appropriate noise control method for Irish wind farm development requires consideration of issues well beyond the comparatively narrow scope of assessments of noise impacts. Other relevant issues include effects on energy yield, community expectations, settlement patterns, regulatory constraints, regulator expertise and associated resource implications and competing requirements from other assessed effects such as, for example, landscape sensitivity analysis.

While recommendations developed simply on the basis of assessment of noise impacts can therefore only provide part of the information set required to decide on wind farm noise assessment practices, such recommendations are considered in this report to help inform any future review in the broader context. These recommendations are not, in isolation, an appropriate foundation for establishing noise control methods or assessment practices.

Issues not within the scope of this study

The following items are not directly addressed in this report:

- Extent of mitigation through turbine technology developments
  While it is recognised that refinements in turbine design have in many cases resulted in reduced sound emission, specific details of the methods of reducing sound and the levels of reduction achieved are not directly addressed in this report.
- Noise health impacts
  Health impacts of noise, including sleep disturbance and direct physiological effects of noise, are outside the scope of this study and are not considered directly in this report. It is noted however that health impacts of noise are a common consideration of regulators in their drafting of noise policies. Therefore, some limited, indirect consideration of health impacts is included in this report insofar as considering the noise control methods employed in different jurisdictions to manage wind farm noise. Additionally, where considered appropriate, this report references documentation provided by peak health bodies, such as regional departments of health, health protection agencies and the World Health Organisation, which discuss health issues associated with either general noise or wind farm noise. The brief overview of selected literature in Appendix G also considers studies where references are made to public health.
- Methodology and content of applications including Environmental Impact Assessments
  This report does not provide methodologies or prescriptive advice for assessment of wind farm noise as may be required for an environmental impact assessment.
- Capacity building for wind farms
  This report does not directly consider methods or strategies for increasing Ireland's wind energy generating capacity.
- Construction noise
  Noise associated with construction of wind farms is not addressed.

3.0 WIND FARM NOISE: SOURCE, PATH & RECEIVER (WORK PACKAGE 1)

This section provides a concise review of sources of noise from wind turbines, the propagation of sound away from turbines and the character and level of wind farm noise at common neighbouring locations.

3.1 Characteristics of wind farm noise

The noise produced by a wind farm is predominantly controlled by noise emissions from wind turbines. This section focuses primarily on wind turbine noise emission, discussing the following:

- Sources of wind turbine noise
- Methods for quantifying wind turbine sound levels
- Practical operation of modern wind turbines and associated sound level characteristics
- Relationships between turbine size and sound level

A full assessment of noise effects could also consider other sources including ancillary infrastructure such as substations, transmission lines and meteorological masts. A brief discussion of wind farm noise sources other than wind turbines is provided in Appendix B.

3.1.1 Anatomy of a wind turbine

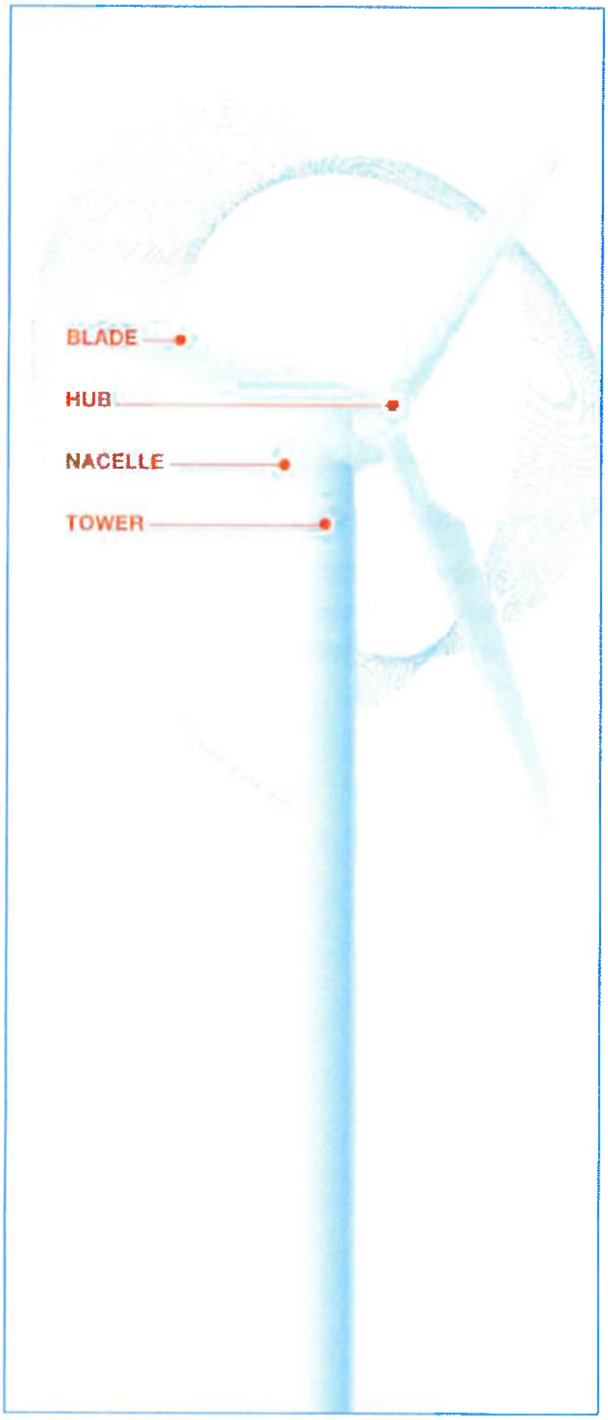


Figure 5: Schematic of a wind turbine[35]

Modern wind turbines are generally configured with a horizontal axis of rotation, comprising three blades with lengths of around 15-50m and tower heights typically ranging from 20m to 125m or more with tip heights reaching in excess of 175m. A schematic of a horizontal axis wind turbine is shown in Figure 5.

The electricity generating process begins with kinetic energy from wind creating lift on turbine blades (aerofoils) and rotating the turbine shaft. The shaft is often connected to an electrical generator via a gearbox which steps up the rotational speed between the shaft and the generator.

An electrical transformer, typically located at the base of the turbine tower, manages the transfer of electricity away from the turbine.

The turbine is turned to face into the wind by a 'yaw' system between the tower and nacelle. Some turbines, referred to as 'pitch controlled', include controls to rotate the angle of the blades with respect to the wind to regulate power output and rotational forces.

The components of a wind turbine are illustrated in Figure 6 below.

[35] (American Wind Energy Association, 2011)

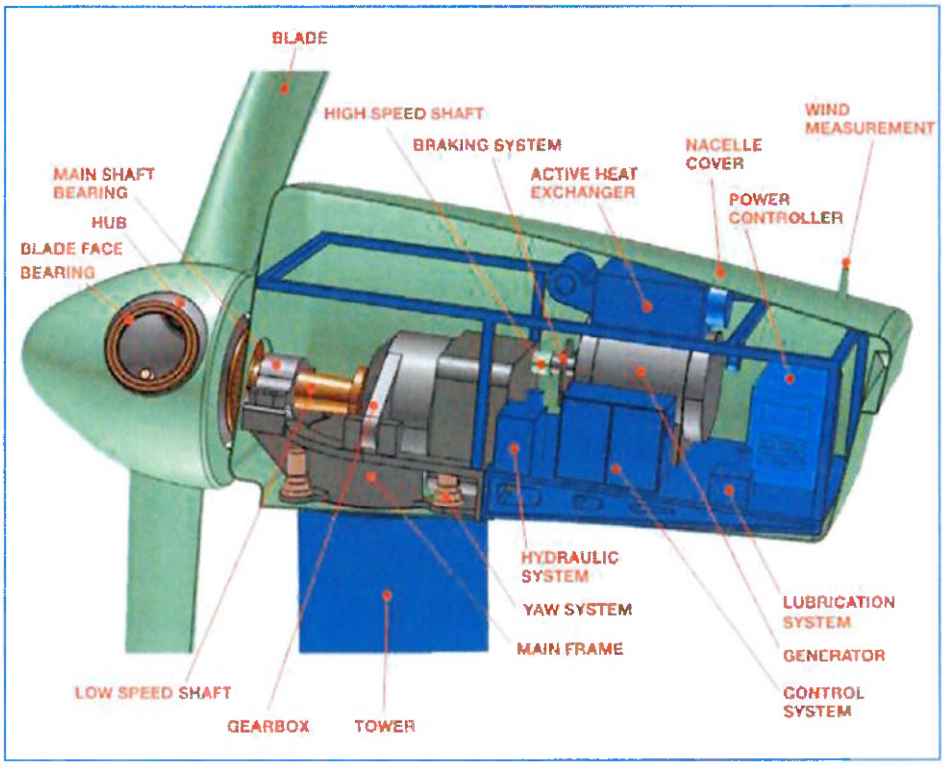


Figure 6: Anatomy of a wind turbine[36]

Alternative turbine types include two blade designs and turbines with a vertical axis of rotation. Due to their limited application they are not directly considered here.

3.1.2 Wind turbine noise sources

What distinguishes wind turbine noise emission from more conventional sources of sound is that it tends to increase with increasing wind speed. Concurrently, the ambient noise environment at neighbouring locations will also often change with wind speed. These variations in both wind turbine sound levels and receiver sound levels create a dynamic and variable interaction which has commonly prompted development of specific wind farm noise guidance documents in many jurisdictions.

A wind turbine's noise sources can be classified into two broad categories:

- mechanical noise from components in the hub and nacelle, and
- aerodynamic noise from the interaction between wind and turbine blades.

Mechanical noise in the nacelle, from sources such as the gearbox, generator and cooling systems, can be attenuated by conventional noise control methods. This can include methods to reduce vibrational forces in moving parts such as improved acoustic and vibration isolation around rotating equipment and improved sound insulation design of nacelle and machinery housings.

Aerodynamic noise involves complex phenomena and is comparatively more difficult to reduce. Aerodynamic noise from turbine blades is generally the dominant noise source from wind turbines[37].

[36] (American Wind Energy Association, 2011)

There are four mechanisms of aerodynamic noise generation on turbine blades, summarised in Figure 7 and Table 1.

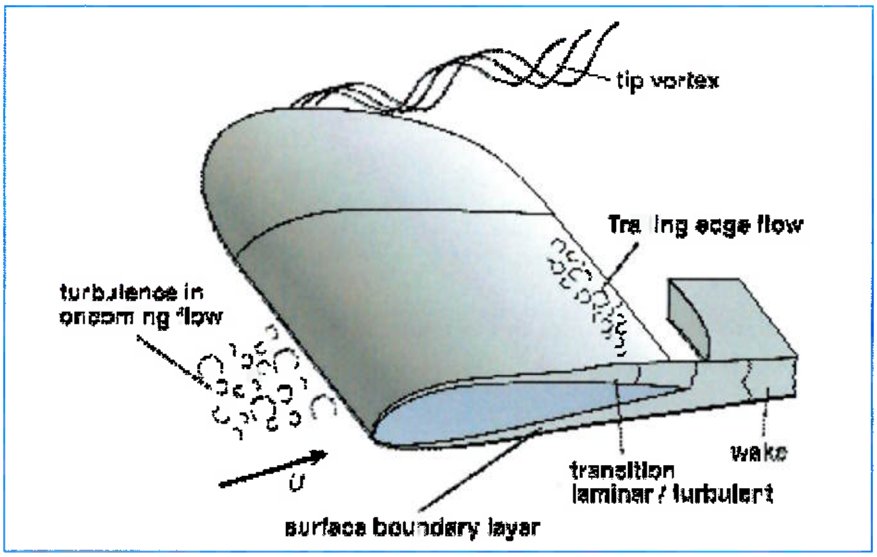


Figure 7: Turbine blade aerodynamic noise generation[38]

Table 1: Turbine blade aerodynamic noise generation[39]

Noise source	Mechanism	Sound characteristics
Inflow turbulence	Atmospheric turbulence in oncoming flow impinging on aerofoil	Broadband sound at lower frequencies
Tip noise	Difference in pressures on either side of turbine blade results in vortex shedding, which may interact with the aerofoil tip, radiating as noise	Broadband sound at higher frequencies
Trailing edge noise	Typically a turbulent boundary layer develops along the aerofoil (blade) cord, with turbulence being scattered as sound at the aerofoil trailing edge	Broadband sound at higher frequencies
Blade tower interaction	Airflow upwind of the tower is disturbed by the presence of the tower downwind, causing a changing in pressure on the aerofoil (blade) as it passes the tower	Broadband sound at lower frequencies, including sound below 20 Hz[40]

[37] (Oerlemans, Detection of aeroacoustic sound sources on aircraft and wind turbines, 2009)
(Oerlemans, Sijtsma, & Mendez-Lopez, Location and quantification of noise sources on a wind turbine, 2007)
(Doolan, 2011)

[38] (Oerlemans, Detection of aeroacoustic sound sources on aircraft and wind turbines, 2009)

[39] (American Wind Energy Association, 2011)
(Oerlemans, Detection of aeroacoustic sound sources on aircraft and wind turbines, 2009)

[40] (Guidati, Bareiz, & Wagner, 1994)

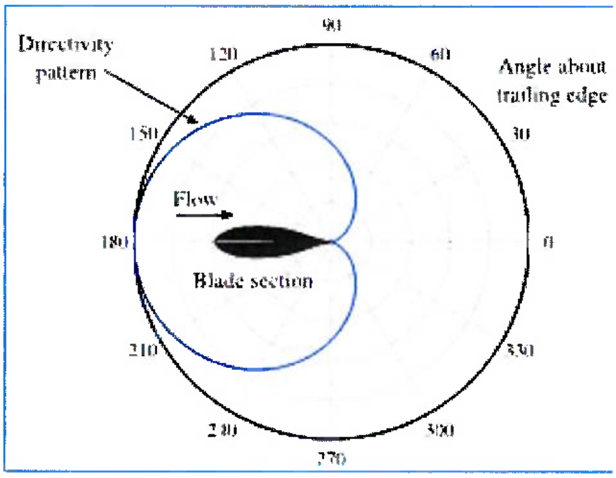


Figure 8: Trailing edge noise directivity pattern[41]

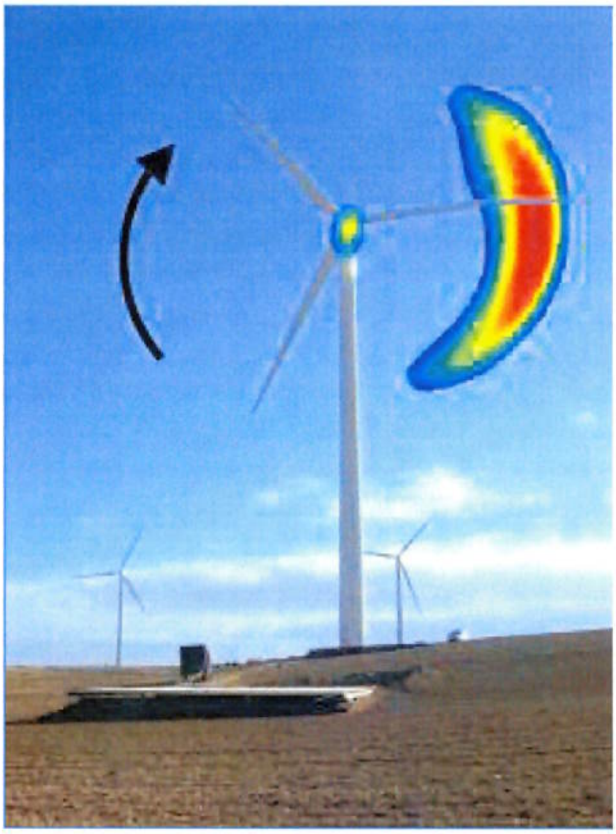


Figure 9: Wind turbine sound source localisation (clockwise rotation)[42]

Trailing edge noise is typically the dominant noise source from wind turbines[38]. It is broadband in chara and theoretically exhibits a cardioic radiation pattern towards the turb blade leading edge, as depicted in Figure 8.

This means that more trailing edge noise is radiated in some directions others and, in the current case, the trailing edge noise will be at a grea level in front of the blade than beh

Noise directivity from the blade or aerofoil trailing edge is considered the cause of the characteristic 'swi: associated with wind turbine sounc

Due to its directivity pattern, trailin edge noise is directed towards a receiver at ground level during the down stroke of the blade, and awa from a receiver on the ground duri the up stroke. This is illustrated in Figure 9.

---

[41] (Oerlemans, Detection of aeroacoustic sound sources on aircraft and wind turbines, 2009)

[42] (Oerlemans, Sijtsma, & Mendez-Lopez, Location and quantification of noise sources on a wind turbine, 2007)

Some aspects of wind turbine sound are less well understood such as the special audible characteristic amplitude modulation which is discussed in Section 3.4.6. Potential causes for such aspects may include source generating mechanisms additional to those outlined above as well as propagation mechanisms such as turbine sound arriving at a dwelling in phase. However, the current state of available knowledge about these aspects is limited and is the subject of ongoing research[43].

3.1.3 Quantifying wind turbine sound

As with most general noise sources, the sound from a wind turbine can be quantified by determining its sound power level. This is a measure of the sound power output, which is a suitable input for sound propagation models, as discussed in Section 3.2.

The prediction of sound power output from a turbine is a complex undertaking, but the measurement of sound power from a given design is a carefully prescribed procedure, described in IEC 61400-11[44]. The use of the standard is a necessary step in the certification of a turbine for commercial use, and provides data which can be used to predict sound levels emitted from a wind farm, subject to the uncertainties described in Section 3.2.

The standard requires measurement of wind turbine sound on the ground near the turbine, with a separation distance approximately equal to the maximum turbine tip height. The measured sound pressure levels are used to calculate the sound power of the test turbine, and levels are correlated with wind speeds to detail how sound levels vary with wind speed. The wind speeds are generally assessed at the hub height of the turbine as this is considered to be a suitable representation of the wind conditions that determine the operating performance of the turbine[45]. In some cases there is a historical convention to express sound power levels as a function of standardised wind speeds, which are wind speeds assessed at hub height which are then re-referenced to 10m above ground level (AGL) using a reference roughness length z_{0ref} of 0.05m. It is important that the wind speed reference height, and any associated wind shear assumptions, are clear when referring to performance characteristics of a wind turbine at any wind speed. Refer to Appendix C for further details.

3.1.4 Characteristics of modern wind turbines

Modern wind turbines begin generating electricity at wind speeds of around 3 m/s to 4 m/s at hub height, referred to as 'cut-in' wind speed. Maximum power output is typically reached at around 10 m/s at hub height, referred to as 'rated power'. At greater wind speeds the rotational speed of the turbine blades must be controlled to prevent damage. This is achieved by either pitch or stall control.

Stall controlled turbines comprise blades that produce reduced lift and increased drag at wind speeds above rated power, thereby controlling rotational forces at high wind speeds. Pitch controlled turbines feather the angle of the blades above rated power, maintaining a steady torque and power output until a maximum or cut-out wind speed, around 25 m/s, where brakes are applied.

---

[43] (Bass, Bowdler, McCaffery, & Grimes, 2011)

[44] (International Electrotechnical Commission, 2012)

[45] The recommended method for assessing wind speeds is the use of power output data, which can be compared to published power curves to estimate wind speeds for the time period of interest.

In general, wind turbines produce very little noise when not turning, that is, at wind speeds below cut-in. Some noise is produced from yaw motors, blade pitch actuators, brakes, and hydraulic pumps which service these functions. The transformer at the base of the turbine is energised and may produce some noise. These noise sources are usually much quieter than the rated aerodynamic noise emissions of a turbine, and so are rarely responsible for noise complaints. However, these noises are more likely to contain tonal or impulsive features.

As the wind speed increases and the turbine begins to rotate, aerodynamic noise is generated. With pitch-controlled turbines, the sound level from the blades generally increases with wind speed until a point at or near the turbine's rated power. The sound level of pitch and stall regulated turbines differ markedly at wind speeds above rated power, as illustrated in Figure 10.

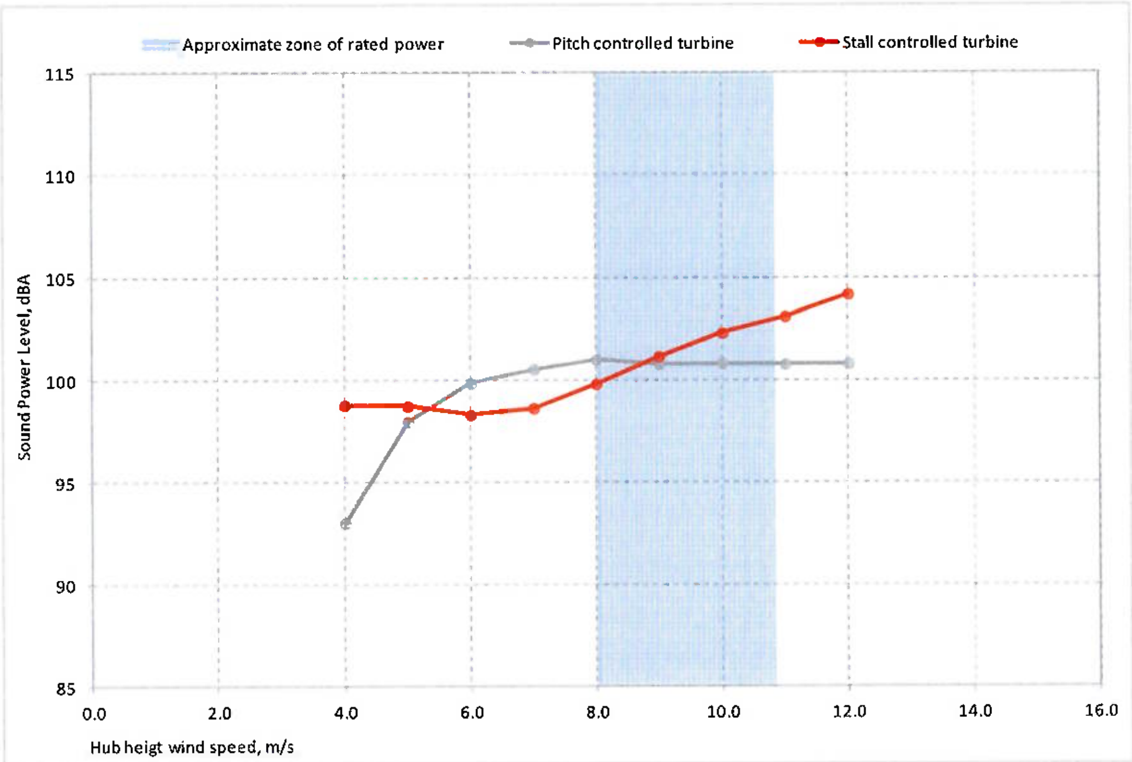


Figure 10: Example sound power level curves for pitch controlled and stall controlled turbines[46]

The sound level output from stall controlled turbines continues to increase above rated power, although power output plateaus or slightly decreases. Increased sound level is due to turbulence associated with turbine stall. A pitch controlled turbine's sound level reaches a maximum at rated power and remains constant, or decreases slightly afterwards.

[46] Wind turbine sound power levels are commonly measured at wind speeds approximately from cut-in to rated power. IEC 61400-11:2006, for example, requires determining sound power levels for the standardised wind speed range from 6m/s t0 10m/s at 10m AGL. It should be noted that while Figure 10 does not present sound levels above 12m/s, the wind turbines will continue to operate at higher wind speeds and will therefore also continue to produce sound.

The sound levels presented in Figure 10 are overall A-weighted levels. The observed A-weighted sound level trends can very when particular frequency intervals are considered. For example, a 2008 study[47] of low frequency noise from two up-wind turbines (1.5-MW and 660-kW) showed that infrasound noise emission from the stall and pitch regulated turbines in the study continued to increase above rated power. Low frequency noise and infrasound are discussed further in Section 3.4.

The most recent developments in wind farm power control have produced pitch regulated turbines which potentially produce better output power quality[48]. These factors have made pitch controlled turbines a common choice for multi-megawatt wind farm developments, both in terms of turbine designs and wind farm installations (as observed by the European Wind Energy Association[49], and a pattern reflected in Australian and New Zealand wind farms).

Modern multi-megawatt turbines can often be operated in different modes allowing reduced noise output, at the expense of power output, under certain operating conditions. The noise reduction achieved by various reduced power modes typically ranges from 1 decibel to 5 decibels or more[50].

This means that a turbines operation may be tailored to specific noise sensitive conditions, for example, a wind direction that supports sound propagation towards a nearby dwelling. This also allows turbines to be "derated" after installation, providing a means of mitigating noise levels once the farm is operational. When evaluating the noise characteristics of a particular wind farm design, it is important to specify not only the turbine but also its operational mode, so that its noise characteristics are known. The operating mode of the turbine may form part of the farm's noise management procedures, and should be understood when carrying out compliance testing.

3.1.5 Turbine size and sound level

A Danish study of wind turbine noise[51] surveyed the noise levels from 48 different wind turbine models with the aim of examining the relationship between emitted sound power and turbine size. The study surveyed 37 turbines of less than 2MW power output, representing small turbines, and 11 larger turbines, greater than 2MW power output, with the largest a 3.6MW turbine.

The study used regression analysis to determine the trend in sound level output as a function of turbine size. It found a positive linear relationship, meaning that larger turbines may produce slightly more noise than small turbines, for equal power generation. A regression analysis of the study is shown in Figure 11 below for a nominal wind speed of 8m/s.

---

47 (Jung, Cheong, Shin, & Chueng, 2008)

48 See: http://www.wind-energy-the-facts.org/en/part-i-technology/chapter-3-wind-turbine-technology/technology-trends/pitch-versus-stall.html

49 (Gardner, Garrad, Jamieson, Snodin, & Tindal, 2003)

50 (Bowdler & Leventhall, Wind turbine noise, 2011) Chapter 2 & (Probst, Probst, & Huber, 2013)

51 (Moller & Pedersen, 2011)

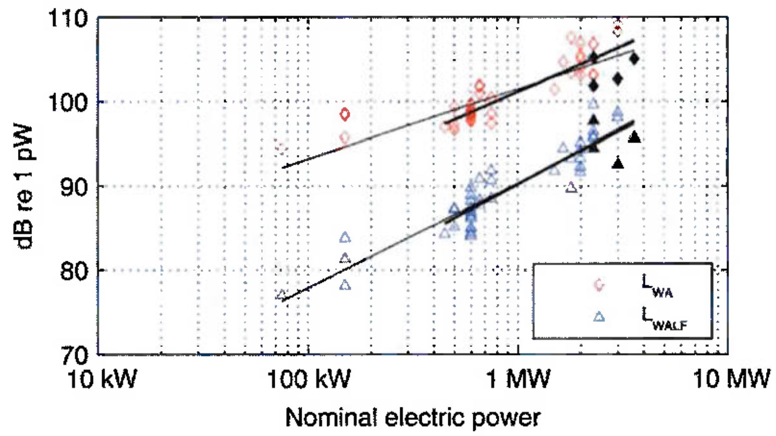


FIG. 1. (Color online) Apparent sound power levels (L_{WA} and L_{WALF}) in the reference direction as a function of turbine size. Wind speed is 8 m/s. Regression lines: all turbines included (thin lines), four turbines below 450 kW excluded (bold lines). Black-filled marks are for turbines 1–4.

Figure 11: Sound level versus turbine size[52]

For example, as shown by the regression line through the red points, a doubling of in turbine generating capacity from 1MW to 2 MW may result in slightly more than a doubling of the overall A-weighted sound power level (L_{WA}), that is, an increase of more than 3 dB. The study does, however, note that the relationship is not necessarily statistically significant[53]. Also, it should not necessarily be taken to mean that, for a given site, large turbines would result in more noise at a dwelling than smaller turbines. As the turbine size increases, greater distance between turbines is generally required to avoid detrimental interaction between turbines[54]. Also, as shown by the scatter of data in Figure 11, for a range of turbines with the same power generating capacity, sound level output can vary by several decibels.

The regression curve through the blue dots in Figure 11, the low frequency sound power levels (L_{WALF}), has a steeper slope than the A-weighted regression curve through the red dots implying that turbine size has a comparatively greater influence on low frequency noise. This trend can be further demonstrated by considering the frequency spectra of the turbines. The different spectra of turbines with power less than 2MW, and larger turbines with output greater than 2MW are illustrated in Figure 12, which illustrates a downward shift in the spectra of sound with increasing turbine size[55], in the order of 1/3 of an octave.

---

[52] (Moller & Pedersen, 2011)

[53] A comment in Section IV.A of the study notes: *It must be added that the slope of the regression line is not significantly higher than 10 dB [90% confidence interval 9.53–12.40, p(slope10 dB)¼0.133]. With a slope of 10 dB, the noise-occupied area is the same for small and large turbines for the same installed nominal electric power*

[54] This often is a factor in the total number of turbines which can be operated on a given site.

[55] That is, a shift to the left

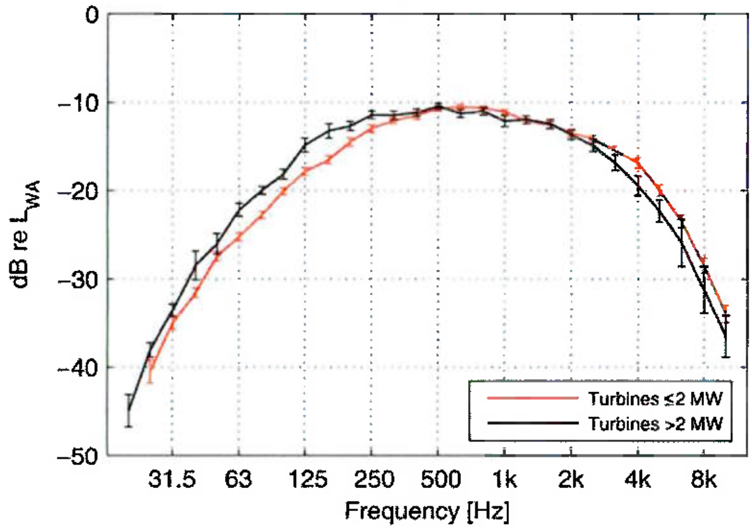


FIG. 4. (Color online) Normalized A-weighted apparent sound power levels in one-third-octave bands, means of two groups of turbines: ≤ 2 MW and > 2 MW. Error bars indicate ± 1 standard error of mean.

Figure 12: Spectrum comparison between larger and smaller turbines[52]

The study concludes that a '*further shift of similar size is suggested for turbines in the 10-MW range*'. However, this conclusion is based on data review for turbines up to 3.6MW only. Given the complex range of factors that could influence future turbine sound levels, it would seem wise to consider such comments judiciously.

3.2 Sound propagation

Noise from a wind farm arrives at a noise sensitive location almost exclusively by propagation through the air. Several studies have examined the possibility that ground-borne transmission could be significant, but have shown that such transmission produces vibration levels which are orders of magnitude less than that which can be perceived by humans[56].

The impact of wind farm noise therefore depends on the manner in which sound propagates through the air, and this forms the basis for noise level prediction methodologies. A number of methods exist to predict the level of sound received at noise sensitive locations. These methods have been developed as general tools for sound propagation, but significant effort has been made to validate their use specifically for wind farms as discussed in Section 3.2.2 below.

In the planning stages of a wind farm, it is necessary to apply these methods to establish the noise level which will be received by neighbours of a wind farm. This allows the developer to tailor the design of the wind farm and control the level of noise.

[56] (Bowdler, et al., 2009), (Styles, Stimpson, Toon, England, & Wright, 2005)

3.2.1 Factors of sound propagation

A number of physical factors affect the amount of sound propagated from source to receiver. Major factors include distance, absorption by air, interaction with ground and ground cover, interference by barriers, and wind effects. Minor factors include interaction with vegetation and buildings or other scattering features.

These factors are described in detail as follows.

Distance

Sound from a single-point source reduces in intensity at a rate of 6 decibels per doubling of distance. For instance a noise source which produces 70 dB at a distance of 5 metres could be expected to produce 64 dB at 10 metres, and 58 dB at 20 metres.

This change in intensity relates to the sound energy being spread over a greater area as the measurement point moves further from the source – the energy is potentially being shared by a greater number of receivers so each receiver receives less.

While at small distances a wind turbine may be difficult to view as a single-point source, the typical distances from which they may be heard (e.g. hundreds or thousands of metres) allows a wind turbine to be treated as a point source.

The sensitivity of noise level to source-receiver distance is large at close distances, but relatively small at typical distances that houses would be found from a wind farm. For example, at a distance of 1000 metres, it is necessary to move approximately 500 metres closer, or 1000 metres further from a point source to cause a 6 decibel change in noise level.

Air absorption

The interaction of sound energy with the atmosphere causes energy to be lost with distance. This loss occurs in addition to the reduction due to spreading discussed in the preceding section.

Unlike spreading attenuation, air absorption losses are calculated on a per-meter basis—the loss due to the 1st metre of travel is the same as the loss due to the 1000th meter of travel.

Air absorption also differs from spreading attenuation in that it is frequency dependant – high frequencies are lost more rapidly than low frequencies. The following table[57] describes the losses in decibels per 1000 metres of distance, for air at 70% relative humidity and 10° C.

Table 2: ISO 9613-1: 1993 Example air absorption coefficients

	One-third octave band centre frequency (Hz)								
Description	**63**	**125**	**250**	**500**	**1k**	**2k**	**4k**	**8k**	**Hz**
Air Absorption coefficient	0.12	0.41	1.04	1.93	3.66	9.66	32.8	117	dB/km

[57] (International Standards Organisation, 1993), ISO 9613-1:1993

It is apparent from Table 2 that at a separation distance of, for example, 1000m, air absorption removes very large amounts of high frequency sound, but makes almost no change to low frequency sound. This can be a significant factor in removing sounds such as whistles which are significant in the near field of a wind turbine, and shifting community attention to the low and mid-frequency features of a wind farm. A comparison of the air absorption coefficients from Table 2 with an example sound power level spectrum for a multi-megawatt turbine is illustrated in Figure 13. Comparing the magnitude of the wind turbine octave-band sound power levels (red bars) with the air absorption coefficients (red line) demonstrates that large portions of high frequency sound, in the 4 kHz and 8 kHz octave bands, will be attenuated by air absorption over a path of 1000m. The grey bars on the chart show A-weighted octave-band sound power levels for the wind turbine.

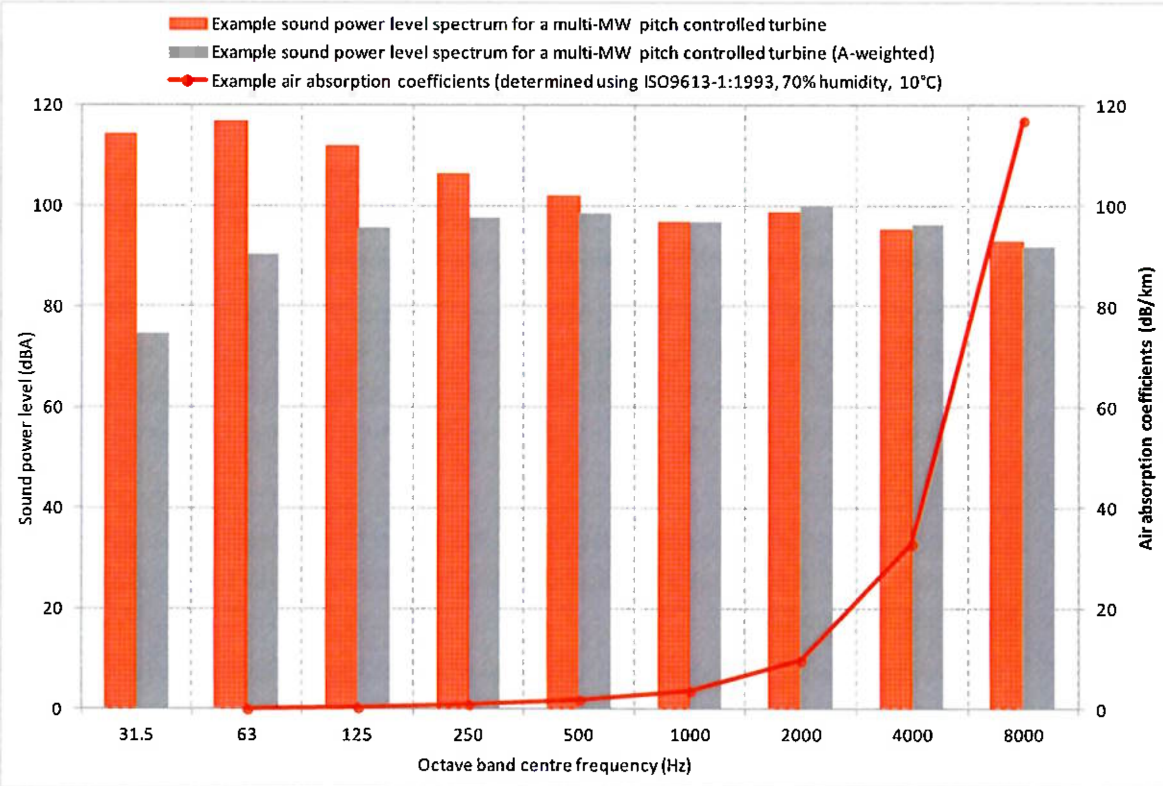


Figure 13: Example sound power level spectrum compared with air absorption coefficients

Ground effect

Ground effect concerns the interaction between reflections of sound from the ground and the direct sound path from source to receiver. Ground effect depends on the height of the source and the receiver, and on the characteristics of the ground, specifically its reflectivity or impedance.

For practical purposes, ground is characterised by its hardness or softness, generally relating to the amount of sound it reflects or absorbs. In more complex prediction models it is also characterised by roughness or unevenness.

Ground effect occurs when the ground is reflective to some degree, causing a series of peaks and dips in the frequency response of the received sound. When the ground is completely absorptive, no reflected energy reaches the receiver such that the resulting sound level is not affected[58].

The practical effect on wind farm sound from ground effect is typically that some frequencies will increase in level by 1 – 6 decibels, and others will decrease significantly. The significant changes generally occur in the lower midrange of frequencies – below 1 kHz.

Screening

Screening can provide attenuation generally between 0 – 20 decibels[58] when blocking or nearly blocking line of sight between a source and a receiver. The effectiveness of a screen or barrier depends on the difference in path length between the direct source-receiver path and the indirect source-barrier edge-receiver path.

For most practical situations involving wind farms, the screening attenuation is caused by terrain such as hills intervening in the propagation path. At the distances commonly involved, the potential path length differences are small, and the effective attenuation that can be realised is often less than 5 decibels. Special conditions arise when barriers are very close to receiver locations, and attenuation can be higher.

Screening attenuation varies by frequency, with greater attenuation offered to high frequencies than to low frequencies. At residential distances from wind farms, much of the high frequency noise content is already lost to air attenuation, and the screening effects must be considered in relation to the remaining lower frequency sound.

Barriers and screens can also change the degree of ground effect which is realised, as they may significantly change the amount of reflected sound which contributes to the energy at the receiver location.

Atmospheric effects

Sound propagation can be significantly affected by atmospheric conditions such as wind and temperature inversion. At wind farm sites, noise is mainly an issue under windy conditions when temperature inversions are uncommon, suggesting that wind effects are the most important atmospheric situation to consider.

The effect of wind on sound propagation is due to the wind speed gradients which arise as wind flows along the terrain. The resistance of flow along the ground causes the wind speed to be slower nearer to the ground, and faster with increasing elevation. The resulting wind speed gradient creates a sound speed gradient, which causes sound to bend in the direction of the slower flow.

[58] (Bowdler & Leventhall, Wind turbine noise, 2011)

For a receiver downwind from a source, this causes sound to bend toward the receiver. As a result, barrier attenuation can be reduced or eliminated, and ground reflection paths can be reinforced. This can result in a slight increase in sound level, around 2 dB[59], due to reinforced hard ground reflections. Where significant barrier attenuation is present the increases may be larger as these barriers become less effective.

For a receiver upwind from a source, the propagating sound bends upward, and a "shadow region" beyond a certain distance appears. In this region the attenuation of sound can be as much as 20 decibels[59].

Vegetation and Buildings

The attenuation provided by vegetation, for instance stands of wind break trees, is generally of limited magnitude—typically less than 1 decibel. However this attenuation can become significant when sound passes through large depths of trees or vegetation, such as through several hundred metres of plantation, where up to 10 decibels of attenuation is predicted by one noise model[60]—albeit under conditions where foliage is consistently high enough to block line of sight between the wind farm turbines and the receivers.

Buildings can also offer screening to noise sources, but in practical wind farm applications this is rarely significant. The screening in built-up areas is often negated by reflections from the sides of buildings.

3.2.2 Sound propagation models

A number of models have been developed to take the above aspects into account and predict sound levels at a distance from the source. They differ in method, complexity, and ease of use. Selecting an appropriate model for a given situation is a matter of striking a balance between these aspects.

A review of several noise models with respect to wind turbine predictions is presented in Wind Turbine Noise[61]. The review considers the ISO 9613-2[62], HarmoNoise, and Nord2000[63], and also briefly discusses other methods which are in some ways more accurate, but more difficult to practically implement. ISO 9613-2, HarmoNoise, and Nord2000 are discussed in further detail below along with limited applications models which offer simpler model set up in exchange for reduced prediction accuracy.

[59] (Bowdler & Leventhall, Wind turbine noise, 2011), Chapter 3.

[60] (International Standards Organisation, 1996), ISO 9613-2:1996, Annex A

[61] (Bowdler & Leventhall, Wind turbine noise, 2011)

[62] (International Standards Organisation, 1996), ISO 9613-2:1996

[63] (Plovsing, 2007)

ISO9613-2

The ISO 9613-2 propagation model is a general purpose noise propagation method which directly models the effects discussed previously. It has become established as the primary international standard for calculation of industrial noise into the environment. ISO 9613-2 predicts noise for receivers which are generally downwind (under light wind conditions) from sources. The model is validated in the Standard for a maximum source height of 30 metres, and a maximum source-receiver distance of 1000 metres. Within these bounds the stated accuracy of the model is +/- 3 dB. Use beyond these parameters is not precluded, but no statement of error bounds is provided in that case.

Work to validate the use of ISO 9613-2 has been described in a number of studies[64]. ISO 9613-2 has been shown to be a reliable predictor of wind turbine noise. It is limited in that it does not contain a means for predicting noise upwind of or crosswind to a wind farm, but in the common practice of calculating the worst-case scenario under a variety of meteorological conditions this is not necessarily a significant shortcoming. Some guidance has been provided[65] on the selection of parameters that are left to the investigator's discretion, to best achieve reliable results using ISO 9613-2 for wind farm prediction. Specific issues considered include barriers, to determine attenuation based on turbine tip height, and ground effects across including consideration of valleys and suitable values for the Ground Factor variable.

HarmoNoise and Nord2000

Nord2000 and more recently HarmoNoise have been developed as more detailed methods for predicting sound propagation, based on ray methods. Both models consider the same parameters as the ISO 9613-2 model, but handle ground reflections, barrier diffraction, reflection, and scattering, in a more detailed manner.

Of particular interest to wind farm applications, this allows the effects of wind movement to be more accurately modelled, and provides a means of predicting upwind noise propagation, albeit with a greater uncertainty than in the downwind case[66].

The accuracy of these models may be better than ISO 9613-2. For example, a recent wind farm noise modelling validation report for Nord2000[66] states that:

> *Generally the conclusion on validation is that for the tested situations Nord2000 shows a fine agreement with noise measurements for simple flat terrain with simple meteorology and for complex terrain with complex meteorology. When compared to ISO 613-2:1996 the Nord2000 model is an improvement especially for the complex situations.*

The accuracy of these models depends on a somewhat greater degree of input complexity, particularly with regard to terrain and ground characteristics. Therefore the improved accuracy may not be realised if limited data is available as input to the model.

[64] (Bass, Bullmore, & Sloth, 1998), (Alberola, 2004), (Adcock, Bullmore, Jiggins, & Cand, 2007), (Bullmore, Adcock, Jiggins, & Cand, 2009), (Halstead & Hunt, 2007)

[65] (Bowdler, et al., 2009), (IOA JS2009)

[66] (Sondergaard & Plovsing, 2009)

Limited Application Models

In some instances, for example in the 1998 and 2010 versions of New Zealand Standard NZS6808, prediction methods have been offered which provide a lower accuracy in exchange for simpler data requirements and calculation complexity. The reduced accuracy is considered to err on the more conservative side of the true value, in other words an over-prediction of sound level.

In the 1998 version of the standard, a model is proposed which takes into account distance and air absorption, but not ground effect or barriers or miscellaneous attenuations. The standard permits calculation of the single-value A-weighted noise level only, rather than calculation of individual octave bands. This has since been shown to lead to under prediction at larger distances.

In the 2010 version of the standard, a simplified version of ISO 9613-2 is presented which requires the user to calculate noise in octave bands, and takes account of distance, air absorption, and ground attenuation in a simplified way. Barrier attenuation is not considered, and the requirement for using the simplified method is that it only be used when barriers are not occurring in the topography.

3.2.3 Implementations

Models such as the those discussed above can be evaluated manually or implemented into a spreadsheet, but are more usefully applied with software[67] which incorporates GIS data input and output, allowing a representation of the 3D environment to be integrated into the noise calculations and therefore into the design process.

Within any of these models, the sound level at a receiver which is produced by each source is calculated, and then these levels are summed to produce the total contribution of the wind farm. This result can be displayed as a table of noise levels at particular properties, or can be calculated over a grid of locations and presented as noise contours.

3.2.4 Design assumptions

As noted above, ISO 9613-2 predictions assume that receivers are generally downwind from each source. In the context of wind farm noise predictions, this implies that each turbine at a site is exposed to the same wind conditions at the same time. Using sound power level data measured in accordance with IEC 1400-11 typically further implies that each turbine has the same sound power output as the turbine that the test report relates to, irrespective of specific site conditions such as wind shear and turbulence effects.

[67] Examples of this type of software include CadnaA (http://www.datakustik.com/index.php?id=52&L=1), IMMI (http://www.woelfel.de/en/products/modelling-software/immi-noise-mapping.html) and SoundPLAN (http://www.soundplan.com/)which are general purpose sound prediction packages, WindPRO (http://www.emd.dk/WindPRO/) and WindFarm (http://www.resoft.co.uk/English/) which is a purpose built wind farm design package incorporating other aspects of design as well as noise.

In practical terms, such assumptions are pragmatic and are generally considered appropriate for the purposes of an engineering assessment intended to provide a reliable representation of the upper noise levels expected in practice. Indeed, a range of comparative measurement and prediction studies[68] for wind farm sites have provided support for the use of ISO 9613, for example, when it is used in combination with an appropriate range of parameter values for inputs[69].

However, if input values are not selected carefully, assumptions of uniform wind conditions and uniform sound power output have the potential to over-estimate the expected upper noise levels. Adcock et al (2007)[70] note that:

> *...the assumption of a single wind speed reference for all turbines that form a large wind farm site may over estimate the actual wind speed seen by each individual turbine.*
>
> [...] *This means that a single wind speed reference will likely overestimate the sound emissions of the turbines nearest to a location of interest.*

3.3 Wind farm neighbours

As wind farms are commonly located in rural areas, wind farm neighbours are commonly residential or farming properties often with a low density of residential dwellings. In Ireland, the extent of dispersed rural housing can frequently mean that there are wind farm neighbours on all sides of a potential wind farm development.

A discussion of a common ambient noise environment at such wind farm neighbours is outlined below. A discussion of types of neighbours, primarily noise sensitive locations, is provided in Section 5.2.1.

The prominence of any wind farm noise at a noise sensitive location depends on two key sound related factors:

- The level and character of the wind farm noise
- The level and character of other ambient noise sources, which can potentially mask the wind farm noise

3.3.1 Wind farm sound levels and character

The level and character of wind farm noise at neighbouring locations will depend on the noise source features of the turbines and the influence of sound propagating factors as outlined respectively in Section 3.1 and Section 3.2 above.

Sound levels

Wind turbine sound will have a different level and character close to the turbine compared with further away. For example, if the level of sound at 200m from a wind farm is in the range of 50-55 dBA then at a distance of, say, 2400m it would be substantially reduced, likely in the range 25-35 dBA[71].

---

68 (Adcock, Bullmore, Jiggins, & Cand, 2007), (Bullmore, Adcock, Jiggins, & Cand, 2009), (Delaire, Griffin, & Walsh, 2011)

69 For example, a ground factor G=0.5 , all turbines emitting sound levels equal to the test measured levels plus a margin for uncertainty, at a temperature of 10 degrees and relative humidity of 70%

70 (Adcock, Bullmore, Jiggins, & Cand, 2007)

71 Refer to Appendix F for a summary of the noise prediction model used to estimate these sound levels.

Wind farm sound levels at noise sensitive locations will vary with the direction of the wind. This is due to sound propagation effects that vary with downwind, as discussed in Section 3.2 as well as the moderate directivity of wind turbines as a noise source. Wind farm sound levels at a noise sensitive location will generally be higher when the location is downwind from the wind farm, as noted in Section 3.1.23 of the IOA GPG which states:

> *...the background noise environment can change due to wind direction in the presence of a distant noise source. In these circumstances, a change in wind direction between upwind and downwind of the dominant noise source could result in a 5 – 15 dB L_{A90} difference in levels.*

Sound character

The specific character of wind turbine or wind farm noise outdoors at a noise sensitive location will depend inherently on the features of the propagation path to the receiver location, as discussed in Section 3.2. Generally, the wind farm sound will contain comparatively less high frequency content as this will have been dissipated during propagation, primarily through air absorption. The perceived level of low and mid frequency sound may therefore be comparatively more prominent. However low and mid frequency sound levels can be subject to some variability due to the competing influences of barriers and ground effects.

Wind farm sound will generally include a noticeable swish from the rotating blades of individual turbines. This is generally considered to be an intrinsic character of wind farm noise except in cases where the swishing becomes excessive, as discussed in Section 3.4.

Sound levels indoors

Wind farm noise levels inside a dwelling or building at a noise sensitive location will generally be lower than outside. Assuming that a partially open window is the controlling path for sound from outdoors to indoors, wind farm noise levels indoors are typically expected to be 10-15 decibels lower inside. [72]

It can also be noted that most building materials reduce high frequency sound levels more readily than lower frequency levels. This means that wind farm noise levels indoors can contain a greater proportion of sound at lower frequencies, particularly to rooms or spaces with no open windows.

3.3.2 Ambient noise environment

The level and character of ambient noise depends on the environment surrounding the noise sensitive location, including any regularly occurring activities such as vehicle pass-bys. Factors that affect the ambient noise include: the separation distance to any nearby major noise sources; the presence of tree breaks; heavy vegetation; streams and waterways, and; other significant natural or manmade noise sources such as roadways and coastal activity.

In rural areas ambient noise levels can be low for significant periods of time, particularly at night and during periods of low wind at noise sensitive locations. Ambient noise levels typically increase with increasing wind speed, as demonstrated in Figure 14, extracted from ETSU-R-97, which plots the relationship between wind speed, on the horizontal axis, and overall A-weighted sound level on the vertical axis.

[72] To typical indoor spaces such as bedrooms, offices and residential living areas (Waters-Fuller, MacKenzie, MacKenzie, & Lurcock, 2007)

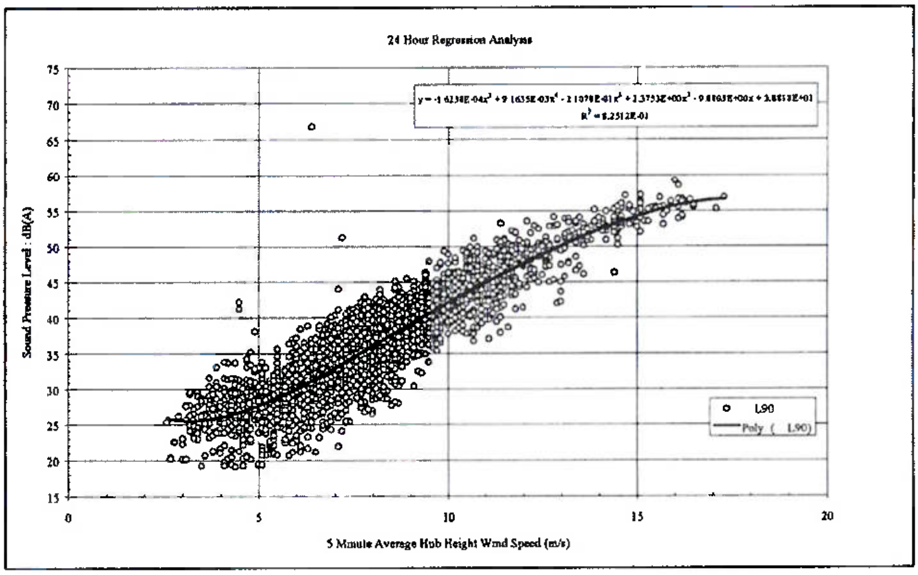


Figure A3 Regression analysis of all measured wind speed and noise data to determine the prevailing background noise level

Figure 14: Example data analysis for sound pressure levels vs wind speeds[73]

The ambient noise environment at a noise sensitive location can potentially be subject to significant variability in time and place, particularly in rural areas. Some ambient noise sources may come and go with time, for example seasonal variations associated with deciduous trees and leaf fall: some may vary with location, for example proximity to rivers or forests; while others may vary with weather conditions such as streams that swell after rainfall. Section 2.2.3 of the IOA GPG notes the following:

> *In many cases there will be significant variation in general background noise levels within the study area, because of topography and the varying influence of existing noise sources such as roads. In rural or semi-rural areas, noise generated by wind in trees is generally a dominant noise source at higher wind speeds and therefore the proximity of the monitoring location to trees and vegetation, and the type of such vegetation, may be significant. Noise from streams and other watercourses can also be a local factor.*

This variability will be evident in most site measurement data collected and it could be expected that different measurement campaigns at a common site but during different periods in time may result in measured noise levels that are not always in entire agreement. This is not to say that any of the measured data is incorrect, rather, it is simply a reflection of the inherent variability of the factors influencing the ambient noise environment.

3.3.3 Masking of wind farm noise

The prominence of any wind farm noise at noise sensitive locations depends not only on the complex array of sound propagation mechanisms between the source and receiver but also on the local ambient noise environment at the receiver. To this end, WEDG06 says:

[73] (The Working Group on Noise from Wind Turbines, 1996)

Turbine noise increases as wind speeds increase, but at a slower rate than wind generated background noise increases. The impact of wind energy development noise is therefore likely to be greater at low wind speeds when the difference between noise of the wind energy development and the background noise is likely to be greater.

[...] *At higher wind speeds noise from wind has the effect of largely masking wind turbine noise*

However, the ability of ambient noise to mask wind farm noise levels can be variable. While in some cases the masking can be effective, in other circumstances it can be less so - it has been noted by Sondergaard[74] that:

...the periodic and deterministic nature of wind turbine noise makes it more audible through the more stochastic wind noise.

Masking noise is also less effective if its frequency characteristics are substantially different from the sound to be masked[75].

3.4 Special characteristics

Any sound with special audible characteristics is likely to cause annoyance at lower levels than the sound without these characteristics. Special audible characteristics that are considered in relation to environmental noise assessments can include amplitude modulation, impulsiveness, infrasound, low frequency noise and tonality.

Each of these characteristics is described briefly below including:

- Comments about definitions for each characteristic
- Examples of noise sources exhibiting each characteristic

The relevance of these characteristics to wind farm noise is variable. For example, impulsiveness is not commonly associated with wind farm noise while, conversely, tonality has been identified as an issue requiring mitigation works at some wind farms[76,77]. Comments regarding how each characteristic relates to wind farm noise are therefore also included below.

Comments regarding planning and operational stage assessments of special audible characteristics are provided in Section 6.3 and Section 7.4 respectively.

---

[74] (Bowdler & Leventhall, Wind turbine noise, 2011), Chapter 4

[75] (Zwicker & Fastl, 2010)

[76] (Cooper, Evans, & Petersen, 2013)

[77] (Sondergaard & Pedersen, Tonality in wind turbine noise. IEC 61400-11 ver. 2.1 and 3.0 and the Danish/Joint Nordic method compared with listening tests, 2013)

3.4.1 Amplitude modulation

If a sound has a noticeable change in sound level, often which is regular and repeating, this can in some cases be described as amplitude modulation. Examples include a ringing telephone and the sound of waves crashing on the shore.

In practice, both describing and identifying amplitude modulation can be a source of some confusion. An HGC Engineering report[78] defines amplitude modulated sound as *"a sound which noticeably fluctuates in loudness over time."* The report also comments that:

> *There appears to be come confusion between this low speed temporal modulation of sound and low-frequency or low-pitched sounds. To avoid misunderstanding, it should be realised that any sound, with predominantly low, middle or high-pitched frequency content can be modulated in time, without changing the pitch of the sound.*

Depending on the context, amplitude modulation may refer to any kind of noticeable fluctuation of sound level or to a fluctuation of sound level which is more noticeable than normal. A degree of regularity of the fluctuating sound level can also be necessary.

Wind turbine sound is often described using terms such as swish, swoosh and whooshing. The use of such terms is likely due in part to the broadband noise generated from the trailing edge of the turbine blades. Some wind farm noise guidance documents, such as ETSU-R-97, state that some amount of amplitude modulation is a characteristic of wind turbine sound and that specified noise limits account for this character.

The University of Salford report NANR233[79] reviewing amplitude modulation at wind farms describes amplitude modulation, or aerodynamic modulation as it can also be called, as

> *"a greater than normal degree of fluctuation* [of sound level] *at about once per second which makes it more noticeable."*

The NANR233 was prepared following a report[80] investigating low frequency noise in which it was noted that *"the cause of complaints was not low frequency noise or infrasound, but was audible modulation of aerodynamic noise, i.e. aerodynamic noise which displays a greater degree of fluctuation than usual."*

Amplitude modulation has been the subject of considerable attention since the publication of WEDG06. Despite this, there is currently only limited evidence of the potential presence of this type of effect[81]. This may be due to the limited numbers of sites where the effect has been reported, and at the sites where it has been reported, the limited and specific atmospheric conditions required to result in the reported effect. However, some recent work suggests amplitude modulation may be more prevalent than previously thought[82].

At present there are no widely accepted methods of predicting either the occurrence or level of any amplitude modulation from wind farms.

---

[78] (HGC Engineering, 2007)

[79] (Moorhouse, Hayes, von Hunerbein, Piper, & Adams, 2007)

[80] (Hayes Mckenzie Partnership Ltd, 2006)

[81] (Moorhouse, Hayes, von Hunerbein, Piper, & Adams, 2007)

[82] (Stigwood, Large, & Stigwood, Audible amplitude modulation - Results of field measurements and investigations compared to psyco-acoustical assessment and theoretical research, 2013)

A study sponsored by Renewable UK has been undertaken to improve the understanding of this enhanced amplitude modulation. At the time of writing, no reports of this study have been released.

Refer to Section 6.3 and Section 7.4 for further comments.

3.4.2 Impulsiveness

New Zealand Standard NZS 6808:2010 *Acoustics – Wind farm noise* (NZS6808:2010) defines impulsive sound as "*transient sound having a peak level of short duration, typically less than 100 milliseconds.*" Examples of impulsive noise include gunfire sounds, car door slamming and pile driving[83].

Many sound level meters include the capacity to measure sound with an impulsive time weighting, which has been developed to assess the significance of sound with impulsive characteristics. However, ISO 1996-2:2007 states the following with regard to assessment methods for impulsiveness:

> *There is no generally accepted method to detect impulsive sound using objective measurements. If impulsive sound occurs, identify the source and compare it to the list of impulsive sound sources in ISO 1996-1. In addition, make sure that the impulsive sound is representative and present in the measurement time interval.*

The characteristic swish associated with wind turbines tends to involve a fluctuation in A-weighted sound level of approximately +/-3 dB[84]. Whether or not this fluctuation is sufficiently rapid to be considered a possible impulsive sound, the variation in sound level is generally considered to be too small for the sound to be identified as a problematic impulsive sound.

There are currently no direct methods for predicting either the occurrence or level of any impulsiveness of wind farms noise. However, as it is not generally considered to be a significant feature of wind farm noise, the lack of assessment capability has not been identified as a significant shortcoming and has not been the subject of any significant recent research undertakings.

Refer to Section 6.3 and Section 7.4 for further comments.

3.4.3 Infrasound

A UK Department of Trade and Industry (DTI LFN) report *The measurement of low frequency noise at three UK wind farms* [85] notes that "*Infrasound is noise at frequencies below the normal range of human hearing, i.e. <20 Hz*". Despite the inference by the term itself, infrasound can be audible. This DTI report also notes that "*frequencies down to a few hertz are audible at high enough levels*".

---

[83] (International Standards Organisation, 1996), ISO 1996-1:2003

[84] See ETSU-R-97

[85] (Hayes Mckenzie Partnership Ltd, 2006)

Several points are worth noting:

- Infrasound is naturally occurring in the environment including sources such as waves and waterfalls[86,87]
- Infrasound is also present from manmade sources including aircraft, rail traffic and mining explosions[86,87]
- Human perception of sound energy in the infrasound frequency range is much less acute than other frequency bands[88]. Significant energy is required to produce levels of infrasound which are high enough to be perceived by humans.

With respect to infrasonic noise levels below the hearing threshold, the World Health Organization has stated[89] that:

> *There is no reliable evidence that infrasounds below the hearing threshold produce physiological or psychological effects*

In 2010, the UK Health Protection Agency published a report[86] on the health effects of exposure to ultrasound and infrasound. The exposures considered in the report related to medical applications and general environmental exposure. The report notes:

> *Infrasound is widespread in modern society, being generated by cars, trains and aircraft, and by industrial machinery, pumps, compressors and low speed fans. Under these circumstances, infrasound is usually accompanied by the generation of audible, low frequency noise. Natural sources of infrasound include thunderstorms and fluctuations in atmospheric pressure, wind and waves, and volcanoes; running and swimming also generate changes in air pressure at infrasonic frequencies.*
>
> *[...]*
>
> *For infrasound, aural pain and damage can occur at exposures above about 140 dB, the threshold depending on the frequency. The best-established responses occur following acute exposures at intensities great enough to be heard and may possibly lead to a decrease in wakefulness. The available evidence is inadequate to draw firm conclusions about potential health effects associated with exposure at the levels normally experienced in the environment, especially the effects of long-term exposures. The available data do not suggest that exposure to infrasound below the hearing threshold levels is capable of causing adverse effects.*

Some assessment guidance for infrasound is available. ISO 7196:1995[90] provides guidance on quantifying measured infrasound levels, using a G-weighting for adjusting measured frequency data. German Standard DIN 45680:1997[91] also provides guidance relating to part of the infrasound frequency range, down to 8 Hz, including advice regarding human hearing threshold levels. Measuring infrasound levels can be problematic; particularly outdoors where measurements can be significantly affected by wind induced noise on the microphone.

---

86 (The independent advisory group on non-ionising radiation, 2010)

87 (Department of Health (Victoria), 2013)

88 (International Organisation of Standardisation, 1995), ISO 7196:1995

89 (Berglund & Lindvall, Community noise, 1995)

90 (International Organisation of Standardisation, 1995) ISO7196:1995

91 (Technical Committee Grundlagen der Schallmessung/-bewertung, 1997)

In relation to wind farms, an early study[92] of infrasound in 1997 as part of a UK government funded investigation reported measured levels of infrasound, low frequency sound and vibration in the vicinity of a wind farm comprising 450 kW turbines. The results demonstrated that noise levels complied with recommended residential criteria even on the wind turbine site itself, and the measured levels were below accepted levels of perception below 20 Hz.

The DTI LFN report[93] also indicated that measured infrasound levels in the vicinity of modern multi-megawatt wind farms were substantially lower than the threshold of hearing for even the most sensitive members of the population.

The UK Institute of Acoustics Bulletin in March 2009[94] included a statement of agreement between acoustic consultants regularly employed on behalf of wind farm developers, and conversely acoustic consultants regularly employed on behalf of community groups campaigning against wind farm developments (IAO JS2009). The intent of the article was to promote consistent assessment practices, and to assist in restricting wind farm noise disputes to legitimate matters of concern. On the subject of infrasound the article notes:

Infrasound is the term generally used to describe sound at frequencies below 20 Hz. At separation distances from wind turbines which are typical of residential locations the levels of infrasound from wind turbines are well below the human perception level. Infrasound from wind turbines is often at levels below that of the noise generated by wind around buildings and other obstacles. Sounds at frequencies from about 20 Hz to 200 Hz are conventionally referred to as low-frequency sounds. A report for the DTI in 2006 by Hayes McKenzie concluded that neither infrasound nor low frequency noise was a significant factor at the separation distances at which people lived. This was confirmed by a peer review by a number of consultants working in this field. We concur with this view.

A Portuguese group has been researching 'Vibro-acoustic Disease' (VAD) for about 25 years. Their research initially focussed on aircraft technicians who were exposed to very high overall noise levels, typically over 120 dB. A range of health problems has been described for the technicians, which the researchers linked to high levels of low frequency noise exposure. However other research has not confirmed this. Wind farms expose people to sound pressure levels orders of magnitude less than the noise levels to which the aircraft technicians were exposed. The Portuguese VAD group has not produced evidence to support their new hypothesis that infrasound and low frequency noise from wind turbines causes similar health effects to those experienced by the aircraft technicians.

92 (Snow, 1997)

93 (Hayes Mckenzie Partnership Ltd, 2006)

94 (Bowdler, et al., 2009)(IOA JS2009)

Recent measurements in Australia[95] have demonstrated that infrasound and low frequency sound produced by regularly encountered natural and man-made sources, such as the infrasound produced by the wind or distant traffic is comparable to that of modern wind turbines, noting that:

> *Infrasound levels in the rural environment appear to be controlled by localised wind conditions. During low wind periods, levels as low as 40 dB(G) were measured at locations both near to and away from wind turbines. At higher wind speeds, infrasound levels of 50 to 70 dB(G) were common at both wind farm and non-wind farm sites.*
>
> *Organised shutdowns of the wind farms adjacent to* [sic: measurement locations] *indicate that there did not appear to be any noticeable contribution from the wind farm to the G-weighted infrasound level measured at either house.*

In response to ongoing concerns regarding potential health effects associated with these types of emissions, the Australian Government's National Health and Medical Research Council issued a public statement in July 2010 titled *Wind Turbines and Health* supporting the view that there is no published scientific evidence to positively link wind turbines with direct health impacts.

Conversely, a cooperative study into infrasound and low frequency noise at a wind farm in Wisconsin USA by four acoustic consulting firms considered that:

> *The four investigating firms are of the opinion that enough evidence and hypotheses have been given herein to classify LFN and infrasound as a serious issue, possibly affecting the future of the industry. It should be addressed beyond the present practice of showing that wind turbine levels are magnitudes below the threshold of hearing at low frequencies*

Infrasound remains a comparatively high profile issue in some jurisdictions and it is the subject of ongoing research[96].

For comments regarding prediction methods for infrasound refer to Section 3.4.4 as the comments regarding low frequency noise prediction are also generally applicable to infrasound.

Refer to Section 6.3 and Section 7.4 for further comments.

3.4.4 Low frequency noise

The specific range of frequencies encompassed for an assessment of Low Frequency Noise can vary. A Casella Stanger report[97] provides the following comments regarding low frequency noise:

> *Low frequency noise is not clearly defined but is generally taken to mean noise below a frequency of about 100 to 150 Hz.*

---

[95] (Sonus Pty Ltd, 2010), (Evans, Cooper, & Lenchine, Infrasound levels near wind farms and in other environments, 2013)

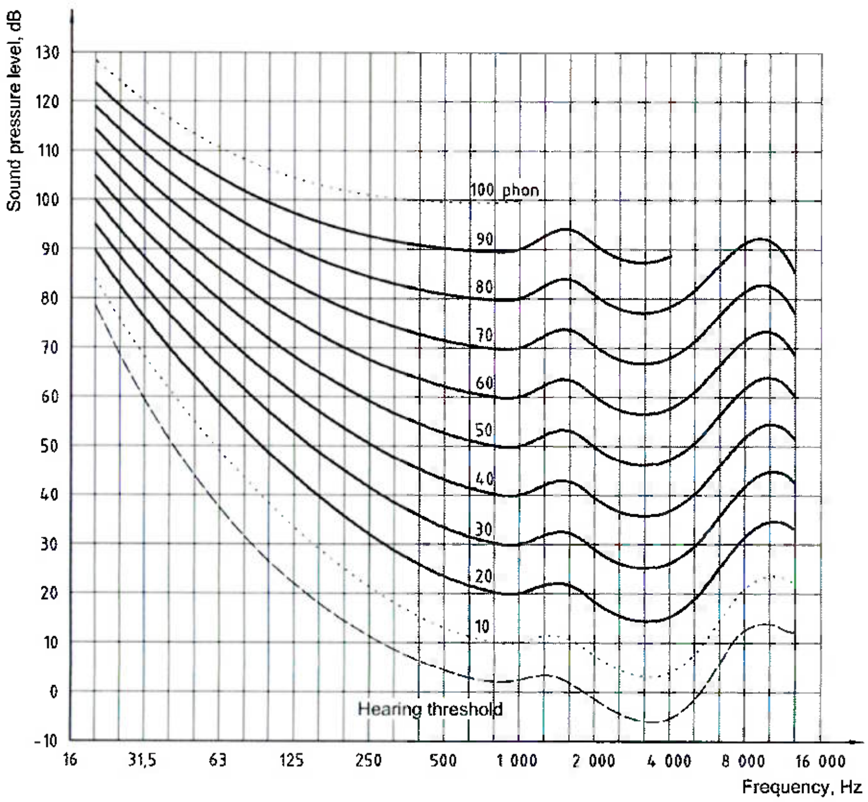
[96] For example, the South Australia EPA Waterloo Wind Farm Noise Study: http://www.epa.sa.gov.au/environmental_info/noise/wind_farms/waterloo_wind_farm_noise_study

[97] (Casella Stanger, 2001)

Leventhall[98] states that *"low frequency noise is defined as from about 10 Hz to 200 Hz."* A State Government of Victorian Department of Health document[99] details low frequency noise as occurring at frequencies less than 200 Hz.

The sound of a horn on a large ship is an example of low frequency noise. The lowest key on a piano is 27.5 Hz which is also in the low frequency range.

Human thresholds to low frequency noise are much less sensitive than to sound in other frequency ranges, such as the range of speech frequency. The relationship between the sensation of 'loudness' and frequency is demonstrated in Figure 15, which shows combinations of sounds of differing frequency and level judged to be equally loud by people.



NOTE 1 The hearing threshold under free-field listening condition, T_f, is indicated by a dashed line.

NOTE 2 The contour at 10 phon is drawn by dotted lines because of the lack of experimental data between 20 phon and the hearing thresholds. Moreover, the 100-phon contour is also described by a dotted line because data from only one institute are available at this loudness level.

Figure A.1 — Normal equal-loudness-level contours for pure tones
(binaural free-field listening, frontal incidence)

Figure 15: Equal loudness contours for pure tone sounds[100].

[98] (Leventhall, 2004)

[99] (Department of Health (Victoria), 2013)

[100] (International Organisation of Standardisation, 2003), ISO 226:2003

For assessment of low frequency noise, the World Health Organization has stated[101] that:

> *Since A-weighting underestimates the sound pressure level of noise with low-frequency components, a better assessment of health effects would be to use C-weighting.*

C-weighted broadband noise levels are often cited in low frequency noise assessment guidance documents. For example, the German Standard DIN 45680:1997[102] provides a relative preliminary assessment of low frequency noise by comparing measured A and C weighted sound levels for the same sound:

> *To determine whether the noise to be investigated is low-frequency noise as defined in this standard, take the difference between the L_{Ceq} and L_{Aeq} values, or that between the L_{CFmax} and L_{AFmax} values, measured during the measurement time interval. If this difference is greater than 20 dB, perform measurements using third-octave band filters*

Other available assessment methods can include preliminary assessment and trigger levels, expressed as C-weighted decibels, above which a detailed investigation should be carried out or, alternatively, limits proposed explicitly as C-weighted levels[103].

By contrast, in Denmark, for example, the DSO1284 document has maintained reference to A-weighted levels using a tailored index, $L_{pA,LF}$, which only considers sound levels in the frequency range from 10 Hz to 160 Hz.

In relation to wind farm noise, a 2011 Danish study of wind turbine noise[104] discussed in Section 3.1.5 above states in its abstract that

> *"Even when A-weighted levels are considered, a substantial part of the noise is at low frequencies, and for several of the investigated large turbines, the one-third-octave band with the highest level is at or below 250 Hz. It is thus beyond any doubt that the low-frequency part of the spectrum plays an important role in the noise at the neighbours"*

Concurrently, a 2011 Swedish review[105] of available literature about low frequency noise from wind turbines noted the following.

> *LFN* [Low Frequency Noise] *from modern wind turbines are audible at typical levels in residential settings, but the levels do not exceed levels from other common noise sources, such as road traffic noise. Although new and large wind turbines may generate more LFN than old and small turbines, the expected increase in LFN is small.*

---

[101] (Berglund & Lindvall, Community noise, 1995)

[102] (Deutsches Institut fur Normung, 1997)

[103] (NSW Department of Planning and Infrastructure, 2011), (Broner, 2011)

[104] (Moller & Pedersen, 2011)

[105] (Bolin, Bluhm, Eriksson, & Nilsson, 2011)

The Victorian Department of Health document[106] notes that:

> *...low frequency sound from wind farms may be audible at neighbouring residences, and may become more prominent at night under stable conditions. However, while it may be audible, the actual impact of low frequency sound on residents near wind farms is low, because of the low levels produced overall.*
>
> *For example, the levels of low frequency sound 600 m from a large wind turbine, measured both indoors and outdoors, are lower than in many other environments, such as light industrial or suburban areas or inside a passenger car.*

This is consistent with recent low frequency noise measurement work from South Australia[107] which concluded:

> *Measured low frequency noise levels were considerably higher in urban areas than in rural areas....*
>
> [...]
>
> *Typically, low frequency noise levels at the two* [sic: measurement locations near wind farms] *were not noticeably higher than those at the two rural houses away from wind farms.*

Refer to Section 6.3 and Section 7.4 for further comments.

3.4.5 Tonality

ETSU-R-97 describes tonal noise as "*noise containing a discrete frequency component most often of mechanical origin*". Examples include the hum from an electrical transformer, which exhibits low frequency tones, the dial tone on a phone, a mid frequency tone, and whistling which tends to comprise higher frequency tones.

An example of a frequency spectrum exhibiting tonal peaks is illustrated in Figure 16, an extract from IEC61400-11[108].

[106] (Department of Health (Victoria), 2013)

[107] (Evans, Cooper, & Lenchine, 2013)

[108] (International Electrotechnical Commission, 2012)

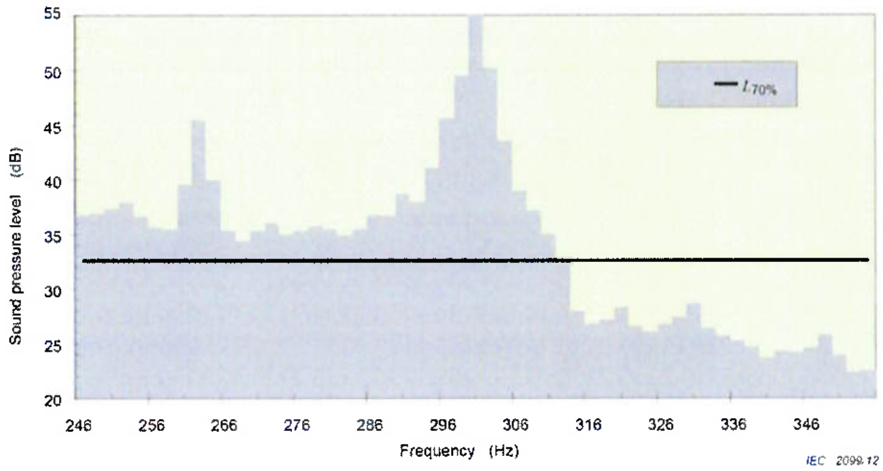


Figure 8 – Illustration of $L_{70\,\%}$ level in the critical band

Figure 16: Example of a partial frequency spectrum exhibiting tonal peaks

Wind turbine sound can be tonal in some cases, for example if there is a defect in a turbine blade or a fault in the mechanical equipment such as the gearbox. Typically however, a correctly operating wind turbine is not considered to have tonal sound emission.

A detailed tonality assessment method is provided in IEC61400-11[108] and so typically forms part of the data set that is supplied from the turbine manufacturer. Alternatively, in lieu of providing this data as part of the wind turbine specification, a manufacturer will often simply guarantee, on the basis of the results of a tonality assessment according to IEC 61400-11, that the wind turbine is not tonal.

Refer to Section 6.3 and Section 7.4 for further comments.

3.4.6 Discussion

Special audible characteristics are not unique to wind farms and can be a readily occurring characteristic of many types of noise. Often jurisdictions will have existing regulations or methods in place to assess such characteristics such that the discussion in a wind farm guidance document need only refer to the existing information, perhaps with additional comments about how to address variations with wind speed.

Further comments regarding regulating special audible characteristics, their prediction and their measurement are provided in Section 5.5, Section 6.3 and Section 7.4 respectively.

4.0 INTERNATIONAL BENCHMARKING (WORK PACKAGE 2)

The international benchmarking review, which is the core task of Work Package 2 of the briefing documents, is described across three report sections, as follows.

Section	Topic	Outline
5	Control methods for wind farm noise	Review of control methods for wind farm noise including discussion of cumulative impacts, setbacks & special audible characteristics.
6	Planning stage assessments	Planning considerations including background noise monitoring.
7	Operational assessments	Operational considerations including post-construction noise measurement procedures.

5.0 CONTROL METHODS FOR WIND FARM NOISE (WORK PACKAGE 2)

This section provides a review of wind farm noise control and assessment methods used internationally. This is followed by consideration of a number of specific noise control issues including cumulative impacts and setbacks.

5.1 Types of noise control methods

A range of different control methods is available to regulate noise from wind farms. Three key methods which are commonly applied for wind farm noise are outlined briefly in this section.

An informative discussion of general noise control methods is also provided in Appendix D.

5.1.1 Absolute noise limits

Absolute limits establish a fixed numeric value that must be complied with regardless of the specific ambient noise environment at the property. This style of method can involve assigning noise limits at receptors based on the level of noise sensitivity of the receiver. Commonly this is managed by classifying receivers according to land zoning. For example, land in a commercial zone is likely to be less noise sensitive than land zoned residential. To match this expectation, land in a commercial zone will often have higher noise limits, allowing greater levels of sound exposure, than residential zones.

Advantages of an absolute noise limit include its ease of application to different sites and the comparative simplicity of assessment. However, as absolute noise limits do not take into account the noise environment prior to the introduction of the noise source in question, their use can result in varied levels of change to the ambient noise environment.

For example, residential properties in different locations may have the same noise limit because of common land zoning. If a potential noise producer is considering moving adjacent to one or other of the properties, the producer's decision would not involve noise control issues as they would be the same for either site. Similarly, if one of the residential properties happens to be near a major road then the residents may not even notice noise from the potential future neighbour above existing levels of traffic noise. Conversely, if the other residential property was adjacent to a quieter, minor back street with no significant noise sources in the area, they may find noise from their potential future neighbour to be much more intrusive.

5.1.2 Relative or Background based noise limits

The relative (or background based) noise limit method takes into account the noise environment at the potential affected receiver without the introduction of the noise source under assessment. Relative limits are usually in the form of a noise level plus some pre-determined margin. For example, 'the background noise level L_{A90}, plus 5 dB.'

An advantage of relative limits is that they can be tailored to the ambient noise environment at the site of interest. A disadvantage is that they can be less responsive to sudden future changes in land use and can result in background noise creep.

5.1.3 Combination of absolute and relative limits

The combination approach to noise limits typically employs a relative noise limit, as described above, in conjunction with a lower bound or absolute noise limit that would apply in particularly quiet ambient noise environments. The lower bound or absolute component of the noise limit is typically chosen so that appropriate amenity protection is provided in the quiet environments where the limit would apply.

The objective of this style of limit, which incorporates a lower bound, is to not unduly restrict development in very quiet areas, a point that is well described in WEDG06 in relation to wind farm noise:

> [...] *in very quiet areas, the use of a margin of 5dB(A) above background noise at nearby noise sensitive properties is not necessary to offer a reasonable degree of protection and may unduly restrict wind energy developments which should be recognised as having wider national and global benefits.*

It should also be noted that assessing compliance with a relative noise limit in very quiet environments can often be difficult due to practical limitations of readily available noise measurement equipment.

For example, the noise floor of a sound level meter can influence measured sound levels in very quiet areas resulting in less accurate measurements. A pragmatic advantage of combination style limits, therefore, is the comparative ease of assessing compliance with the absolute component of the limit in very quiet environments.

5.2 Review of international noise limits for wind farms

The core objective of wind farm noise policies is to balance the advantage of developing wind energy projects with protecting the amenity of the surrounding community from adverse noise impacts, as noted in WEDG06, which states that:

> *An appropriate balance must be achieved between power generation and noise impact. Noise impact should be assessed by reference to the nature and character of noise sensitive locations.*

5.2.1 Receptor types

General noise policy guidelines and documents in a jurisdiction are typically adequate for identifying properties or types or properties which are more sensitive to noise and therefore should be included in any assessment of noise effects be it from a wind farm or some other noise source. For example, in Ireland the Environmental Protection Agency Act, 1992 requires assessment of noise as a nuisance to a person:

> *'In any premises in the neighbourhood or to a person lawfully using any public place'*

Relating to wind farms, WEDG06 provides the following guidance regarding receptor types:

> *'Noise impact should be assessed by reference to the nature and character of noise sensitive locations. In the case of wind energy development, a noise sensitive location includes any occupied dwelling house, hostel, health building or place of worship and may include areas of particular scenic quality or special recreational amenity importance.'*

In the UK, the discussion of receptor types in the recently released IOA GPG is limited. However, Section 2.2.4 of the GPG does provide comments in relation to suitable noise monitoring locations which are likely to be applicable to general assessment also:

Background noise measurements should preferably be made in the vicinity of noise-sensitive receptors, principally houses (existing or for which planning consent is being sought / has been given) and any building used for long-term residential purposes (such as a nursing home).

In Canada, the ONG2008 notes that:

the Point of Reception may be located on any of the following existing or zoned for future use premises: permanent or seasonal residences, hotels/motels, nursing/retirement homes, rental residences, hospitals, camp grounds, and noise sensitive buildings such as schools and places of worship.

The Australian SAG2009 defines relevant receivers as:

Relevant receiver locations are premises:

- *where someone resides or has development approval to build a residential dwelling;...*

Australian Standard AS4959:2010 *Acoustics – Measurement, prediction and assessment of noise from wind turbine generators* (AS4959:2010) defines Receivers as:

A location requiring prediction of the impact of wind turbine generator noise. Generally taken to be an existing dwelling, a future dwelling with development approval, or the location of potential future noise sensitive development (an occupied dwelling where people might sleep or stay) promoted by the planning system for that jurisdiction

NZS6808:2010 notes that:

In some instances holiday cabins and camping grounds might be considered as noise sensitive locations. Matters to be considered include whether it is an established activity with existing rights

Commercial and industrial land uses are not commonly located adjacent to wind farm projects and are not commonly included in regulatory limits. Indeed wind farm guidelines commonly identify sleep disturbance as a primary issue, which is not typically applicable to commercial and industrial applications.

5.2.2 Approaches to wind farm noise limits

What distinguishes wind turbines, and in particular wind farms, as a noise source is that sound levels tend to increase with increasing wind speed. This introduces challenges of measuring and assessing wind farm noise due to the presence of wind effects and other noise sources caused by wind in the environment. Levels of both ambient noise and wind farm noise have the potential to vary significantly depending on the meteorological conditions at any given time.

An example of a how these variations can be addressed is in the specification of an absolute noise limit and an associated wind speed at which the turbine noise sound be assessed. For example, a noise limit of 42 dB L_{Aeq} at a wind speed of 6 m/s referenced to 10m AGL.

An alternative means of coping with ambient noise levels that vary with wind speed, is the use of relative noise limits across a range of wind speeds, effectively with a separate ambient noise level/limit established for each integer wind speed over some pre-determined assessable range of wind conditions. The noise limit at a given wind speed can be determined from an estimate of background noise levels at that wind speed, determined from a regression analysis. For example, for the regression curve illustrated in Figure 14 above, the background noise level at 10 m/s is approximately 42 dBA. For a relative noise limit of the form 'the background noise level L_{A90}, plus 5 dB', the associated limit value at 10 m/s would be 47 dBA.

Wind farm noise limits can also use the combination approach which is based on relative limits and includes an absolute limit component which is typically applied at low wind speeds. The absolute component of the limit removes the dependence on relative limits under conditions of very low ambient noise, on the assumption that during periods of low noise levels an adequate level of amenity protection can be provided irrespective of the margin between the background noise level and the source level.

Because wind farm noise depends on the weather conditions, particularly wind speed and direction, occurring at a particular time, the level of sound at given receiver will also vary with time. Irrespective of this, wind farm noise limits are often developed on the premise that the noise would be constantly present at receptor locations[109]. In other words, the noise limits are not adjusted to account for the rate of exposure to the wind farm noise at the receptor location.

5.2.3 Noise limits and control methods

Table 3 below summarises the approach to wind farm noise control in key international regions, with emphasis on areas where wind farm noise policy is well established and has, potentially, benefitted from longer term application and any resulting refinement of the methods. This section should be read in conjunction with the more detailed review of control methods used across different regions is provided in Table 16 in Appendix E.

[109] Examples of such limits are detailed in NZS6808:2010 and SAG2009

Table 3: Summary of outdoors wind farm noise limits across jurisdictions*

Noise limit category	Region	Absolute limit**	Relative limit**
Absolute limit***	Spain	≈ 45-50 dB(A)	-
Absolute limit	Denmark	37-44 dB L_{Aeq}	-
	Germany	≈ 35-55 dB L_{Aeq}	-
	Netherlands	≈ 47 dB L_{Aden}	-
	South Korea	40-55 dBA	-
	Sweden	35-40 dB L_{Aeq}	-
Combination limit	Australia	35-40 dB	+5 dB, L_{A90}
	Canada	≈ 40-50 dB L_{Aeq}	+0-7 dB, L_{A90}
	France	30 dBA	+3-7 dB
	Ireland	35-45 dB $L_{A90(10min)}$	+5 dB, $L_{A90(10min)}$
	New Zealand	35-40 dB	+5 dB, L_{A90}
	United Kingdom	35-43 dB $L_{A90(10min)}$	+5 dB, $L_{A90(10min)}$
Other	USA	Varies by state	

* The descriptors used to specify noise limits very across jurisdictions. For example, the Irish limit is expressed in terms of $L_{A90(10min)}$ while the Danish limits is described in terms of L_{Aeq}. The relationship between different descriptors is not constant and can vary with the type of noise being measured as well as the requirements of each particular assessment methodology. As a guide, however, the variation between the wind farm noise limit descriptors in the table may range from 0 dB to 3 dB or more. ETSU-R-97, for example, estimates that $L_{A90(10min)}$ wind farm sound levels are likely to be 1.5-2.5 dBA less than measured L_{Aeq} levels over the same period.

** Limits generally applicable outdoors at residential or noise sensitive locations without involvement in the wind farm project. Refer to Table 16 in Appendix E for further details.

*** The Spanish absolute limits can also include a minimum setback distance in some cases. Refer to Table 16 in Appendix E for further details.

It can be seen from Table 3 that, for the countries considered, approximately half have developed absolute noise limits without a relative noise limit component while half have implemented combination noise limits which include both absolute and relative components.

With the exception of the French regulations, absolute noise limits[110] at residential dwellings typically range from 35-45 dBA. This is comparable with the noise limit range currently specified in WEDG06 for Irish wind farm developments. Irish noise limits are discussed further in Section 8.0.

Limit values in the range 35-45 dBA are typically employed where the limits are intended for protecting resting and sleeping conditions. For example, Section C.5.1.2 of NZS6808:2010 provides the following comments to justify its choice of absolute noise limits:

> *This* [outdoor noise limit, 40 dB $L_{A90\,(10\,min)}$] *is based on an internationally accepted indoor sound level of 30 dB L_{Aeq} to protect against sleep disturbance (refer to Berglund, Lindvall, and Schwela). This assumes a reduction from outdoors to indoors of typically 15 dB with windows partially open for ventilation. The typical reduction of 15 dB would reduce an external level of 40 dB L_{A90} to 25 dB L_{A90}. Given that the internal target is 30 dB L_{Aeq} this allows for the difference between L_{EQ} and L_{90}, and for variations in the outside to inside reduction*

It should be noted that differences in noise level descriptor, and to a greater extent, assessment methodology can mean that two regions which share a common numerical base noise limit may have different wind farm noise outcomes. This is discussed further below.

5.2.4 Associated assessment methods

While Table 3 details numerical values for noise limits, it should be recognised that the methodology used to assess compliance with limits, and the specific form of the limits, are integral to the resulting outcomes. Regions which share a comparable noise limit may produce very different outcomes for wind farm neighbours, as well as developers and regulators, due to the form of the limit and its assessment.

For example, it could be conjectured from Table 3 that the noise limits in the UK and Denmark are largely comparable, with absolute limits approximately[111] in the range of 35-45 dB. However, applying the relative component of the UK limit can require potentially extensive additional assessment by way of unattended background noise monitoring and analysis. This additional assessment work could be viewed as a burden on a proposed development or, concurrently, as a means of facilitating development through increased noise limits at higher wind speeds. In comparison, the Danish limit is an absolute limit and applies at one or two wind speeds. There is no dependence on ambient noise levels, that is, there is no relative limit, and the assessment and any resulting commissioning measurements are likely to be comparatively simpler to apply.

---

[110] Including absolute limit components of a combination noise limit

[111] The approximate range makes allowance for differences in limit caused by the use of different noise level descriptors. For example, L_{Aeq} vs $L_{A90(10min)}$

As this example demonstrates, while noise limits can be specified as well defined numerical values, details of associated assessment methodologies could readily result in differences in outcome. Common points of difference across guidance documents include choice of noise index, for example L_{A90} and L_{Aeq} and the choice of noise prediction method used for planning stage assessment. An in-depth review of assessment methodologies across different jurisdictions is outside the scope of this document. In lieu, it should be noted that the limits detailed in Table 3 are most useful to review the types of control method used internationally for wind farm noise, rather than directly comparing noise limit levels as the latter is not necessarily a reliable indicator of outcomes.

5.3 Separation distances and setbacks

5.3.1 Overview

Minimum separation distances or setbacks between wind turbines and noise sensitive locations are applied as a control method in some jurisdictions. In contrast to noise limits which, by design, typically only directly address the potential impacts of noise, setbacks can be implemented to address a number of potential issues concurrently. For example, there is a view that a minimum set back distance could concurrently address:

- Noise impact
- Shadow flicker
- Visual impact
- Safety issues addressed through provision of clearance to major roadways etc.

Accordingly, in reviewing a setback distance in a particular jurisdiction the intention of the setback should be clearly understood. Watson et al[112] carried out a review of setback distances in various Canadian provinces in 2011. Their concluding remarks note that:

> *The planners we interviewed did not use a consistent method to determine appropriate setback distances. Setbacks proposed by planners were informed by the local context and subjected to modifications during the political and public process. Jurisdictions with similar setbacks may have arrived at the setback distances through very different means.*

In the simplest and perhaps most common form, setbacks specify a minimum allowable distance between a wind turbine and the nearest noise sensitive location. More complex setbacks are specified as a factor of the height or size of the source. For example, a minimum distance that is at least five times the hub height of a wind turbine.

5.3.2 Merits and drawbacks

Anecdotally, set backs are not commonly used as a direct method for noise control either for wind farms or for more general types of noise source. However, in some cases a set back required for reasons other than noise control, such as occupational health and safety buffer zones, may have a secondary benefit of reducing noise emission.

As discussed in Section 5.3.1, advantages of setbacks include the simplicity and transparency of assessment. This can be of particular benefit to regulatory authorities with limited resources. Watson et al note that "*most respondents* [municipal authorities] *chose to establish distance setbacks, often due to a lack of expertise or resources.*"

[112] (Watson, Betts, & Rapaport, 2011)

Disadvantages of setbacks in relation to controlling noise impact include the following:

- It is not possible to reliably link setback distance with sound level or character without knowing the given wind turbine sound emission levels, the wind farm layout, and the topographic details which control sound propagation
- Setbacks are a comparatively static method that is less responsive to changes in the wind farm noise situation over time. For example, if the noise level of new wind turbines drops dramatically at some point in the future, and development at that time is regulated using setback distances established based on current wind turbine technology, then significant areas of land may be precluded from development even though the associated noise impacts could be considered acceptable were they to be assessed directly[113].
- Setbacks do not necessarily take account of the number of turbines proposed for a particular project or the propagation attenuation between turbines and receivers.
- Setbacks do not promote technological advances for reduction of turbine noise
- Setbacks do not take into account the effect of background noise to mask, or not, wind turbine noise. In some cases this can mean that areas may be considered unsuitable for development despite the wind farm noise potentially having a negligible contribution to the ambient noise environment. Examples of this scenario include locations close to busy motorways and noisy coastal areas.
- Setbacks may preclude areas with dispersed settlement patterns from wind farm developments when they may otherwise be considered suitable if assessments were based on controlling noise levels directly.

5.3.3 Setback examples

To illustrate the shortcomings of simple setbacks as a noise control method, several examples are presented.

1. Reference case: Single Commercial Turbine

   A single 2.3 MW turbine in plain view of the receiving location 700 m away is predicted to produce a sound level of approximately 35 dB L_{Aeq} at full output.

   A 2.3MW model is a large-scale modern turbine, and it is highly likely that even smaller and quieter turbines could be found which would result in an even lower noise level at the receiver.

[113] And conversely if wind turbine noise levels increase dramatically at some point in the future.

2. Multiple Commercial Turbines

   A wind farm of 25 3MW turbines, meeting a 700 m setback rule and spaced according to the technical constraints of "5 rotor diameters downwind and 3 diameters crosswind", is predicted to produce a sound level of around 47 dB L_{Aeq} at 700 m from the edge of the wind farm. It is important to note in this case, and for most wind farms, that the nearest turbines are not solely responsible for the noise received at a given location.

   The wind farm sound levels in this scenario are 12 decibels higher than the reference case even though the setback distance to the receiver in each case is the same, 700m. In this example a setback could incorrectly promise a degree of protection to neighbours which would not be realised.

3. Multiple Commercial Turbines in shielded Terrain

   The 25-turbine wind farm in the preceding example, built on terrain in which the receiving house is sited opposite a hill which obstructs the house from view of the wind farm, produces a level of produces a predicted wind farm sound level[114] of approximately 35 dB L_{Aeq}.

   This example demonstrates that variations in the height of the turbines, or the hill, or the residence site, can have a significant further reduction on noise level. The wind farm sound levels in this scenario are approximately the same as the reference case, despite the proposed wind farm in this scenario comprising 25 turbines rather than 1.

4. Property affected by high noise levels

   None of the simple scenarios above have taken into account the existing noise environments surrounding the house in question. Such an assessment could show that, during windy conditions, the existing background level is already higher than relevant noise limit and may not produce any significant noise effect. In this case a given setback could be unnecessarily restrictive to the design of the wind farm.

An overview of modelling parameters for the above examples is provided in Appendix F.

5.3.4 Setbacks in practice

Comments provided in WEDG06 include reference to separation distances as follows:

> *Separate noise limits should apply for day-time and for night time. During the night the protection of external amenity becomes less important and the emphasis should be on preventing sleep disturbance. A fixed limit of 43 dB(A) will protect sleep inside properties during the night. In general, noise is unlikely to be a significant problem where the distance from the nearest turbine to any noise sensitive property is more than 500 metres.*

[114] Barrier attenuation is discussed in Section 3.2.
It should be noted that the model used to generate the predicted sound levels for Scenario 3 includes a limit to barrier attenuation of 20dB. This level of attenuation is greater than is typically be included in a wind farm noise assessment where limits of 2-5dB are common. The greater allowance for barrier attenuation in this example is intended to provide a less conservative and more realistic account of wind farm sound levels in the presence of significant obstacles.

A 2011 review by the Minnesota Department of Commerce of wind farm setbacks applied in various jurisdictions internationally[115] notes that average setback distances range from 470 m to 700 m.[116] The review suggests that in many cases setbacks are applicable in tandem with the more commonly employed control method of noise limits. The following details are also noted:

- A range of setbacks are applied across some of Germany's sixteen regions, ranging from 300-500m up to 1000m
- In 2011, France introduced a mandatory requirement for a setback of at least 500 m to all residential areas
- Some municipalities and counties in Sweden have adopted setbacks in the range of 400m to 1000m

A 2009 report from the Ontario Ministry of Environment (MOE), *Development of Noise Setbacks for Wind Farms Requirements for Compliance with MOE Noise Limits*[117], establishes possible setbacks for noise:

> *...with the intention of facilitating the planning and review process of such projects while protecting human health and the environment.*

A range of setbacks is provided from 550m to 1500m, depending on the number of turbines being proposed and their estimated sound power levels.

An amendment to wind farm development guidelines[118] in the Australian state of Victoria in 2012 details an indirect approach to setbacks which effectively requires all residential properties within 2000m of a wind farm to be involved in the project:

> *If an existing dwelling is located within two kilometres of any turbine that forms part of a proposed wind energy facility, the permit application must be accompanied by evidence of the written consent of the owner of the dwelling. The application is prohibited by the planning scheme where evidence of written consent is not provided. This does not apply:*
>
> 1. *where the turbine is principally used to supply electricity for domestic or rural use of the land*
> 2. *on land in a residential zone, an industrial zone, a business zone or a special purpose zone. This allows for the consideration of turbines in an urban setting.*

---

[115] (Haugen, 2011)

[116] The conclusion of (Haugen, 2011) notes,
"Some countries or regions only had one setback distance rather than a range of distances [...] *For countries with required or recommended wind turbine setback distances, the average lower setback distance is approximately 470 meters(1,542 feet), and the average upper setback distance is approximately 700 meters(2,297 feet)...*

[117] (Ontario Ministry of the Environment, 2009)

[118] (Victoria Department of Planning and Community Development, 2012)

5.3.5 Discussion

It is considered that set backs are not universally appropriate for managing noise emission from wind farms. In particular, the relationship between distance from a wind farm and noise effects is significantly variable[119]. Setbacks may also be comparatively slow to respond to changes in turbine technology such as development of significantly quieter or louder turbines at some point in the future.

In contrast, the issues noted above can be addressed inherently where noise limits are applied directly as the control method. That is, specific circumstances of a development such as the number of turbines, turbine sound level, propagation effects and, potentially, the ambient noise environment at receptors, can all be accounted for with a noise limit method. Conversely, it can be noted that the application of noise limits is typically more complex than setbacks.

As noted by the examples above, setbacks have the potential to either over-protect or under-protect wind farm neighbours. This means, in turn, that setbacks have potential to result in poor levels of amenity protection in some cases, and poor utilisation of wind resources in others. In this sense, noise limits may offer a comparatively better means of achieving a reliable balance between acceptable levels of amenity protection and capacity for infrastructure development.

5.4 Cumulative noise impacts

The cumulative noise impact of multiple wind farms is an ongoing issue as wind farm developers seek to optimise the use of the limited land areas with viable wind resources, particularly in countries with high rural population densities such as Ireland.

5.4.1 Approach to cumulative limits

Limits for total wind farm noise

In the UK, the guidance provided in ETSU-R-97 recommends that noise limits should apply to the cumulative effect of all wind turbines affecting noise-sensitive premises, noting:

> *"It is clearly unreasonable to suggest that, because a wind farm has been constructed in the vicinity in the past which resulted in increased noise levels at some properties, the residents of those properties are now able to tolerate higher noise levels still."*

While it would be easiest to consider all turbines as one wind farm with one set of limits, in practice proposed or operational wind turbines may be under the control of multiple separate parties with each development the subject of separate planning applications and subject to separate planning conditions, if subsequently approved.

[119] Depending on the details of the wind farm including the number of turbines and their spacing as well as the topography of the wind farm site and surrounding area.

To address some of the challenges associated with cumulative assessment, the Department of Energy and Climate Change (DECC) in the UK requested the Institute of Acoustics prepare a guidance document - *A Good Practice Guide To The Application Of ETSU-R-97 For The Assessment And Rating Of Wind Turbine Noise* (IOA GPG) - outlining current good practice in the application of the ETSU-R-97 assessment methodology for wind turbine developments, which address cumulative noise assessment. The summary note of the IOA GPG states that *"whenever a cumulative situation is encountered, the noise limits for an individual wind farm should be determined in such a way that no cumulative excess of the total ETSU-R-97 noise limit would occur."*

Noise limits per wind farm

Some guideline documents assign noise limits per wind farm which, in effect, means the limits for total wind farm noise can be higher than the limits applied to any particular wind farm. For example, Section 4.2 of AS4959:2010 notes that:

> *To provide a satisfactory level of protection of amenity against the potential adverse effects of wind farm noise, the cumulative impact of all wind farm development in an area should meet the noise limits derived from measurements of the background noise environment at relevant receivers prior to any wind farm development taking place.*

These comments imply that the noise limits can apply per wind farm, provided that background noise data used to establish limits does not include contribution from any operating turbines.

Discussion

For either approach to limiting cumulative noise impacts, assessment requires further development of the methods available for assessing noise from one wind farm development. For example, how should cumulative noise limits be established at a property if they have a noise agreement in place for one of the projects? Alternatively, if a property is far enough removed from two separate developments that it is not explicitly included in the assessment for either project, how will it be identified for inclusion in an assessment of cumulative effects, for which the impacts could be more significant? Also, how should adjacent wind farms be assessed if the basis for wind speed analysis uses a different reference height for each project?

The IOA GPG provides a fairly comprehensive and robust account of methods to assess cumulative impacts which generally reflects current industry practice. The discussions below are therefore presented with reference to the details provided in the IOA GPG, unless noted otherwise.

5.4.2 When is cumulative assessment needed?

If two wind farms are proposed to be immediately adjacent to each other then it is immediately apparent that a cumulative assessment of noise from both wind farms together will be necessary. Similarly, if two wind farms are proposed to be located tens of kilometres apart, then a cumulative assessment of noise from both farms is unlikely to be required. For cases between these two extremes it is less obvious when a cumulative assessment is required and, if it is, how noise sensitive locations should be identified for assessment.

To address these issues, the IOA GPG recommends that a cumulative assessment of noise be considered when a proposed wind farm produces a level of noise that is within 10 dB of noise from any existing wind farm(s) at the same receptor location.

An alternative approach is noted in Section 6.4.9 of the ONG2008 document which implies that cumulative impact assessments only need to be carried out at dwellings which are located within 5km of more than one wind farm development:

> *The standard on which the noise impact prediction method is based, namely standard ISO 9613-2, Reference [6], is designed for source/receiver distances up to about 1000 m. Although the use of the standard may be extended to larger distances, other factors affecting sound level contributions from the distant sources may need to be considered. In practice, sound level contributions from sources such as wind turbines located at very large distances from receptors are affected by additional attenuation effects. To address the above in a prediction method, contributions from sources located at very large distances from receptors, larger than approximately 5 km, do not need to be included in the calculation.*

5.4.3 Background noise

As noted by the IOA GPG, ETSU-R-97 sets relative noise limits based on the prevailing background noise level and requires that the background levels are not influenced by existing turbine noise. The IOA GPG offers a number of options for deriving suitable background noise levels in the presence of existing turbines including: switching turbines off during background surveys; measuring during upwind conditions; using proxy locations not affected by turbine noise; and using background data from the original wind farm noise assessment with consideration to differences in wind speeds between the site.

5.4.4 Derivation of fixed lower limit

As noted by the IOA GPG, ETSU-R-97 noise limits for the day-time period include a fixed or absolute limit that generally applies at lower wind speeds when background levels are low, and is within the ranges of 35-40 dB L_{A90}. The justification for the choice of the fixed part of the limit depends on a number of factors: the number of properties affected by noise; the effect of the fixed limit on the potential power generating capacity of the wind farm; and the duration and level of exposure. Consideration of these factors may result in different absolute limits being justified depending on whether all turbines affecting a receiver location are considered, or just those from a single wind farm development.

Ordinarily, the absolute limits would be selected based on a single wind farm considered in isolation; however it may be appropriate to consider an absolute limit based on all turbines for the purposes of determining a cumulative limit and derivation of subsequent partial limits.

5.4.5 Derivation of the relative noise limits

The options available for determining the relative noise limits for each wind farm in isolation - so that cumulative noise limits are not breached - is dependent on the planning stage arrangements of each separate wind farm, e.g. in planning, consented, operational, and individual site layout and noise limit considerations. For example if the applications are concurrent, there is an opportunity to apportion partial limits applicable to each development in isolation, such that the total cumulative limits (fixed part and relative to background) are not exceeded. This may not be possible if one of the wind farms is already consented and has "used up" the available cumulative limit already.

The IOA GPG recommendations aim to use the "noise budget" fairly so that wind resources can be optimised. Under most scenarios some level of cooperation, coordination and negotiation between neighbouring developer teams and the local planning authority is key to the success of the process to determining "fair" relative noise limits.

Strategic planning can also assist in efficient appraisal of cumulative impacts, promoting proposals that provide greater contribution to renewable targets.

The summary provided in the IOA GPG states that:

> *" whenever a cumulative situation is encountered, the noise limits for an individual wind farm should be determined in such a way that no cumulative excess of the total ETSU-R-97 noise limit would occur."*

5.4.6 Comparison of Cumulative Noise Impacts with Derived Noise Limits

An assessment of cumulative impacts can in some cases consider directional effects as some receptors may not be simultaneously downwind from all wind farms. Such an approach would not typically be employed in the first instance but could be considered, for example, if it was not possible to demonstrate compliance with the cumulative noise limits based on downwind propagation from all turbines and the layout of the turbines meant such an approach was likely to over predict levels compared to those which would occur in reality.

A potential outcome of directional considerations in application of the IOA GPG, however, is that noise levels from two separate wind farms could be higher than if the two projects were developed as a single wind farm where directional effects are commonly not considered.

5.4.7 Cumulative impacts in practice

As noted in Section 5.4.1, in the UK wind farm noise limits apply to total or cumulative wind farm noise levels.

Similarly, in New Zealand, Section 5.6.1 of NZS6808:2010 notes that:

> *The noise limits in 5.2 and 5.3 should apply to the cumulative sound level of all wind farms affecting any noise sensitive location.*

Comparably, the ONG2008, Section 6.4.4 states:

> *If a Point of Reception or a Participating Receptor is or can be affected by adjacent, approved Wind Farms, the detailed noise impact assessment must address the combined impact of the proposed and the adjacent Wind Farms. The distance requirements described in Sections 6.4.1 and 6.4.9 apply.*

Where Australian Standard AS4959:2010 indirectly details noise limits per wind farm, the SAG2009 similarly notes that:

> *...as for staged development, any additional wind farm that may impact on the same relevant receiver as an existing wind farm should meet the criteria using the background noise levels as they existed before the original wind farm site development.*

5.5 Special characteristics

As noted above in Section 3.4, where special audible characteristics are present the sound is considered to be subjectively more annoying. To account for this increased annoyance, corrections are typically applied to sound where special audible characteristics are observed. These corrections either apply as a reduction to the noise limit or a penalty added to the predicted or measured sound level. For example, Section 5.4.2 of NZS6808:2010 requires that:

> *Wind turbine sound levels with special audible characteristics* [...] *shall be adjusted by arithmetically adding up to +6 dB to the measured level at a noise sensitive location.*

Some wind farm noise policies require that an assessment of special audible characteristics comprise a subjective test followed by an objective test. ETSU-R-97 states the following:

> *The determination of the character of the noise emitted by wind turbines is performed by both a subjective and an objective test. This takes the form of listening to the emitted noise at the affected property and/or performing objective measurements of the incident noise at the property.*

Assessing special audible characteristics subjectively on-site can in some cases be critical for a robust compliance appraisal for the following reasons:

- For some special audible characteristics, objective assessment methods have limited accuracy and could result in false negative[120] or false positive[121] assessments. Examples can include unattended outdoor measurements of infrasound, low frequency noise and impulsiveness.
- For some special audible characteristics, objective assessment methods have limited correlation with rates of annoyance.
- If audio samples have been collected, reviewing these samples during post-processing can misrepresent the significance of characteristics of a sound because of variability in the audio playback system.

Depending on the jurisdiction, penalties for special audible characteristics can be either one off or, perhaps less commonly, additive, as the following two examples demonstrate.

[120] Failing to identify a special audible characteristic when it *is* present

[121] Identifying a special audible characteristic when it is not present or is attributable to ambient noise rather than the noise in question.

Table 4: Examples of penalty arrangements for special audible characteristics

Example	Guidance document	Comment
A	NZS6808:2010, Section B4	*Only one adjustment value* [sic: for special audible characteristics] *shall be applied to each measurement, even if more than one type of special audible characteristic is present.*
B	Tasmanian Noise measurement procedures manual[122], Section 6.1	*If a sound contains more than one of the characteristics, then all applicable individual adjustments must be made and the adjustments are all linearly added to the measured level.* *If the total adjustment exceeds 10 dB, the total adjustment is to be regarded as 10 dB.*

The choice of a suitable penalty for special audible characteristics is intrinsically linked to the underlying noise control method in the jurisdiction, and the associated measurements and assessment methods. Therefore, two jurisdictions applying different special audible characteristic penalties could conceivably arrive at a comparable outcome for wind farm noise owing to other differences in assessment methods.

A variation on the requirement to apply penalties is incorporated into some guidance documents that recognise special audible characteristics should not typically be a component of a correctly functioning wind turbine or wind farm. For such cases, in lieu of a penalty, there is a requirement for the wind farm operator to correct any issues that may be contributing to any observed special audible characteristics. For example, SAG2009 notes:

> *These guidelines have been developed with the fundamental characteristics of noise from a wind farm taken into account. These include the aerodynamic noise from the passing blades (commonly termed 'swish') and the infrequent and short-term braking noise.*
>
> *However, annoying characteristics that are not fundamental to a typical well-maintained wind farm should be rectified. Such characteristics may include infrasound (low frequency noise below the audible frequency range that manifests as a rattle in lightweight materials such as glass) or adverse mechanical noise (perhaps generated as a failure of a component).*

Special audible characteristics are discussed further in Section 6.3 and Section 7.4.

[122] (Tasmania Department of Primary Industries, Water and Environment, 2004)

6.0 PLANNING STAGE ASSESSMENTS (WORK PACKAGE 2)

This section summarises key practices relevant to assessment of wind farm noise during the planning process which are used to inform regulatory authorities and the community about the likely impacts of the wind farm and to inform decisions on granting planning permission for a development.

6.1 Assessment of wind farm noise during planning

During the planning phase of a wind farm development, before the wind farm is built, compliance with noise limits, if applicable in a given jurisdiction, is typically demonstrated using predictions of wind farm noise.

Sound levels from the wind farm are predicted to surrounding receptor locations, using prediction methodologies such as those outlined in Section 3.2 above. The predictions are generally based on proposed turbine layouts developed by the proponent, along with wind turbine sound power level data supplied by one or more proposed turbine suppliers.

Predicted noise levels can be compared with established noise limits for each receptor location being assessed to determine whether the planned wind farm complies with the limits.

6.2 Measuring background noise levels

Measurement of background noise levels can be inherently variable whether around a wind farm site or at other rural or urban sites proposed for development, particularly when unattended noise monitoring is involved[123].

In relation to wind farms where noise limits include a relative noise limit component, that is with a margin above background noise level, it is common for background noise levels to be measured at several receptor locations during the planning stage. There are no universally accepted methods for quantifying background noise levels at receptor locations around either proposed or operational wind farms, effectively on account of the difficulties associated with measuring noise levels in the windy environments where wind farms are located. The methods that are employed across different jurisdictions all have a range of advantages and disadvantages which are briefly outlined here and also in Section 7.2.

Common to several methods[124], however, is the unattended measurement of noise levels using logging equipment for a period of a week or more. In most cases, this measurement approach has been derived from the approach originally described in the UK document ETSU-R-97. The measurements commonly record background noise levels at receptor locations which allows the determination of relative noise limits at the location. In some cases, the data measured at one location can be considered representative of other nearby receptor locations with the collected data used as a proxy to establish noise limits at the other locations.

[123] (Adcock, Bullmore, & Flindell, Balancing risks and uncertainties in environmental noise measurements, 2005)

[124] ETSU-R-97, NZS6808:2010, AS4959:2010, SAG2009

The background noise levels, typically L_{A90} or L_{A95}, are measured across a series of consecutive 10 minute periods. The measurements can be required to continue either for a minimum number of days, such as 10 days[125], or for a sufficient time to collect a minimum number of data points, for example, 2000[126]. Emphasis is generally placed on collecting a sufficient amount of data across a representative range of weather conditions, particularly periods where wind direction is from the wind farm to the receptor, for wind speeds from cut-in, where the turbines start generating electricity, to rated power, where turbines reach their maximum power generation capacity.

In some cases it can prove difficult to capture sufficient data for some weather conditions, if they do not frequently occur at the site. This issue can be addressed by nominating a maximum monitoring period. For example, the New South Wales Draft document *NSW Planning guidelines: Wind farms*[127] states that monitoring should be carried out for a *maximum* of six weeks.

At the end of the monitoring period the measured levels can be compared with wind speed, and in some cases wind direction, data that is typically collected by the wind farm proponent on the proposed site. The purpose of collecting wind speed data at the wind farm rather than, say, the receptor location is that it better represents the weather conditions that would be incident on proposed turbines and is therefore an indicator of the operating performance and sound levels that the turbines would have at a given point in time.

The reference height for wind speed monitoring and reporting has the potential to influence assessment outcomes. Wind speeds have historically been referenced to 10m AGL and assessments carried out using ETSU-R-97 generally continue to reference wind speeds at this height. Where this is done, care is required to take due account of site wind shear influences. This typically involves initially referencing site measurements to the hub height of the proposed turbines and avoiding direct measurement of wind speeds at 10m AGL. The IOA GPG recommends the following:

> *The standard procedure should be to reference noise data to standardised 10 metre wind speed. The standardised 10 metre wind speed is obtained from the turbine hub height wind speed by correcting it to 10 metre height using a ground roughness factor of 0.05.*

A further discussion of wind speed reference heights is provided in Appendix C.

The analysis of collected noise levels can involve filtering the data set to remove periods which may have been effected by rain or wind buffeting of the microphone during periods of high wind speed at the monitoring location. This filtering requires collection of additional data at site, ideally in the form of rainfall rates and wind speeds local to the noise monitoring location, for example by installing a met mast at approximately 1.5-2m AGL near the noise logger[128]. Additionally, the noise measurement microphone can be protected by one or several wind screens to reduce the occurrence of wind buffeting[129].

---

[125] NZS6808:2010 recommends a minimum noise measurement period of 10 days.

[126] SAG2009 states that "*sufficient data is considered to be approximately 2000 measurement intervals...*".

[127] (NSW Department of Planning and Infrastructure, 2011)

[128] In some cases, weather data from a proxy location can be used to assess the influence of extraneous noise from rainfall and high local wind speeds at the noise monitoring location.

[129] (Davis & Lower, 1996)

A regression analysis can be carried out for the noise level and wind speed data to determine an estimated relationship between noise levels at the receptor location and wind speeds at the proposed wind farm site. An example of such a regression analysis is provided in Figure 10 in Section 3.3.2.

A note-worthy alternative to measuring background noise levels for establishing relative noise limits is an approach employed in Ontario Canada, where the regulatory authority's guidance document ONG2008 provides a nominal set of *'wind induced background sound levels'* across a range of applicable wind speeds and prescribes limits based on this data. The guidelines note:

> *The measurement of wind induced background sound level is not required to establish the applicable limit. The wind induced background sound level reference curve* [...] *was determined by correlating the A-weighted ninetieth percentile sound level (L_{90}) with the average wind speed measured at a particularly quiet site. The applicable L_{eq} sound level limits at higher wind speeds are given by adding 7 dB to the wind induced background L_{90} sound level reference values, using the principles for establishing sound level limits described in Publication NPC-232...*

6.3 Special audible characteristics

Consideration of special audible characteristics during the planning stage of a wind farm development can be considered broadly in three parts as outlined in Table 5.

Table 5: Assessment approach for special audible characteristics

Category	Special audible characteristics	Comments
Not directly assessed	Amplitude modulation Impulsiveness	There are currently no reliable means of predicting the occurrence of excessive amplitude modulation or impulsiveness during the planning stage of a wind farm development.
Assessed based on measurements	Tonality	Tonality assessment results according to IEC 61400-11 can inform a wind farm planning assessment.
Assessed based on predictions or not directly assessed	Infrasound (partial) Low frequency noise	Prediction of sound pressure levels across the frequency range from 200 Hz to less than 20 Hz is possible, with limited accuracy. In many jurisdictions low frequency noise and infrasound are not required to be directly assessed during the planning stage for a wind farm.

Each of these categories is discussed directly below.

6.3.1 Unassessed characteristics

Amplitude modulation and impulsiveness are complex characteristics of sound that involve variations in level, time and frequency. The obstacles to developing suitable prediction and measurement methods for these characteristics include:

- *Limited understanding of source mechanisms*
  Causes of excessive amplitude modulation, for example, are not well understood. Possible influencing factors include weather conditions at the turbine, aerodynamic conditions at the turbine blades, turbine controls and propagation effects. Accounting for such a wide range of potential sources, each with a potentially unique generating mechanism, in any prediction method is likely to be problematic at least until the source mechanisms are better understood.

- *Limited site occurrences*
  The literature search for this report has not uncovered any documented cases of impulsive characteristics at a wind farm. Similarly, while there is some emerging evidence of amplitude modulation at some wind farms[130], its occurrence is commonly cited as being infrequent[131].

- *Lack of reliable metrics to assess effects*
  As discussed in Section 3.4 above, neither impulsiveness nor amplitude modulation have widely accepted metrics that are field proven and are shown to correlate with peoples subjective impression of the sound. This, in turn, prohibits the development of prediction tools and regulations.

6.3.2 Measurement based assessment

As with amplitude modulation and impulsiveness, there is no readily available method for predicting tonality, primarily due to the wide range of potential sources. For example, tonal noise could potentially be generated from imperfections on the blades leading to whistling noise, mechanical or electrical noise from the nacelle, or noise from the transformer associated with the turbine which is typically located at the base of the turbine tower[132].

However, the levels of tonal audibility that are measured as part of an IEC61400-11 assessment of sound power levels for a turbine provide an indication of the likelihood of tones from that turbine during operation. For example, SAG2009 notes:

> *If tonality is a characteristic of the WTG noise, 5 dB(A) should be added to the predicted or measured noise level from the wind farm.*
>
> *To help determine whether there is tonality, the method and results of testing (such as in accordance with IEC 61400–11) carried out on the proposed WTG model to determine the presence of tonality should also be specified in the development application*

[130] (Stigwood, Large, & Stigwood, Audible amplitude modulation - Results of field measurements and investigations compared to psyco-acoustical assessment and theoretical research, 2013)

[131] (Moorhouse, Hayes, von Hunerbein, Piper, & Adams, 2007)

[132] (Bowdler & Leventhall, Wind turbine noise, 2011), Chapter 4, page 116

The application of IEC61400-11 data is, however, limited. The levels of tonal audibility established using this method relate to locations that are typically 100-200m from a single turbine. Extrapolating these results to greater distances, such as are typical for common receptor locations, is complex and will be significantly influenced by the frequency dependent propagation characteristics of the intervening path as well as the ambient noise levels at each receptor considered.

6.3.3 Prediction based assessment

Unlike amplitude modulation, impulsiveness and tonality, which can involve complex variations in time, level and frequency, infrasound and low frequency noise essentially represent an extension of the broadband frequency range that is currently addressed by sound propagation prediction methods such as ISO 9613-2:1996, discussed in Section 3.2. However, the ISO9613-2:1996 prediction method has been developed using octave-band algorithms for octave band centre frequencies from 63 Hz to 8 kHz. The nominal lower frequency limit for the method therefore does not fully encompass the infrasound or low frequency noise regions of the sound spectrum.

While the prediction of infrasound and low frequency noise during the planning stage of a wind farm is not especially common, since the release of WEDG06, some guidance has been provided for such predictions, with Danish research contributing significantly.

Infrasound

There are currently no methods for predicting infrasound levels across the frequency range 0 Hz to 20 Hz which have a well documented record of reliability or accuracy.

However, the Danish EPA document *Statutory Order on Noise from Wind Turbines (Translation of Statutory Order no. 1284 of 15 December 2011)* (DSO1284) provides a method for estimating expected wind farm noise levels at low frequencies from 10 Hz to 160 Hz. The method is comparable to ISO 9613-2:1996 but details a number of parameter values that are expected to provide a more robust prediction of lower frequency sound.

DSO1284 includes a criterion, expressed in terms of dB L_{pALF}, assessed indoors. The criterion states:

> *The total low-frequency noise from wind turbines may not exceed 20 dB* [L_{pALF}] *at a wind speed of 8 and 6 m/s indoors in dwellings in open countryside or indoors in areas with noise sensitive land use respectively.*

However, the calculations are carried out in one-third octave bands and insertion loss values adjusting outdoor predicted levels to indoor predicted levels are well documented so prediction of other indices such as a G-weighting may be possible[133], though likely with increased uncertainty tolerance.

For G-weighted assessments of infrasound, ISO 7196:1995 notes the following in its introduction:

> *Weighted sound pressured levels which fall below about 90 dB*[G] *will not normally be significant for human perception.*

133 At least for the part of the G-weighted frequency range encompassed by the DSO1284 method: frequencies of 10Hz up to 160Hz.

Low frequency noise

The DSO1284 method extends up to 160 Hz and therefore includes a significant component of the low frequency region meaning the method could be used to provide estimates of low frequency noise, perhaps in conjunction with results of ISO 9613-2:1996 at frequencies of 63 Hz and greater where the ISO 9613-2:1996 method has been validated.

A further method for calculating low frequency noise would be the use of the Nord2000 prediction method. This method is not widely used internationally, likely due to the need for a wider range of input parameters into the model, many of which can often be difficult to determine. However, the model has been validated for frequencies down to 25 Hz[134].

Predicted levels of low frequency noise could be compared to a noise limit value to assess compliance. As an example, predicted L_{pALF} levels could be compared to the DSO1284 criterion of 20 dB L_{pALF} noted above as a measure of compliance. Further discussions of low frequency noise criteria are provided in Section 7.4.4.

Sound power level data

For the prediction of noise levels in either the infrasound or low frequency regions, it is important to recognise that predictions carry a greater margin of uncertainty owing to the greater uncertainty associated with the measured or reported sound power level data for the nominated turbines.

Test standard IEC 61400-11[135], which is the common reference for sound power level data reported by manufacturers, details a method for measuring wind turbine sound power levels at frequencies of 20-50 Hz and greater. In our experience, reported uncertainty values at low frequencies can range from +/-1 dB up to approximately +/-6 dB or more at frequencies below 63 Hz. The standard does not provide any detailed methodology for measuring across the full range of frequencies for either infrasound or low frequency noise.

6.3.4 Discussion

With the exception of tonality, special audible characteristics are not commonly directly predicted or assessed during the preparation of a planning application for a wind farm. As noted in Section 6.3.1 in relation to amplitude modulation and impulsiveness, this approach has likely evolved pragmatically, reflecting the limited documenting of occurrences at operating wind farms.

Recently, perhaps reflecting the heightened profile of wind farm developments in some jurisdictions, there has been a trend towards including some assessment of infrasound and low frequency noise special audible characteristics. In addition to the Danish example discussed in Section 6.3.3, the *Draft NSW Planning guidelines: Wind farms*[136] provides the following comments which imply a requirement to assess C-weighted noise levels during planning phase:

> *It should be noted that the low frequency characteristic penalty applies only if excessive low frequency noise is present, or predicted to be experienced at the relevant receiver.*

[134] (Plovsing, 2007)

[135] (International Electrotechnical Commission, 2006), (International Electrotechnical Commission, 2012)

[136] (NSW Department of Planning and Infrastructure, 2011)

It could be considered that not directly assessing special audible characteristics during a planning assessment increases the risk of a wind farm not complying with noise limits once it's operational. However, as discussed in Section 7.4 below, wind farm noise guidance documents typically include an operational stage assessment method for special audible characteristics. This means that any operational wind farm exhibiting special audible characteristics will be penalised for their presence, regardless of the circumstances of the planning stage assessment.

An alternative to this approach is to assume, during the planning stage, that all wind farms exhibit special audible characteristics and that a penalty for their presence should therefore be included in the planning assessment. While this kind of approach is less commonly adopted an example of it is documented in the Australian Environment Protection and Heritage Council (EPHC) guidelines *National wind farm development guidelines – Draft July 2010*[137] which state:

> *These guidelines recommend that certain audible characteristics be assessed as part of the wind farm development but only tonality is assessed at the pre-construction phase. Other characteristics are assessed at the post construction phase. As this poses a risk to an operator it is recommended that a 5 decibel penalty be added automatically to the predicted level of a wind farm to provide certainty and a safety margin in the event that these unpredicted audible characteristics are found at the compliance monitoring stage.*

Such an approach is particularly conservative and equates to establishing a noise limit that is 5 dB more onerous than it otherwise would be. It should also be noted the Australian EPHC guideline has not been finalised and is not directly used for wind farm noise assessments in Australia.

A consequence of this approach could be the inadvertent exclusion of wind farm developments from some areas due to having to account for special audible characteristics that are never actually present in practice. Such an approach could therefore be disadvantageous for increasing wind energy capacity.

[137] (Environment protection and heritage council, 2010)

7.0 OPERATIONAL ASSESSMENTS (WORK PACKAGE 2)

This section summarises key assessment practices relevant to operational wind farms, in particular, assessing whether the wind farm is satisfying its noise emission obligations consistent with planning documentation and any association planning permit conditions. Accordingly, a range of available post-construction assessment methods are discussed in detail as are a number of methods for addressing special audible characteristics.

7.1 Assessment of noise from operational wind farms

There are a range of means for assessing levels of operational wind farm noise.

In the simplest case, the noise levels are not directly assessed, on the premise that the noise issues were sufficiently addressed during planning stage of the development.

More directly, assessment can be carried out in response to complaints, on an as-needs' basis, as is generally the case for UK wind farms. This kind of assessment would typically only be carried out at a complainant's property and would not necessarily inform a regulatory authority of the broader wind farm noise situation.

An assessment of operational wind farm noise can also be included as a requirement in planning approval documents or permit conditions. Such requirements can often involve measurements at a number of receptor locations around a wind farm. The locations are typically selected on the basis that they are representative of the larger set of sensitive receptors.

A further approach to assessment can rely on noise measurements close to turbines rather than an receptor locations, with noise prediction modelling relied on to confirm outcomes at receptor locations. This style of approach has been adopted recently in the Netherlands[138].

A range of commonly available measurements methods is discussed below.

7.2 Post-construction noise monitoring methods

7.2.1 Unattended measurements at receptor locations

As discussed in Section 6.2 above, measuring ambient noise levels at receptor locations during the planning stage of a wind farm development, before a wind farm is built, can often involve medium term unattended noise monitoring and subsequent correlation of noise levels with time synchronised wind speed data.

When a wind farm is operational, post-construction, an obvious methodology for assessing wind farm noise is to repeat this process: to measure ambient noise levels at neighbouring receptor locations and compare these levels with applicable noise limits. This approach is illustrated in Figure 17.

[138] (Voklijk & Dijkstra, 2011)

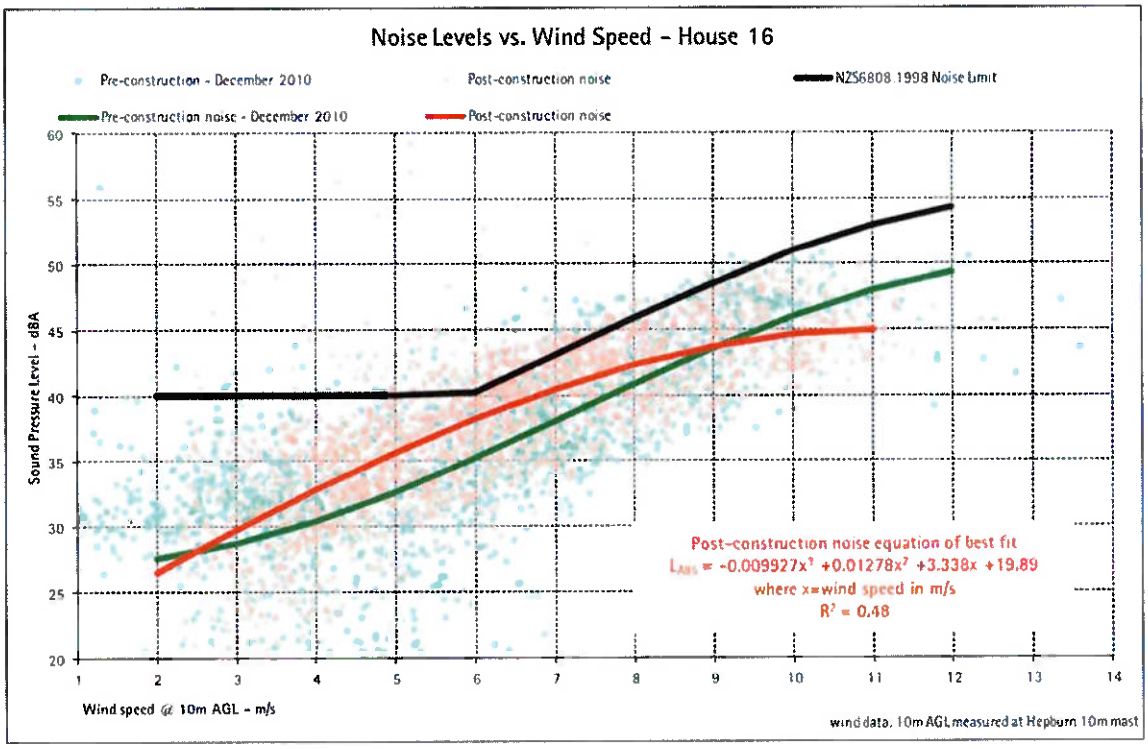


Figure 17: Example of post-construction measured background noise levels[139]

It can be seen in the figure that the measured post-construction noise level (red line) is closest to the limit value (black line) at the mid-range wind speeds. In this example, the noise limits at lower and higher wind speeds are less relevant for compliance assessment, as the margin between measured noise levels and limits is comparatively greater.

An important consideration with this approach is whether the measured post-construction noise levels are significantly influenced by ambient noise. This is because the measured post-construction noise levels will necessarily include not only wind farm noise but also noise from all other ambient sources in the areas. A recent draft Australian wind farm development guideline document[140] notes the following:

> *With unattended measurements it is generally only ever possible to demonstrate compliance with assessment criteria. In the case that measurements suggest noncompliance there will be doubt as to whether the measured levels are dominated by wind farm noise emission or some other source.*
>
> *One particular scenario when this is likely is where the background noise environment at the monitoring location, in the absence of wind farm noise emission, has become louder. This may be a result of new trees having been planted around the monitoring location, or an increase in foliage on trees relative to when the original background noise monitoring was carried out.*

[139] Chart extracted from (Marshall Day Acoustics Pty Ltd, 2012)

[140] (Environment protection and heritage council, 2010)

Some standards address this matter directly. For example, Section 7.5.3 of NZS6808:2010 notes that:

> *Post-installation measurements will capture both the wind farm sound and the background sound. In order to assess the wind farm sound level alone, the contribution of the background sound shall be removed from the regression curve drawn in 7.5.2 at each integer wind speed*

The note to Section 7.5.3 goes on to say:

> *While a simple energy subtraction of background and post-installation sound levels is not strictly mathematically correct for L_{90} centile levels, the difference may be taken as the L_{90} wind farm sound levels.*

In practice, pre-construction background noise levels are often used to correct the measured post-construction noise levels for the influence of ambient noise. An obvious issue with this approach, aside from mathematical technicalities referred to in NZS6808:2010 as noted above, is that months or years can often elapse between the pre-construction and post-construction measurements. This substantial time delay increases the uncertainty associated with the correction process. In New Zealand this issue has been addressed in some planning permit conditions requiring that pre-construction background noise level monitoring be repeated not more than 2 years prior to any post-construction noise commissioning measurements[141].

There are a number of direct advantages of this approach to monitoring and, concurrently, a number of technical challenges, primarily associated with assessing levels of wind farm noise that are comparable to the existing ambient noise levels at receptors. The key advantages and disadvantages are outlined in Table 6 below.

[141] (Tararua District Council and Masterton District Council, 2013)

Table 6: Merits and drawbacks of unattended measurements at receptor locations (extract [142])

Pros	Cons
Direct account of the actual noise levels at the receptor locations, rather than relying on predictions.	Evidence supports that predictions offer a reliable means of determining wind farm noise levels at receptor locations.
Demonstrates that noise levels at receptor locations comply with the requirements.	Measurements at some receptor locations are significantly complicated by background noise variations. Complex results can create uncertainty about compliance outcomes.
Supports the methods used to design wind farms, in turn offering credibility for the use of those methods for future projects.	Continued emphasis on the need for measurements at receptor locations may inadvertently undermine the perceived reliability of predictions.
Extended unattended survey durations enable a range of conditions to be assessed.	Repeated wide scale surveys at receptor locations are impractical to demonstrate ongoing compliance.
	The bias toward prolonged unattended surveys limits the amount of compliance information available for audible characteristics.
The results offer a valuable reference for objective noise policy reviews.	The results are typically not retained in centralised public records, and the results are not correlated with community satisfaction/dissatisfaction with noise.
Allows for a practical method of adjusting for background influence which is sufficient for demonstrating compliance at the majority of receptor locations.	Background noise levels are inherently variable, and in instances where background noise levels are higher, the assessment is dependent on alternative data sources not detailed in the guidance documentation.

7.2.2 Attended measurements at receptor locations

Attended measurements at receptor locations can assist in confirming the contribution of the ambient noise environment to total noise levels.

This process typically involves attended measurements for a period of one to several days. Measurements of wind farm noise at receptor locations are carried out in conjunction with measurements during regular periods of wind farm shut down, in order to estimate the influence of ambient noise levels during the wind farm measurements.

There can be difficulties with this approach, in coordinating site wide shut down and start up of turbines. Additionally, a significant amount of shut down testing may be necessary to capture a sufficient amount of data over a suitable range of wind conditions which can be costly both in terms of measurement time and lost power generation.

[142] (Delarie, Griffin, Adcock, & McArdle, 2013), pp 10-11

Conversely, this method offers the advantage that ambient noise level data, with the wind farm off, is captured on the same day as the wind farm noise level measurements. This is in contrast to the unattended approach to monitoring, where the data used for background correction may have been captured months or years before the compliance monitoring is carried out.

7.2.3 Derived points

As noted above, in cases where the background noise environment at the receptor, in the absence of wind farm noise, may have become louder since the time of the original background noise level measurements, then unattended monitoring may not demonstrate compliance with noise limits due to ambient noise rather than wind farm noise, even if the analysis makes a correction for background.

In such situations, unattended monitoring could be carried out at a secondary or derived location which is likely to offer a better signal to noise ratio for wind farm noise. The intention with such monitoring is to repeat measurements near to the original monitoring location, but removed from any obvious sources of elevated extraneous noise. The Australian EPHC draft wind farm development guideline document[143] provides the following guidance:

- *The secondary location selected for monitoring shall be the same distance from the wind farm, be exposed to noise emission from the same wind turbines and be of the same geographical setting as the original location. The predicted level of wind farm noise emission must be the same at each location.*
- *The expected background noise level, in the absence of wind farm noise emission, should be lower at the secondary location. This may be achieved in practice by placing the sound monitoring equipment in a nearby field or other location that may be further away from trees or other sound sources associated with the original location.*

7.2.4 Intermediate points

Somewhat analogous to derived points, measurements at intermediate points between the wind farm and receptor can be helpful to address ambient noise level related issues at receptor locations. The *Draft NSW Planning guidelines: Wind farms*[144] provides the following comments about intermediate locations:

> *To improve the ability to undertake compliance measurements alternative techniques may be employed. Such alternate methods will need to be assessed individually and on their merits. Methods may include the use of supplementary intermediate locations between the wind farm and the relevant receiver where the signal to noise ratio is much higher, and for which there are well established theoretical and empirical relationships to the relevant receivers. Data from such sites may be used to supplement and support conclusions obtained at the receiver locations.*
>
> *In most cases, it is expected that intermediate locations will be chosen from predicted noise contour maps and that these intermediate locations would return L_{eq} levels of around 45 – 55 dB(A) under down wind conditions or be at around 400m from the nearest turbines.*

[143] (Environment protection and heritage council, 2010)

[144] (NSW Department of Planning and Infrastructure, 2011)

A key advantage of intermediate locations is the improved signal to noise ratio. A disadvantage of this method is that results are not likely to be directly comparable to those at the receptor location and a degree of inference will be required to estimate wind farm noise levels at receptors from the intermediate location results:

- In the case that the measured levels at the intermediate location satisfy the noise limits applicable to a more distant receptor, it could be expected that wind farm noise levels at that receptor will be lower[145] and therefore also comply with the noise limits. In such cases the inference from one location to another is reasonably simple.
- However, if measured levels at the intermediate location are greater than the receptor noise limits, then any assessment of compliance at the receptor location would need to take account of the extent of uncertainty associated with inferring noise levels at the receptor.

7.2.5 Alternative monitoring equipment

A further alternative to unattended monitoring at receptor locations, for cases which are significantly influence by ambient noise, is the use of alternative monitoring techniques. This can include the use of noise loggers which monitor frequency data, such as one-third octave band noise levels, which can in some cases identify extraneous noise such as insect noise[146].

Additionally, recording the audio signal during measurements can be helpful in some cases to allow a listening study of selected time periods to identify extraneous noise sources as well as the subjective contribution of wind farm noise to measured levels. Care must be taken with this analysis however, as the actual sound field at the site may not be sufficiently represented by the audio recording and desktop playback process. Further, analysing audio recordings can lead to onerous analysis requirements which potentially are not justified by the certainty of the outcomes that they provide.

A further alternative is the use of directional noise monitoring equipment. SAG2009 notes:

> *Recent advancement in acoustic data acquisition (such as directional noise monitors) has introduced a method to separate wind farm noise contribution from other sources. If the methods above* [sic: unattended measurements at receptor locations] *can not be used for the compliance checking, alternative techniques may be employed*

However, care is also required with this approach as directional measurements may not satisfy applicable measurement standards in the jurisdiction. Additionally, directional monitoring equipment can be limited in output ability and may not be able to produce statistical noise levels such as the widely used L_{A90} descriptor.

[145] Exceptions to this circumstance are possible where significant shielding or ground effects influence propagation to the intermediate location but have little influence on propagation to the receptor location.

[146] (Griffin, Delaire, & Pischedda, 2013)

7.2.6 Sound power level testing and model verification

The discussion of *Intermediate points* above notes that the method relies on measuring wind farm noise at a location with suitable signal to noise ratio and then extrapolating these measured levels to receptor locations which are further away. A variation to this approach is to carry out sound power level testing near to turbines: the intent of testing being to confirm the validity of the sound power levels used during the planning stage noise modelling.

These test results could be used in combination with derived point measurements to develop a case demonstrating expected levels of wind farm noise at the receptor locations.

Alternatively, the testing can be used in combination with weather information and noise models to calculated long term average noise indices, such as the L_{den}, at receptor locations[147].

7.3 Complaints handling

The initial point of contact for a noise complaint in Ireland should be the local regulatory authority. All local authorities have to comply with the Recommendations providing for Minimum Criteria for Environmental Inspections (RMCEI)[148].

This procedure requires the local authority to log complaints and investigate them. In cases where the local authority has investigated the complaint and the problem persists the complainant should contact the Environmental Protection Agency (EPA). However the EPA will typically only become involved when the relevant local authority has been given an opportunity to investigate the noise complaint.

7.4 Special characteristics

The range of methods employed to assess and regulate special audible characteristics across the various jurisdictions considered in this report are varied. Some guidance documents rely explicitly on objective assessments while others apply subjective and objective assessments in tandem. Section B1 of NZS6808:2010 notes that:

> *Sound that has special audible characteristics, such as tonality or impulsiveness, is likely to cause adverse community response at lower sound levels, than sound without such characteristics. Subjective assessment can be sufficient in some circumstances to assess special audible characteristics.*

7.4.1 Amplitude modulation

To our knowledge there are no widely accepted methods for assessing or regulating excessive amplitude modulation from wind farms.

To date, a number of relevant guidance documents have generally considered that amplitude modulation is a characteristic part of wind turbine sound which is inherent in the setting of noise limits, implying that special audible characteristics penalties would not commonly be applied. For example, item 27 from the Executive Summary for ETSU-R-97 notes the following:

---

147 (Voklijk & Dijkstra, 2011)

148 (Kramers, 2008)

The noise levels recommended in this report take into account the character of noise described as blade swish. Given that all wind turbines exhibit blade swish to a certain extent we feel this is a common-sense approach given the current level of knowledge.

Also, AS4959:2010 states:

When setting limits of acceptability, the limits should take into account the fundamental characteristics of wind farm noise, including aerodynamic noise from the rotating blades, occasional aerodynamic modulation, [...]

However, where amplitude modulation is greater or more prominent than normal, enhanced or excessive amplitude modulation may be considered to be present which may be more likely to justify a special audible characteristics penalty. Comment CB3.1 of NZS6808:2010 states the following:

By the very nature of wind turbine blades passing in front of a support tower, some amplitude modulation will always be present in the sound of a rotating wind turbine although this will not always be audible at distances from the wind farm. Amplitude modulation special audible characteristics occur when there is significant amplitude modulation of the aerodynamic sound from one of more wind turbines such that there is a greater than normal degree of fluctuation as a function of the blade passing frequency (typically about once per second for larger turbines).

NZS6808:2010 details a methodology aimed at determining whether enhanced amplitude modulation is a characteristic of the assessed noise. However, this method is described as interim and should be preceded by a subjective evaluation of the character of the noise to establish whether enhanced amplitude modulation is a noticeable feature. The method is detailed in Section B3.2 of the standard and states that:

...modulation special audible characteristics are deemed to exist if the measured A-weighted peak to trough levels exceed 5 dB on a regularly varying basis, or if the measured third-octave band peak to trough levels exceed 6 dB on a regular basis in respect of the blade pass frequency

Comment CB3.2 notes the following regarding the interim method:

This method is considered to be an adequate interim test that has been used in New Zealand. It is envisaged that appropriate objective tests for modulation special audible characteristics will be developed in future to replace B3.2 [Interim method] *or provide a more robust objective method than B3.2.*

Recently, a method for assessing amplitude modulation formed part of the consent for the Den Brooke Wind Farm[149]. This method shares a similarity of approach with the NZS6808:2010 method. Subsequent discussions in the IOA Acoustics Bulletin[150] have provided conflicting views about the suitability of the proposed method.

[149] (Appeal Decision: Land to the south east of North Tawton and the south west of Bow, 2011)

[150] (Bass J. , Investigation of the 'Den Brook' amplitude modulation methodology for wind turbine noise, 2011), (Stigwood, Wind farms and the control of excess amplitude modulation (EAM) [Letter], 2012), (Bass J. , Response to Wind farms and the control of excess amplitude modulation (EAM) [Letter], 2012)

Some recent research[151] has outlined methods for measuring amplitude modulation more readily, based on assessment in a frequency domain. However, these newer methods have not been widely tested across a wide range of situations nor have there been any detailed studies of potential correlations between the metrics and annoyance.

7.4.2 Impulsiveness

Section 8.4.8 of ISO1996-2:2007 states that there is *"no generally accepted method to detect impulsive sound using objective measurements"*.

Notwithstanding this historically there have been a limited number of examples of impulsiveness assessment methods. For example, the Tasmanian Noise measurement procedures manual includes a procedure for assessing impulsive sound which has been used to assess impulsiveness at some wind farm projects. The method is as follows:

> *"An impulsiveness adjustment is determined by taking a measurement when impulsive noise is observed using a sound level meter set initially to fast and then impulse time response. If it is found after taking measurements with these two time responses that the impulse level is greater than 2 dB above the fast response measurement, then the difference is the impulsiveness adjustment."*

AS1055-1:1997[152] provides an assessment method which is similar to the Tasmanian Noise measurement procedures manual method. However, the in relation to this method it has been noted that[153] *"in some cases, impulsiveness may be indicated using the AS1055.1 assessment method when, subjectively, it is not considered to be present"*.

7.4.3 Infrasound

Guidance for assessment of infrasound levels from operational wind farms and examples of its regulation are very limited. This absence of regulation is perhaps consistent with the consensus of documents discussed in Section 3.4 which indicate infrasound levels are not significant at receptor locations.

Some general guidance is available for assessment of infrasound, irrespective of noise source, including the use of G-weightings[154] [155]. Care must be taken when applying these methods to wind farm noise, particularly if measurements are intended to be carried out outdoors where the influence of wind on the microphone can be very significant.

Examples of measurement methodologies that may be suitable are included in recent research work carried out in Denmark[156] and Australia[157]. However, these methods were developed for specific assessment scenarios and may require significant development to allow them to be applied more generally.

---

[151] (McCabe, 2011), (Lundmark, 2011)

[152] (Standards Australia, 1997)

[153] (Environment protection and heritage council, 2010)

[154] (International Organisation of Standardisation, 1995) ISO7196:1995, (Jakobsen, 2001)

[155] See: http://www.mst.dk/English/Noise/recommended_noise_limits/noise_zones/noise_zone_low_frequency_etc/

[156] (Sondergaard & Sondergaard, 2008)

[157] (Sonus Pty Ltd, 2010) (Evans, Cooper, & Lenchine, Infrasound levels near wind farms and in other environments, 2013)

7.4.4 Low frequency noise

Wind farm noise policy documents do not generally provide assessment procedures for identifying low frequency noise. Where reference is made to the issue it is generally accompanied by comments suggesting that low frequency noise is not expected to be problematic for modern wind turbine installations. For example, Section 5.5.2 of NZS6808:2010 states:

Claims have been made that low frequency sound and vibration from wind turbines have caused illness and other adverse physiological effects among a very few people worldwide living near wind farms. The paucity of evidence does not justify at this stage, any attempt to set a precautionary limit more stringent than those recommended in 5.2 and 5.3.

The *Draft NSW Planning guidelines: Wind farms*[158] does include an assessment method for low frequency noise. The first element of the proposed criteria is an outdoor screening test based on the following:

If it is shown that the C-weighted noise (measured from 20 Hz upwards) from a wind farm (excluding any wind induced or extraneous C-weighted noise) is repeatedly greater than 65 dB(C) during the daytime or 60 dB(C) during the night-time a more detailed low frequency noise assessment should be undertaken.

The draft NSW Guideline[158] states that if the quoted values are exceeded, a more detailed low frequency noise assessment should be undertaken based on a procedure which requires measurements inside non-associated residences. The draft Guideline recommends the UK Department of Environment Food and Rural Affairs (DEFRA) document *Proposed criteria for the assessment of low frequency noise disturbance*[159] as the relevant reference to assess internal low frequency noise levels.

The DEFRA document is well researched and includes a recommended methodology and proposed criterion which are valuable references for the assessment of low frequency noise levels inside residential dwellings. Subsequently, the draft Guideline proposes that the DEFRA criterion be used to determine if the noise levels are excessive, and where found to be excessive, to apply a 5 dB penalty to the measured or predicted L_{Aeq} noise level. However, applying the DEFRA criterion in this manner, as a definitive test for excessive noise levels, extends beyond its intended application. Specifically, the DEFRA document states:

"It is suggested the proposed criterion be used not as a prescriptive indicator of nuisance, but rather in the sense of guidance to help determine whether a sound exists that might be expected to cause disturbance. Some degree of judgement is required by the EHO [Environmental Health Officer] is both desirable and necessary in deciding whether to class the situation as a nuisance, and is likely to remain so. One of the main reasons is that, from the control cases, it is clear that problems do not necessarily arise when the criteria are exceeded. Indeed, we can conjecture that genuine LFN complaints occur only in a few such cases. Therefore, factors like local knowledge and understanding of the broader situation are likely to remain important aspects of the assessment. [...]"

[158] (NSW Department of Planning and Infrastructure, 2011)

[159] (Moorhouse, Waddington, & Adams, 2005)

Alternative approaches to assessing low frequency noise levels include comparison of A-weighted and C-weighted noise levels, as discussed in Section 3.4. This style of method is used in the German Standard DIN 45680:1997[160] and the Tasmanian *Noise measurement procedures manual*[161], though these documents are not tailored to wind farm assessment specifically but are more general in application.

As with infrasound, measuring low frequency noise outdoors can be problematic due to the contaminating influence of wind over the microphone[162]. However, some recent studies of low frequency noise levels outdoors in windy environments have been completed[163], though not in the context of assessing compliance with regulatory limits. Careful consideration also needs to be given to any indoor measurements of low frequency noise as measured levels can readily vary across different microphone positions in a room[164].

7.4.5 Tonality

At an operational wind farm, a tonality assessment in accordance with IEC61400-11[165] can be carried out at locations close to the turbine. If such an assessment does not identify any tones, then tones are generally unlikely to be identified at more distance receptor locations.

To carry out a tonality assessment at receptor locations, as is perhaps more appropriate given this would be the location where annoyance would be most likely to occur, there are a number of methods available:

- *Simple assessment methods*
  Such as that detailed in Annex D of ISO 1996-2:2007[166] based on one-third octave band centre levels. Given the potential complexity of tones from wind turbines, including tone frequencies that can vary with time, it is considered that such simplified methods may often not be suitable and that, pragmatically, it's more helpful to implement complex methods in the first instance.

- *IEC 61400-11 method*
  The sound power level test method can be repeated at the more distant locations, though some deviations from the documented methodology are necessary to account for the greater separation distance to the monitoring location and the potential increase in monitoring duration. Additionally, the method does not provide guidance on what magnitude of penalty might apply to any identified tones.

- *ISO 1996-2:2007 Reference method*
  Perhaps the most commonly used complex tonality assessment method, it includes a sliding penalty scale from 1 to 6, based on a range of values of tonal audibility. However, as the method has been developed for general application, some ambiguity would exist about how it should be applied in the wind farm context, to manage the variations in tonal audibility that are likely to occur with changes in wind speed.

---

[160] (Technical Committee Grundlagen der Schallmessung/-bewertung, 1997)

[161] (Tasmania Department of Primary Industries, Water and Environment, 2004)

[162] (Hessler & Hessler, 2011)

[163] (Evans, Cooper, & Lenchine, 2013)

[164] (Bowdler & Leventhall, Wind turbine noise, 2011), Chapter 4

[165] (International Electrotechnical Commission, 2006), (International Electrotechnical Commission, 2012)

[166] (International Standards Organisation, 2007) ISO 1996-2:2007

- *ETSU-R-97 tonality assessment*
  This method has been developed specifically for assessment of tones at wind farm neighbours. The method is comparable to both ISO 1996-2:2007 and IEC 61400-11 and includes a sliding penalty scale. Notwithstanding this, the method is perhaps less widely used and may only have regular application in the UK.

Discussion

It is our understanding that the methods presented in ISO1996-2:2007, IEC61400-11 and ETSU-R-97 are all effectively based on the Joint Nordic Method[167] (JNM). Although the three methods have been developed from a common foundation document, tonal audibility levels determined using each method are likely to be slightly different as various changes are made in each guideline, to suit varying applications and measurements circumstances.

It is noted that the ISO1996-2:2007 and ETSU-R-97 methods define penalties ranging between 2-6 dB and 1.54-5 dB, respectively, depending on the level of tonality. No penalties are defined in IEC61400-11.

A brief overview of advantages and disadvantages of each method is provided in Table 7.

Table 7: Tonality assessment method overview

Method	Pros	Cons
IEC 61400-11 method	Developed for wind turbine tones and directly relatable to wind turbine sound power level test results	No direct guidance for assessing tonality at noise sensitive receivers
	Directly implemented in proprietary software packages	No direct guidance on annoyance or applying penalties for certain values of tonal audibility
ISO 1996-2:2007 Reference method	Widely used for a range of noise sources	No direct guidance on assessing tonality across a range of wind speeds
	Provides guidance on suitable penalties	
ETSU-R-97 tonality assessment	Developed specifically for assessment of wind turbine tones at neighbouring noise sensitive locations	Not widely used outside the UK
	Provides guidance on suitable penalties	

[167] (Pedersen, Sondergaard, & Andersen, 1999)

8.0 WIND FARM NOISE ASSESSMENT IN IRELAND (WORK PACKAGE 3)

This section provides a review of legislation, guidelines and commonly employed assessment practices for wind farm noise in Ireland. This includes a detailed review of the guidance offered by WEDG06 and a comparison between the WEDG06 advice and other approaches used internationally. Additionally, a discussion and overview of submissions from recent public consultation work is provided.

8.1 Review of current assessment practices

8.1.1 Planning and Development Act 2000

Applications for wind farm developments within Ireland that are below the threshold for strategic infrastructure as set out in the Planning and Development Act 2000 (as amended) are primarily assessed by the planning authority for the area where development is proposed.

When making its decision in regard to a planning application, the planning authority is restricted to considering the proper planning and sustainable development of the area, with regard being had to the matters set out in s34 of the Act of 2000 as amended. This includes, where relevant, the policy of the Government, the Minister or any other Minister of the Government.

Planning authorities must also have regard to any additional requirements in their Development Plan, Local Area Plans or Wind Energy Strategies.

8.1.2 Ministerial Guidelines

Section 28 of the Planning and Development 2000 Act, as amended, provides that the Minister may at any time issue Guidelines to planning authorities regarding any of their functions under the Act and planning authorities must have regard to those guidelines in the performance of their functions . The Wind Energy Development Guidelines 2006 (WEDG06) were published under this section.

8.1.3 WEDG06

WEDG06 identifies noise as a relevant consideration for new developments, and provides broad guidance on the types of noise limits and separation distances to be considered when assessing new and cumulative proposals.

WEDG06 identifies noise as having potential *Environmental Implications* and requires the noise impact to be assessed by reference to the nature and character of noise sensitive locations. It presents criteria based on a combination of absolute limit values and relative limits that allow a margin above the existing background noise[168]. A detailed review of noise related aspects of WEDG06 is provided in Section 8.3.

8.1.4 LARES

Local authorities commonly deliver wind-energy strategies in response to the statutory requirement to have regard to WEDG06 and to facilitate a plan-led approach to the sensitive siting of wind farms.

---

[168] Refer to Section 5.0 for discussion of noise control mechanisms including absolute and relative noise limits.

Along with local authority wind energy strategies, some authorities develop renewable energy strategies to facilitate planning for the use of all local renewable energy resources. In relation to this, SEAI have provided the following comments:

> *A number of local authority stakeholders indicated to SEAI that they would welcome assistance in the preparation of more comprehensive renewable energy strategies for their areas. In 2013 the SEAI published a methodology and template to guide local authorities in the preparation of their Local Authority Renewable Energy Strategy (LARES). This methodology aims to facilitate consistency of approach in the preparation of LARES, and to assist local authorities in developing robust, co-ordinated and sustainable strategies in accordance with national and European obligations. The LARES methodology usefully provides an overview of all current EU and Irish policies and guidance relevant to planning for renewable energy development. The key land use interactions for onshore wind energy developments are identified in Appendix A4 of the methodology with reference to the WEDG06.*

8.1.5 Additional guidance

ETSU-R-97

ETSU-R-97 was drawn up under the direction of a UK Working Group on Wind Turbine Noise in 1996 with the aim of providing advice to developers and planners on the environmental assessment of noise from wind turbines.

ETSU-R-97 provides a detailed methodology for the assessment of noise from wind turbines but does not prescribe all relevant assessment choices. ETSU-R-97 lays down noise requirements for wind turbine proposals with the intention of offering a reasonable degree of amenity protection to properties located within proximity to the proposed wind turbine(s). The criteria detailed in ETSU-R-97, which are in the form of noise limits, are based on a number of references including existing research, existing guidance and regulation relating to noise emissions and the requirement for the provision of renewable energy sources.

The document recommends that separate noise limits apply for daytime and night-time with the emphasis on the protection of external amenity during the daytime and the prevention of sleep disturbance during the night-time.

The limits are set relative to background noise at nearest noise-sensitive properties and should reflect the variation in both turbine source noise and background noise with wind speed. The noise limits are specified for conditions where wind speeds are 12m/s or below at a height of 10m. ETSU-R-97 considered that impacts due to noise from the turbines will be significant only if the limits are exceeded.

Current practice in the UK commonly involves refinements of some of the methods detailed in ETSU-R-97, such as those detailed in IOA JS2009 and the IOA GPG.

EPA licensed sites

The Environmental Protection Agency (EPA) has produced its own guidance document[169] in relation to the operation of wind turbines at EPA licensed sites. This document proposes a cumulative noise limit for both the site and the turbine, with different limits applicable for the day and night-time.

The EPA references the same documents as the ETSU-R-97 as an applicable guideline for carrying out noise modelling and background assessment for noise impact assessments.

8.1.6 Variations in the application of WEDG06

The planning authority in each County Council area generally applies planning conditions in relation to noise. Below are example planning conditions from two wind farm sites in different counties:

- Site 1
  "Noise levels arising from the operation of the wind farm shall not exceed 40 dB(A) $L_{A\,90}$ when measured over a ten minute period during the daytime and a fixed limit of 43 dB(A) at night-time at any noise sensitive location."
- Site 2
  During the operational phase of the development noise levels when measured over any 10-minute period externally at the nearest dwellings shall not exceed 45 dB(A) L_{A90} or 5 dB above LA90 between the hours of 08:00-20:00 and 43 dB(A) otherwise

The conditions on both sites comply with WEDG06, but provide significantly different noise limitations on the wind farm in each area. The daytime limit at Site 1 is 5 dB lower than site 2.

8.2 Comparison with Irish noise assessment practices for other sources

It can be helpful to compare assessment practices for wind farm noise to those of other noise sources which are regularly encountered such as roads and general industry.

As discussed in Section 5.2 in relation to wind farm limit comparisons, differences in noise level descriptor, and to a greater extent, assessment methodology can mean that two noise sources which share a common numerical noise limit may have different noise outcomes. The examples provided in this section should therefore only be used for general information and not for direct comparison to wind farm noise limits.

8.2.1 Roads

The National Roads Authority (NRA) produced *Guidelines for the Treatment of Noise and Vibration in National Roads Schemes*. This guideline defines an assessment procedure for proposed roads developments and sets a design goal for new roads developments of 60 dB L_{den}[170] at the nearest residential façade.

---

[169] (Environment Protection Agency (Ireland), 2011)

[170] L_{den} is a noise indicator that is a composite of the long term L_{eq} values for the day, evening and night periods. See Glossary for full description

In Northern Ireland the *Noise Insulation Regulations (Northern Ireland) 1995* provides a target level of 68 dB $L_{A10,\ 18hr}$[171] at the façade of residential properties in the vicinity of new roads.

8.2.2 Industrial Operations

The Republic of Ireland Environmental Protection Agency (EPA) has provided a *Guidance Note for Noise* (NG4) to assist licensed sites with the assessment of their noise emissions. Suggested limit values from such sites range depending on the time of day:

- Daytime (0700-1900hrs) - 55 dB $L_{Ar,t}$[172]
- Evening (1900-2300hrs) - 50 dB $L_{Ar,t}$
- Night-time (2300-0700hrs) - 45 dB $L_{Aeq,t}$

The noise limits may apply to individual sources of noise on the site itself, at the boundary of the site or at the nearest noise sensitive location.

8.3 Comparison with international wind farm noise assessment practices

8.3.1 Critique of WEDG06

A detailed review of the key noise related comments in WEDG06 is provided in Table 8 page over.

[171] The $L_{10,18hr}$ is the noise level exceeded for 10% of an 18 hour period

[172] $L_{Ar,t}$ Is the rated noise level equal to the L_{Aeq} during a specified time interval plus a specified adjustment for tonal character and/or impulsive sound.

in WEDG06

ise sources associated with the operation of wind turbines; aerodynamic noise caused by blades passing hanical noise created by the operation of mechanical elements in the nacelle - the generator, gearbox 've-train. Aerodynamic noise is a function of many interacting factors including blade design, rotational flow turbulence; it is generally broadband in nature and can display some "character" (swish). wind turbine is tonal in nature.

ıology and design have resulted in reduced noise emissions. Aerodynamic refinements that have ıes quieter include the change from lattice to tubular towers, the use of variable speed operations, and ɔine designs. Improvements in gearbox design and the use of anti-vibration techniques in the past ten nificant reductions in mechanical noise. The most recent direct drive machines have no high-speed and therefore do not produce mechanical noise.

	Comments
ıes have no high- ıerefore do not	In light of the tonal comments at the end of paragraph 1, it should perhaps be noted that electrical and hydraulic components of the wind turbine may still produce tonal noise, even if the transmission elements are eliminated.
tubular towers, and the switch to	In our experience, the majority of turbines installed commercially since 2006 feature tubular towers and a 3-blade pitch controlled design. In this sense the comments in WEDG06 are correct. However, in light of current wind turbine trends the comments appear dated and could benefit from being updated or removed.

s wind speeds increase, but at a slower rate than wind generated background noise increases. The :velopment noise is therefore likely to be greater at low wind speeds when the difference between noise ɔpment and the background noise is likely to be greater. Wind turbines do not operate below the wind n speed, usually around 5 metres per second. Larger and variable speed wind turbines emit lower noise n smaller fixed speed turbines. Noise from wind turbines is radiated more in some directions than others, 'periencing the highest predicted noise levels. At higher wind speeds noise from wind has the effect of bine noise.

	Comments
:ds increase, but ! background noise	This statement is often true when the wind farm and the receiving locations are exposed to the same wind flow. However it is not uncommon for hills and other ground features to cause poor correlation between wind farm and receiver wind conditions. When this occurs, the amount of noise masking offered by local wind is less certain.
nent noise is ɿind speeds when ɿind energy ise is likely to be	The declaration that impacts of wind farm noise are greater at low wind speeds, where the difference to background noise levels is larger, does not account for the absolute level of the noise in question. It could be inferred from the statements that the absolute noise limit components are not appropriate (SeeWEDG06 Section 5.6 Paragraph 4 below). The term 'impact' would perhaps be more usefully phrased as awareness or audibility.
' the wind speed ound 5 metres per	Modern wind turbines typically have cut-in speeds in the order of 3-4 m/s at hub height, which may equate to approximately 2-3m/s at standardised 10m AGL wind speeds. In light of this, the WEDG06 statement could benefit from updating and clarification.

nd carefully considered siting of turbines is essential to ensure that there is no significant increase in ny nearby noise sensitive locations. Sound output from modern wind turbines can be regulated, thus s, albeit with some loss of power.

nust be achieved between power generation and noise impact.

	Comments
ı considered siting there is no levels at any	*"Ensuring no significant increase in ambient noise levels"* is a much more stringent design goal than is generally recommended, and would significantly constrain wind development. The comment is also inconsistent with the discussions of noise limits that follow at paragraph 6. The introductory wording to this could be more appropriately worded, "... *is essential to ensure that the noise contribution of a wind farm is controlled to a reasonable and appropriate level.*"
·bines can be lems, albeit with	This statement is generally correct, particularly for multi-MW wind turbines which are commonly provided with the ability to operate in reduced-power modes As the statement is provided in the context of siting and design considerations there is an implication that noise-reduced operational modes are a relevant consideration for the planning stage of a development. In some jurisdictions, such noise reduced modes are not commonly relied on during planning, where the key task is to establish the ability of a proposed scheme to satisfy all relevant planning requirements.
ıieved between "	This is considered to be the fundamental objective of WEDG06. It may therefore benefit from further emphasis and discussion, perhaps including elevation to the start of the noise section.

ssessed by reference to the nature and character of noise sensitive locations. In the case of wind energy ısitive location includes any occupied dwelling house, hostel, health building or place of worship and may ır scenic quality or special recreational amenity importance. Noise limits should apply only to those areas ɪtion or activities for which a quiet environment is highly desirable. Noise limits should be applied to ɪould reflect the variation in both turbine source noise and background noise with wind speed. The ich allows reliable measurements to be made without corruption from relatively loud transitory noise s, should be used for assessing both the wind energy development noise and background noise. Any ɪot be considered as part of the prevailing background noise.

	Comments
reference to the ɪe locations."	It is not clear how an assessment should reference the nature and character of noise sensitive locations. This statement does not provide clarity. Additional guidance would be necessary to avoid dispute about how local noise character is factored into an assessment.
ation in both noise with wind	With modern pitch-controlled turbines there is less need to introduce the complexity of a wind-speed dependent, relative noise limits.
:onsidered as part	The purpose of this statement is to ensure that existing turbine noise is not used to justify further increases to the appropriate noise limit for future wind development. This should be reinforced by also stating that "*The prevailing limit to wind farm noise should apply to the cumulative noise contribution from all wind farms impacting on a noise sensitive location.*"

'imit of 45 dB(A)10 or a maximum increase of 5dB(A) above background noise at nearby noise sensitive ɔpropriate to provide protection to wind energy development neighbours. However, in very quiet areas, 'B(A) above background noise at nearby noise sensitive properties is not necessary to offer a reasonable may unduly restrict wind energy developments which should be recognised as having wider national and n low noise environments where background noise is less than 30 dB(A), it is recommended that the), 10min of the wind energy development noise be limited to an absolute level within the range of 35-40

	Comments
IB(A) or a background noise considered wind energy	The recommendation of a base limit of 45 dB(A) is somewhat inconsistent with the remainder of the noise limit advice in this document. The use of "background + 5 dB" as an adjustment for increased ambient noise is generally a practical means of considering areas already exposed to significant steady sources of noise (such as roads or industry). Where the predominant ambient noise is wind-related, a "background + 5" noise limit introduces significant complexity to the planning and compliance testing stages of the project.
gin of 5 dB(A) ɔise sensitive reasonable degree	This comment seems inconsistent with the discussion of 45 dB absolute noise limits that precedes it. If the comment is intended to provide a context for the introduction of the concept of the 35-40 dB absolute noise limits, it could benefit from re-wording to address the inconsistency.
ıckground noise is i that the daytime ıergy development vithin the range of	This advice is consistent with approaches used in some jurisdictions internationally, but would benefit from guidance in choosing a limit from the 35 – 40 dB range. The use of a 40 dBA fixed limit for general noise sensitive areas, and a 35 dBA limit for highly sensitive areas has precedents.

uld apply for day-time and for nighttime. During the night the protection of external amenity becomes
nphasis should be on preventing sleep disturbance. A fixed limit of 43 dB(A) will protect sleep inside
ht.*

	Comments
ɪr day-time and for ɜction of external the emphasis ɪance. A fixed limit ɾoperties during	For other sources of noise, international practice is typically to define lower noise limits for night periods. In practice, assessing noise effects from a wind farm during the day can be difficult due to the influence of other activity noise sources. For this reason a more concise and practical rule could be developed without separating the day into different periods. Moreover, if a wind farm design were to take advantage of separate day and night noise limits it would result in having installed power generating capacity which could not be used during large parts of the day. Further, separating the day into different periods would create a more complex task for the council to ensure the developer followed these requirements.

ly to be a significant problem where the distance from the nearest turbine to any noise sensitive property Planning authorities may seek evidence that the type(s) of turbines proposed will use best current ·rms of noise creation and suppression.

	Comments
ˈgnificant problem turbine to any 500 metres"	The difficulties with using a fixed setback (at any distance) to control noise effects are discussed in Section 5.0. For example, where problem have occurred at wind farms internationally, many have had adverse noise effects at distances of beyond 500 metres.
nce that the types ·rent engineering d suppression."	A specific noise assessment of a wind farm should include the noise parameters of the turbines intended to be used, and it is worthwhile to require that the final design of the wind farm be documented prior to construction, along with a specific assessment demonstrating that it will be able to comply with noise limits.

8.3.2 Strengths of current assessment practices

Current wind farm noise assessment practices in Ireland, which generally rely on ETSU-R-97 - particularly for larger developments, are broadly comparable with those used in other jurisdictions in the region, particularly the UK. The practices are also comparable to those used in other regions including New Zealand and Australia.

As noted in Section 2.3, several guidance documents for wind farm noise assessment that were developed during the 1990s and the early part of the 2000s have recently been revised[173]. These revised documents generally detail refined versions of methodologies from the documents they supersede, as opposed to any fundamental shift in approach or methodology. This indicates that the Irish methods remain comparable with assessment practices used in multiple jurisdictions internationally, though presently without the benefit of any significant formal revisions in methodology since WEDG06 was issued in 2006.

An indirect strength of current assessment practices is the early engagement of potential wind farm neighbours in the case where background noise monitoring at neighbouring dwellings is carried out during the early stages of a planning application.

8.3.3 Gaps and improvement opportunities

A number of practical issues have been identified as having the potential to provide improvement opportunities to the assessment of wind turbines in Ireland. These are outlined in Table 9.

Table 9: Noise assessment issues identified for further consideration

Item	Comment
Involved receivers	WEDG06 does not provide any direct discussions of how receivers that are involved in a wind farm development should be assessed. In addition, no comment is provided about what constitutes an involved receiver.
Noise limit values	There is some ambiguity in relation to daytime and night-time periods and the selection process for the fixed limit values as per the site specific assessment. Clarification could be helpful regarding how the noise limit values can be derived and what considerations can be taken into account in the setting of the lower absolute limits.
Cumulative noise limits	WEDG06 provides some guidance about methods for measuring background noise levels in the presence of existing, operational wind farms. However, there is no clarity about whether noise limits in general should apply per wind farm or to the total level of wind farm noise received.
Reverse sensitivity/ encroachment	WEDG06 does not provide discussion of encroachment or reverse sensitivity of noise sensitive development after the wind farm has received planning approval. For example, would construction of a wind farm preclude future residential development in the immediate area?

[173] Examples include NZS6808:2010 and SAG2009

Item	Comment
Prediction methods	There may be benefit in specifying suitable methods for prediction of wind farm noise and, possibly, also specifying suitable input variables for recommended models. This is a practice commonly used in Australia and New Zealand and, to the degree afforded by the IOA JS2009, the UK
Site measurements	The procedure for carrying out on-site measurements is not clearly defined. There are a number of issues in relation on-site assessment which can have a significant effect on the background noise measurement. ETSU-R-97 is commonly referenced in Ireland as an acceptable assessment procedure. Associated guidance updates by the Institute of Acoustics (IOA) in the UK, such as the IOA GPG, can be open to interpretation within the Irish system. The implications of the updated guidance can have a significant effect on the limit values established on the site. Clarity on monitoring locations, wind shields, wind shear, and monitoring equipment would improve consistency across noise assessments.
Wind speed measurements	Additional comments regarding wind speed measurements may be of benefit. Historically wind speeds have been measured at 10m AGL. This can lead to problems in some cases if measurement results are compared directly with turbine sound power levels at 10m AGL without taking due consideration of wind shear effects. In many jurisdictions, current best practice involves referencing wind speed to turbine hub height.
Special audible characteristics	There is some indirect discussion of tonality in WEDG06. However, a broader discussion of special audible characteristics in general including approaches to regulation and methods of assessment is lacking. This is a point of difference with many guidance documents employed in other jurisdictions, where special audible characteristics are addressed to varying degrees. At present it is anticipated that ETSU-R-97 would act as the defacto assessment standard for special audible characteristics issues. Tonality is the special audible characteristic addressed in most detail in ETSU-R-97.
Commissioning	WEDG06 does not provide recommendations for compliance monitoring of operational wind farms.

8.4 Submissions review

Earlier in 2013, the DECLG announced that it was going to undertake an update of the guidance on noise (including separation distance) and shadow flicker in the WEDG06, in consultation with the DCENR. As the starting point to this process, submissions were invited as part of a preliminary public consultation process. Over 550 submissions were received from private individuals, the wind industry, professional institutes and local authorities.

Three key noise related topics have been identified as discussion points in the submissions:

- Setbacks
- A-weighted noise levels
- Special audible characteristics

For these three topics, a cross section of issues raised in the reviewed submissions is noted:

- *Setbacks*
  A significant number of submissions supported mandatory setbacks and where distances were mentioned they were generally significantly higher than the 500 m separation referenced in WEDG06. Some submissions suggested that setback distance be proportional to turbine size, for example, a separation equating to a certain number of rotor blade diameters or multiples of turbine blade tip height. Industry submissions were commonly not in favour of mandatory setbacks, suggesting that they did not provide a means of control which was directly linked to actual noise levels. These submissions also expressed concern that mandatory setbacks set at relatively high levels would prohibit the location of wind farms which were otherwise acceptable from the perspective of noise generated at dwellings or other noise sensitive locations. Some industry submissions stated that setting a fixed mandatory distance would not account for changes in the size or sound generation levels of turbines.

- *A-weighted noise levels*
  The suitability of A-weighted noise limits such as the nominal 43 dBA night-time noise limit applied by ETSU-R-97 was discussed in some submissions. In some cases the A-weighting was noted to not provide adequate emphasis on low frequency noise. In others the 43 dBA limit was considered to be inconsistent with recent changes in WHO recommended indoor noise levels.

- Special audible characteristics
  Infrasound and low frequency noise were mentioned in some submissions, with an emphasis on amenity and possible health impacts which could arise from these types of sound. A general point was that WEDG06 did not take these types of sound into account. Amplitude modulation was not commonly raised.

For further discussion of these issues, refer to Section 5.3 for setbacks, for a review of noise limits applied internationally and Section 3.4 and Section 5.5 for a discussion of special audible characteristics.

Other issues noted from the submissions include concerns raised in relation to the perceived deficiencies in the process of assessment of planning applications for wind farms by planning authorities. Issues were also raised in regard to noise measurement, a lack of information available to the public about proposed wind energy and developments and also a lack of adequate public consultation by wind farm developers. The potential negative health impacts from wind farms was a common issue of concern raised in a significant number of the submissions.

9.0 CONCLUSIONS OF DESKTOP STUDY (WORK PACKAGE 4)

This section provides a summary of the key conclusions of the desktop review of wind farm noise assessment practices.

9.1 Developments since 2006

In the broadest sense the approach to assessment of wind farm noise, particularly developments of a commercial scale, employed across a range of jurisdictions internationally has not changed drastically since the issue of Ireland's Wind Energy Development Guidelines (WEDG06) in 2006. Rather, the changes to assessment procedures largely amount to refinements and developments of existing methods. The most apparent example of this is in the UK where the 1996 document *The assessment and rating of noise from wind farms* (ETSU-R-97) has been retained as the primary tool for assessing wind farm noise while, to compliment the tool and provide supplementary guidance relevant to its application to modern wind farm developments, the UK Institute of Acoustics published the document *A good practice guide to the application of ETSU-R-97 for the assessment and rating of wind turbine noise* in May of this year.

Additional examples of refinements to wind farm noise assessment include:

- *Sources*
  IEC 61400-11 *Wind turbine generator systems - Part 11: Acoustic noise measurement techniques* was updated to Version 3.0 in 2012 from the previous Version 2.1 dated 2006. There are many refinements in the 3rd version, however the fundamental concepts have not changed and the key output from the tests carried out in accordance with the standard are sound power levels across a range of hub height wind speeds that are suitable for input into sound propagation prediction models.
- *Propagation*
  ISO9613-2:1996 *Acoustics - Attenuation of sound during propagation outdoors - Part 2: General method of calculation* remains a commonly used prediction method for wind farms, just as it was in 2006. Some recent guidance documents such as New Zealand Standard 6808:2010 *Acoustics – Wind farm noise* and the South Australian EPA document *Wind farms: Environmental noise guidelines* provide details of suitable input variables for wind farm sound prediction, such as standardised temperature and humidity effects.
- *Receivers*
  Practices for measuring and assessing background noise levels at noise sensitive locations have been refined. For example, wind speeds used in correlation analysis are now often referenced to turbine hub height, particularly for larger developments with turbines rated in excess of 1 MW, to better address variation in atmospheric conditions. Also, advances in sound level meter capabilities have expanded the quality and quantity of data that can be readily collected at site.

9.2 Approaches to wind farm noise assessment

There are no 'perfect' assessment methods for wind farm noise assessment, as demonstrated by the variation in approaches employed internationally which range from simple setback distances to complex limits with wind speed dependence and absolute and relative components.

As noted commonly in wind farm noise assessment documents, a key objective of an assessment methodology is to balance the potential noise impacts of a wind farm development on its neighbours with the wider national and regional benefits of increased wind energy capacity.

A balance is also required between the complexity of assessment inputs on the one hand and the accuracy and robustness of assessment outcomes on the other. For example, if a proposed wind farm is particularly remote and is a significant distance from any noise sensitive receiver then a comparatively simple noise assessment may adequately achieve the intended planning outcomes. Conversely, a proposed wind farm that is comparatively closer to noise sensitive locations would likely benefit from more detailed assessment to better establish the viability of the proposal. The complexity of inputs must also be considered with respect to the skills and expertise of those required to review the appropriateness of the assessment such as regulatory authorities and potential wind farm neighbours.

In addition, the degree of accuracy of the assessment, determined in part by inputs, should be weighted relative to the degree of accuracy of any commissioning works. For example, typical outdoor measurements may have an uncertainty of at least ±1 decibel due to equipment tolerances and variable propagation and ambient noise influences. For wind farm noise measurements, a greater tolerance is likely applicable on account of additional variability associated with changes in wind speed and general atmospheric conditions. In this sense, a planning assessment methodology with an accuracy finer than 1 decibel is perhaps not of critical importance as outcomes could not be measured to the same resolution in practice[174].

9.3 Noise limits

From the review of noise control methods, in particular noise limits, discussed in Section 5.0, there are three broad categories of noise control method[175] that are commonly cited in regard to wind farm noise assessment:

- Absolute limits,
  which nominate a single noise limit value to be applied across a range of assessable wind speeds.
- Relative or combined limits,
  which include provision for limit values that vary with background noise level and, commonly, wind speed.

[174] Refer to Section 2.0 for a discussion of changes in sound level and how these are perceived in practice.

[175] Refer to Section 5.0 for a discussion of types of noise control mechanism and what they entail.

- Setbacks,
  which specify a minimum separation distance between a turbine and the nearest noise sensitive receiver.

9.3.1 Absolute noise limits

A range of advantages and disadvantages are provided in Table 10 below.

Table 10: Absolute noise limit pros and cons

Stakeholder	Pros	Cons
Regulator	Simpler to assess at planning application stage	Potential difficulty assessing compliance at the operational stage
Wind farm neighbour	Easier to understand than wind-speed dependent, background noise dependent limits	A more time consuming compliance assessment process compared with setbacks. Compliance assessment typically involves measurements at receiver locations which can take time to carry out, process and report on.
Wind farm developer	Reduced assessment burden for projects at planning application stage, as background noise measurements would not be required as part of the initial planning submission[176].	Potentially some lost wind generation capacity in areas of elevated background noise
		Some refinement possibly required to cope with high background noise areas such as near motorways.

[176] Background noise measurements would still likely be necessary prior to wind farm construction. However, as the background noise levels need not directly inform noise limits, they could be arranged once a project's initial submission is approved, at which point there is comparatively more certainty of the project going ahead.

9.3.2 Relative or combined noise limits

A range of advantages and disadvantages are provided in Table 11 below.

Table 11: Relative or combined noise limits pros and cons

Stakeholder	Pros	Cons
Regulator	Consistent with the current Irish assessment approach as well as that used in the UK	Assessment of complex planning applications
		Potential difficulty assessing compliance at the operational stage
Wind farm neighbour	-	A more time consuming compliance assessment process compared with setbacks. Compliance assessment typically involves measurements at receiver locations which can take time to carry out, process and report on.
Wind farm developer	Copes more readily with active stall turbines which are characterised by noise levels that continue to increase above the wind speed of rated power.	A more involved pre-planning application scope of works, when compared with absolute limits, to carry out background noise measurements.

9.3.3 Setbacks

A range of advantages and disadvantages are provided in Table 12 below.

Table 12: Setbacks pros and cons

Stakeholder	Pros	Cons
Regulator	Easy to assess compliance at planning application and operation stages	No direct facility to address complaints as there is no assessment standard for noise output.
Wind farm neighbour	Easy to understand	A coarse tool which does not necessarily correlate with noise levels and may result in high levels of wind farm sound at noise sensitive receivers in some cases.
		Developers have no direct, regulatory disincentive for the use of turbines with undesirable sound characteristics
Wind farm developer	Reduced assessment burden for projects at planning application and operational stages of development	Potential for significant lost wind generating capacity.
	No noise related incentive to use more expensive turbines with lower sound emissions	

9.4 Measurements

Noise measurements for a wind farm can be carried out for a range or reasons including:

- Sound power level testing for warranty assessment and noise prediction model verification
- Background noise measurements at receptor locations prior to a wind farm development, to quantify existing ambient noise levels
- Post-construction noise measurements to assess whether wind farm operational noise complies with applicable requirements

The key challenge for noise measurements is acquiring robust and accurate noise level data during periods with moderate to high wind speeds.

Sound power level testing is normally carried out in accordance with International Standard IEC61400-11:2006[177].

[177] IEC61400-11:2006 Wind turbine generator systems - Part 11: Acoustic noise measurement techniques, (International Electrotechnical Commission, 2006)

There are no universally accepted methods for quantifying background noise levels at receptor locations around either proposed or operational wind farms. Common to several approaches[178], however, is the unattended measurement of noise levels using logging equipment for a period of a week or more. The background noise levels, typically L_{A90} or L_{A95}, are generally measured across a series of consecutive 10 minute periods for a number of days or weeks to collect a minimum number of data points, often at least 1500 to 2000. While unattended measurement methods are well documented in a number of jurisdictions, the robustness and accuracy of results can be influenced by many factors such as equipment noise floor and wind screen performance. The results of unattended monitoring can often be disputed during the planning application stage of a development.

A significant further challenge with unattended post-construction noise measurements is that noise levels from an operating wind farm at a receptor are often similar to levels of ambient noise. Distinguishing the relative contributions of wind farm and ambient noise to any given measured level is therefore very difficult. Additional post-construction noise commissioning measurement methods which have been developed to try and overcome this issue include:

- Attended measurements at receptor locations
- Measurements at derived or intermediate points
- Sound power level testing and noise prediction model verification

9.5 Special audible characteristics

The following special audible characteristics have been considered in this report:

- Amplitude modulation
- Impulsiveness
- Infrasound
- Low frequency noise
- Tonality

In some jurisdictions special audible characteristic assessment methods and criteria have been developed for application to general noise sources such as industrial or commercial noise and have been applied for wind farm noise assessment, though some refinement of methods can be necessary to cope with changes in wind speed.

The occurrence of one or more special audible characteristics typically results in a penalty being applied to an assessment of wind farm noise. For example, a 5 decibel penalty is often required to be added to measured wind farm noise levels.

[178] ETSU-R-97, NZS6808:2010, AS4959:2010, SAG2009

With the exception of tonality, special audible characteristics are not commonly directly predicted or assessed during the preparation of a planning application for a wind farm. As noted in Section 6.3.1 in relation to amplitude modulation and impulsiveness, this approach has likely evolved pragmatically, reflecting the limited documentation of occurrences at operating wind farms. In some jurisdictions low frequency noise and infrasound predictions have begun to be included in planning application stage assessments despite any well documented evidence in those jurisdictions to indicate these issues have been problematic[179].

Operational stage assessments of special audible characteristics can also be variable. Methods of assessing tonality are comparatively well established. Similarly, there are methods available for assessing infrasound and low frequency noise although measurement techniques must be carefully considered to eliminate undue influence of the wind, particularly when measuring outdoors. Methods of measurement and criteria for excessive amplitude modulation and impulsiveness are less well established and there is evidence to suggest that they can be significantly influenced by extraneous noise.

9.6 Irish guidance

As essentially the key guidance document for wind farm noise assessment, WEDG06 provides broad high level guidance on general issues associated with noise from wind farms during construction and operation. As discussed in detail in Section 8.3, WEDG06 would benefit from greater clarity regarding noise assessment methods and applicable noise limits.

The ambiguity of some of the existing comments in the guidelines has the potential to result in a higher rate of variability of assessment outcomes across projects owing to different interpretations of a common point or points of guidance. In the extreme, it is quite conceivable that two independent assessments of a single wind farm, both using WEDG06, could result in different outcomes despite each assessment essentially complying with the intent and requirements of WEDG06.

An example of where this may occur is through the application of noise limits. WEDG06 recommends that in low noise environments where the background noise level is less than 30 dBA, the absolute component of the noise limits should be within 35-40 dBA. Because no guidance is provided for selecting an appropriate absolute limit from this range, two different assessments of a single wind farm could both justifiably apply absolute noise limits that are up to 5 decibels different from each other. This could in turn require wind farm noise predictions for one of the assessments to be 5 decibels lower: a significant difference in the context of wind farm development, which could result in significant lost energy yield or bring the viability of the project into question[180].

In practice, the two assessments in this example have the potential to arrive at a consistent outcome if they both referenced ETSU-R-97 for guidance on selecting suitable absolute noise limits. ETSU-R-97 is currently a common point of reference for Irish wind farm noise assessment and in many senses is a default detailed assessment methodology for the implementation of the requirements of WEDG06.

[179] (NSW Department of Planning and Infrastructure, 2011)

[180] (Adcock, Bullmore, Jiggins, & Cand, 2007)

10.0 RECOMMENDATIONS (WORK PACKAGE 4)

This section presents recommendations regarding existing Irish guidance for assessing wind farm noise, in particular the Wind Energy Development Guidelines 2006 (WEDG06).

10.1 Key recommendations

Should WEDG06 be updated or replaced?

Yes.

As discussed above, it is considered that the noise guidance provided in WEDG06 would benefit from greater clarity, particularly regarding applicable noise limits and associated assessment methods.

It is recommended therefore that the noise related discussions in WEDG06 be either revised or replaced.

Should the discussion of noise limits be revised?

Yes.

The current advice regarding noise limits is ambiguous and is a potential source of doubt for wind farm developers, potential neighbours and local regulatory authorities.

It is recommended therefore that the discussion of noise limits in WEDG06 be either revised or replaced.

The revised text should provide clear and direct advice about appropriate noise limits for wind farm developments. Work involved in updating WEDG06 should include not only a review of suitable noise limit values but also of the broader style of noise control method or limit that is applied. See Section 10.2 below for further discussion.

What else needs to be included?

It is recommended that any revision of WEDG06 include additional guidance about a number of noise related issues, including:

- Wind farm noise prediction methods
- Special audible characteristics
- Commissioning requirements
- Cumulative noise from more than one wind farm

These issues are discussed further in pursuant sections.

These additional issues could be discussed directly in updated guidance or, alternatively, developed into a supplementary document or appendix, similar to WEDG06 Appendix 3 which provides comparatively detailed advice relating to landscape impact assessment.

Any discussions should have due regard to the revision of noise limits noted above.

10.2 Noise limits

Review of noise control methods

As discussed in Section 5.0 and Section 9.0, there are three broad categories of noise control method[181] that could be considered for wind farm noise assessment in Ireland:

- Relative or combined limits,
  which include provision for limit values that vary with background noise level and, commonly, wind speed.
- Absolute limits,
  which nominate a single noise limit value to be applied across a range of assessable wind speeds.
- Setbacks,
  which specify a minimum separation distance between a turbine and the nearest noise sensitive receiver.

Deciding on a suitable noise control method involves factors that extend well beyond noise assessment, such as community perception, expected rates of noise annoyance and priorities of the regulatory authority. Notwithstanding these considerations, a limited discussion is provided here to help inform the DECLG and the DCENR of relevant noise assessment considerations during their review of broader issues.

From the review of these noise control methods as detailed in this report:

- Relative or combined noise limits have been employed in many jurisdictions internationally suggesting that they offer a reasonably robust means of assessing wind farm noise. However, there is significant complexity associated with accurately quantifying ambient noise environments, particularly across a range of wind speeds. This can lead to onerous noise measurement and assessment requirements during preliminary stages of a proposed wind farm. It may also lead to reduced certainty for wind farm neighbours if noise limits at their dwellings are based on complex and inherently variable background noise levels. Given the current trend towards pitch-controlled wind turbines for larger developments, whose sound power levels tend to plateau at wind speeds above rated power, the net value of having limits based on wind speed dependent background noise levels is questionable.
- Absolute limits have also been employed in a number of jurisdictions internationally suggesting that they offer a reasonably robust means of assessing wind farm noise. Absolute limits would be expected to provide a comparable or better degree of amenity protection than combined noise limits.[182] Concurrently, they would offer a streamlined assessment of wind farm noise during the planning stage. In particular, there would be no explicit requirement to measure background noise levels prior to preparing a planning application. These measurements may, however, ultimately be required either to address environmental impact requirements or to inform post-construction noise commissioning assessments.

---

[181] Refer to Section 5.0 for a discussion of types of noise control mechanism and what they entail.

[182] Assuming that the absolute component of the combined noise limits is maintained and applied to all wind speeds in the nominated assessable range.

- The relationship between distance from a wind turbine or wind farm and noise effects is significantly variable[183], and there is little means of future proofing when specifying minimum set back distances. In this respect, setbacks therefore have the potential to either over-protect or under-protect wind farm neighbours. It is therefore recommended that setbacks are not used as a control method. Further discussion of setbacks is provided in Section 5.3.

On balance, it is considered that absolute noise limits offer the potential to provide comparable or better levels of amenity protection than the combined noise limits discussed in WEDG06. Concurrently, they offer the opportunity for a simpler planning stage assessment, with background noise level measurements only required if a proposed project receives planning approval.

On this basis, it is recommended that absolute noise limits be strongly considered for incorporation into revised noise assessment guidance. This should include a review of relative wind generating capacity of existing combined noise limits and any proposed absolute limits.

Absolute limits in practice

An absolute limit would nominate a single noise limit value to be applied across a range of assessable wind speeds. In practice this could mean that the most significant pre-construction site noise survey works, that is background noise measurements, are deferred to a time when there is more certainty about the status of the project.

The use of absolute noise limits need not affect the rigour of the noise assessment as background noise measurements, including correlation with wind speed data and subsequent regression analysis, would still generally be required to inform post-construction commissioning works[184].

Also, in the absence of these background measurements, which typically involves early engagement with potential wind farm neighbours, it would be important to ensure that potential neighbours are engaged in the development process at an early stage.

Noise limit values

The selection of appropriate numerical values for noise limits, whether for absolute or combined limits, should take due regard of the balance a regulator wishes to achieve between rates of wind farm development on the one hand and the degree of amenity protection offered to wind farm neighbours on the other. Concurrently, the limit value should be balanced with the measurement and assessment methods that it is paired with.

[183] Depending on the details of the wind farm including the number of turbines and their spacing as well as the topography of the wind farm site and surrounding area.

[184] As detailed in Section 7.2.1, pre-construction background noise levels can be used to correct for the influence of ambient noise during post-construction commissioning measurements.

Providing a noise limit range from which a suitable numerical value can be selected, as is the case in WEDG06 where a limit range of 35-40 dBA is nominated, may offer sensitivity to local planning requirements and ambient environments. Conversely, selecting a single numerical limit value reduces the risk of ambiguity during wind farm noise assessment, particularly for non-involved receivers as there would be clarity about what limit value applies at their property.

The review of noise limits across a range of jurisdictions internationally indicates that limit values in the range of 35-45 dBA are commonly employed where there is an intention by the relevant regulatory authority to reasonably limit sleep disturbance such as where limits are specified for a night-time period. Limit values at the upper end of this range, around 45 dBA, are often only applied for involved receivers, as is the case with ETSU-R-97. Limit values at the lower end of this range, 35 dBA, are in some cases identified as only applying as a special case to areas that are particularly sensitive to noise and not to general rural areas where, for example, agricultural industries are priorities. NZS6808:2010 and SAG2009 offer two such examples of this approach.

10.3 Prediction methods

It is considered essential that revisions of the noise related content in WEDG06 include a discussion of wind farm noise prediction methodologies to reduce the opportunity for inconsistency and dispute to arise during the modelling process.

At a minimum, the discussion should indicate the types of standards and prediction methods that are considered appropriate. Further, prescriptive advice on specific prediction details would help promote assessment consistency and avoid protracted dispute. For example, the UK Institute of Acoustics IOA GPG[185] references ISO 9613-2:1996[186] as a suitable prediction method and provides a discussion of suitable modelling parameters and approaches such as recommended values for humidity and temperature[187], limits on barrier attenuation and suitable values of ground factor.

In the interest of allowing for improvements in technical methods, or simple cases where detailed methods are not required, it may be desirable to allow alternative prediction methods to be used where adequate technical justifications are provided.

[185] *A good practice guide to the application of ETSU-R-97 for the assessment and rating of wind turbine noise,* (Cand, Davis, Jordan, Hayes, & Perkins, 2013)

[186] ISO 9613-2:1996 Acoustics - Attenuation of sound during propagation outdoors - Part 2: General method of calculation, (International Standards Organisation, 1996)

[187] Which can influence the amount of air absorption is predicted by the model.

10.4 Special audible characteristics

It is recommended that revisions of WEDG06 include commentary regarding the following special audible characteristics:

- Amplitude modulation
- Impulsiveness
- Infrasound
- Low frequency noise
- Tonality

The comments should include details of any penalties to be applied where special audible characteristics are identified and, if necessary, how such penalties should be incorporated into a compliance assessment for either a proposed or operational wind farm, particularly if the assessment involves regression analysis[188].

A key benefit of providing such a discussion is a clear and well documented assessment path for evaluating special audible characteristics should their presence be suspected at a planned or operational wind farm. In the absence of any guidance, significant effort can be required from all stakeholders to establish suitable assessment methods on a case-by-case basis.

The extent of the special audible characteristics discussions can be a balance of a range of factors. For example, special audible characteristics are not unique to wind farms and can be a readily occurring characteristic of many types of noise. Often a jurisdiction will have existing regulations or methods in place to assess such characteristics such that the discussion in a wind farm guidance document need only refer to the existing information, perhaps with additional comments about how to address variations with wind speed[189].

The types of potential special audible characteristics for which assessment methods are provided could be weighted toward the considered risks of such characteristics occurring in practice at operational wind farms. For example tonality has been documented to be a feature of some turbines and some wind farms from time to time whereas available literature in relation to impulsiveness and infrasound suggest that they do not commonly occur at problematic levels.

[188] For example, if a regression analysis involves 1000-2000 measured noise levels, should a penalty for, say, tonality, be applied to: individual measured levels prior to determining the regression curve; all measured noise levels at relevant wind speed and wind direction conditions prior to determining the regression curve, or; directly to levels determined from the regression curve?

[189] For example, ISO1996-2:2007 *Acoustics - Description, measurement and assessment of environmental noise - Part 2: Determination of environmental noise levels* is often reference for tonality assessment of general noise sources and with appropriate supplementary guidance it could also be used to facilitate an assessment of tonality for wind farm noise.

Similarly, the magnitude of any special audible characteristics penalties could be weighted in recognition of chosen limit values. For example, if comparatively relaxed noise limit values were selected it may be appropriate to apply special characteristics penalties cumulatively[190] whereas a single penalty[191] may be more appropriate if applied in conjunction with comparatively onerous noise limits values.

Also, it may be worth affording flexibility in any prepared comments that allow for advances in the state of the art. This style of approach has been adopted in NZS6808:2010 *Acoustics – Wind turbine noise* where the assessment method for amplitude modulation has been identified as 'interim'.[192]

10.5 Commissioning

It is recommended that revisions of WEDG06 include a discussion of commissioning measurements and assessment requirements including when commissioning work is considered necessary and how it is to be carried out.

The discussion should detail methods to assess levels of operational wind farm noise in response to complaint. The methods should describe requirements for any un/attended monitoring, what sound levels are to be recorded, how they are to be correlated with wind speeds etc.

Additionally, there could be merit in requiring an amount of pro-active compliance monitoring once a new wind farm development becomes operational, to confirm that any conditions on planning permissions are being adhered to.

10.6 Additional issues

A number of additional issues have been identified as warranting further discussion in any revision of WEDG06. These issues are discussed in Table 13.

[190] That is, the inclusion of a separate penalty for each special audible characteristic that is identified.

[191] That is, a single penalty applying whether one or several special audible characteristics is identified.

[192] Section B3.2 of NZS6808:2010 notes the following:
This method is considered to be an adequate interim test that has been used in New Zealand. It is envisaged that appropriate objective tests for modulation special audible characteristics will be developed in future to replace B3.2 or provide a more robust objective method than B3.2.

ınded for inclusion in wind farm noise assessment guidance

Comment	Example resolution
egarding involved receivers including a definition of suitable noise limits for involved receivers and what lace between the receiver and wind farm developer to ʒotiated adjustments to noise limits.	A higher absolute limit, as is commonly applied for involved receivers in many jurisdictions, could be nominated. In addition, requiring a contract or written agreement between a receiver and wind farm developer of any variation to noise limits could prevent confusion and ambiguity about when an adjustment in noise limits should apply.
ıe in separate noise limits for daytime and night-time periods. can theoretically have the benefit of enhanced amenity tional flexibility, depending and what limit values are :erms, a common limit for day and night may provide a ' of assessment and simplicity of interpretation.	A common noise limit could be adopted for daytime and night-time periods, with the limit value selected to address the most noise sensitive time of day (typically night-time).
tential cumulative noise impacts from more than one ınd how they should be assessed.	Noise limits at a given noise sensitive location could apply to the total level of wind farm noise rather than on a 'per wind farm' basis. This approach to limits could be supported by additional guidance on how to identify receivers for assessment and how to coordinate predictions of multiple wind farm schemes.
guidance about reverse sensitivity and encroachment, :ntial dwellings or other noise sensitive land uses are ty to an approved or operating wind farm. :ial developments are not permitted within a certain the wind farm. This is comparable to the mechanisms croachment around other types of noise-generating ɔf such methods depends on the planning framework ɾed in a particular jurisdiction.	A requirement for the wind farm developer to provide the local regulatory authority with information about noise levels from a wind farm in the form of predicted or measured noise contours. This information could be used for the regulatory authority and perspective developers of land neighbouring the wind farm, to evaluate the suitability of a particular property and development plan.

ɿeighbouring a wind farm development and who have an involvement in the project, often including financial involvement.

10.7 Discussion

The SEAI's stated objective for this desktop study of onshore wind farm noise is to obtain evidence upon which to evaluate the appropriateness of WEDG06 in relation to noise impacts and if considered necessary suggest changes.

The recommendations detailed above include reviewing the noise control methods currently used for wind farm developments in Ireland. As noted in Section 10.2, deciding on a suitable noise control method involves factors that extend well beyond noise assessment. If a new noise control method is nominated as an outcome of the technical update of WEDG06 noise issues, it is recommended that the proposed method be reviewed by the relevant authority with due consideration of the wider planning context including rates of renewable energy development, community perception, rates of noise.

A number of the recommendations detailed above, such as those relating to special audible characteristics and commissioning work, will involve provision of new content in the form of detailed guidance and methodologies. If these recommendations are adopted as part of the technical update of WEDG06 noise issues it is recommended that they be externally reviewed prior to being finalised.

APPENDIX A GLOSSARY OF TERMINOLOGY

AGL Above Ground Level

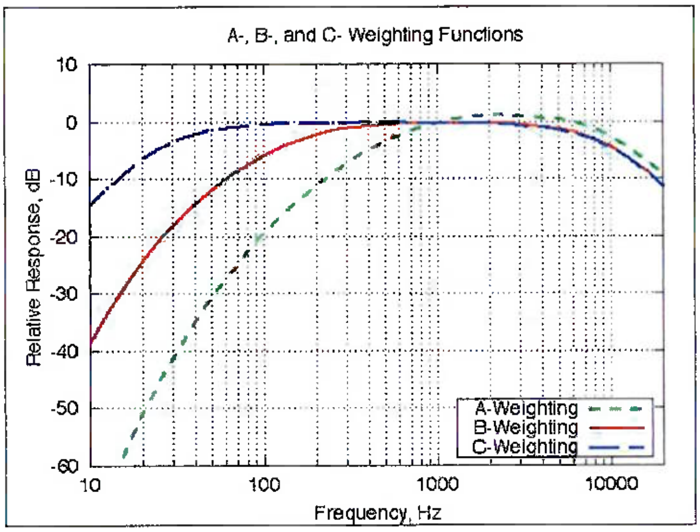
Ambient The ambient noise level is the noise level measured in the absence of the intrusive noise or the noise requiring control. Ambient noise levels are frequently measured to determine the situation prior to the addition of a new noise source.

Amplitude modulation *Amplitude modulation special audible characteristics occur when there is significant amplitude modulation of the aerodynamic sound from one of more wind turbines such that there is a greater than normal degree of fluctuation as a function of the blade passing frequency (typically about once per second for larger turbines.)*[193]
Refer to Section 3.4 for further details.

A-weighting The A-weighting approximates the response of the human ear, particularly for sounds of moderate and low levels.

C-weighting The C-weighting approximates the response of the human ear, particularly for sounds at high noise levels (typically greater than 100 dB).

Comparison of A and C weightings



dB Decibel. The unit of sound level.

A measurement of sound level expressed as a logarithmic ratio of sound pressure P relative to a reference pressure of Pr=20 µPa
i.e. dB = 20 x log(P/P_r)

Frequency Frequency is the number of pressure fluctuation cycles per second of a sound wave. Measured in units of Hertz (Hz).

Sound can occur over a range of frequencies extending from the very low, such as the rumble of thunder, up to the very high such as the crash of cymbals.

Impulsiveness *Transient sound having a peak level of short duration, typically less than 100 milliseconds.*[193] Refer to Section 3.4 for further details.

Hertz (Hz)	Hertz is the unit of frequency. One hertz is one cycle per second. One thousand hertz is a kilohertz (kHz).
L_{Aeq}	The equivalent continuous (time-averaged) A-weighted sound level. This is commonly referred to as the average noise level.
L_{A90}	The A-weighted noise level equalled or exceeded for 90% of the measurement period. This is commonly referred to as the background noise level.
L_{Ceq}	The equivalent continuous (time-averaged) C-weighted sound level.
L_{C90}	The C-weighted noise level equalled or exceeded for 90% of the measurement period.
Low Frequency noise	*Sound below about 200 Hz.*[193] Refer to Section 3.4 for further details.
Masking Noise	Background noise that is not disturbing, but due to its presence causes other unwanted noises to be less intelligible, noticeable and distracting.
Octave Band	Sound, which can occur over a range of frequencies, may be divided into octave bands for analysis. For environmental noise assessments, sound is commonly divided into 7 octave bands. The octave band frequencies are 63Hz, 125Hz, 250Hz, 500Hz, 1kHz, 2kHz and 4kHz.
Sound Pressure Level (L_P)	A logarithmic ratio of a sound pressure measured at distance, relative to the threshold of hearing (20 µPa RMS) and expressed in decibels.
Sound Power Level (L_W)	The level of total sound power radiated by a sound source. A logarithmic ratio of the acoustic power output of a source relative to 10^{-12} Watts and expressed in decibels.
Special audible characteristics	Distinctive characteristics of a sound which are likely to subjectively cause adverse community response at lower levels than a sound without such characteristics. Examples are tonality (e.g. a hum or a whine) and impulsiveness (e.g. bangs or thumps).
Tonality	*Noise containing a discrete frequency component*[193]. Refer to Section 3.4 for further details.

[193] (Standards New Zealand, 2010)

APPENDIX B WIND FARMS: ANCILLARY SOURCES OF NOISE

Whereas wind turbine noise is strongly wind-speed dependant and so requires special methods of assessment, other noise sources within the farm are either not dependant on the wind (such as fans at a service building) or passively wind-related (such as noise from transmission lines). These sources can be assessed using conventional noise rules.

B1 Substations and Transformers

While the transformer located at the base of each turbine may be considered as part of the turbine noise emissions, the switching and substation facilities which are usually located within the wind farm are an additional source of noise. Substations are well understood, and are the subject of measurement and assessment standards such as IEC 60076-10[194]. Transformer noise generally occurs at two times the line frequency, for example 100 Hz for a 50 Hz electrical network, and harmonics of that frequency (e.g. 200, 300, 400 Hz). As such, transformer noise is often tonal and readily discerned in the environment.

B2 Transmission Lines

Transmission lines can produce noise as the wind blows through them (Aeolian noise) and in the case of high-voltage lines (e.g. above 200 kV) by the crackling that occurs especially in humid conditions (corona discharge).

Both of these effects are relatively low in sound level, and are usually only an issue when these lines pass in close proximity to a dwelling.

B3 Meteorological Masts

Meteorological masts are used both before and during the operation of a wind farm to collect wind data. Masts are often erected at similar heights to the turbines used in the wind farm. While they are of much lighter construction than a wind turbine, they are often held in place with multiple guy wires which can produce wind tones especially in the high winds associated with wind farm sites. These should be considered as a significant noise source if located near to dwellings.

B4 General Activity Noise

Noise produced from vehicles, building services, and other installations should be included in an assessment of noise effects. There is generally no special consideration that needs to be given to these as a result of being associated with a wind farm.

---

[194] (International Electrotechnical Commission, 2005)

APPENDIX C WIND SPEED PROFILES

C1 Wind shear

Wind shear describes variations in wind speed with height above ground level.

The rate of change of wind speed with height is influenced by a range of factors including the type of ground coverage, the complexity of the terrain profile, and atmospheric conditions[195].

The following equation can be used to estimate the difference in wind speed between two different heights, based on wind shear conditions that are characterised by the variable roughness length, Z_0 (m). The equation describes a logarithmic wind speed profile.Examples of wind speed profiles calculated using this equation are shown in Figure 18 for four different values of roughness length.

$$V_1 = V_2 \cdot \frac{\ln\left(\frac{h_1}{z_0}\right)}{\ln\left(\frac{h_2}{z_0}\right)}$$

(Equation 2)[196]

Where:
V_1 = wind speed at height h_1 in m/s
V_2 = wind speed at height h_2 in m/s
Z_0 = the surface roughness length

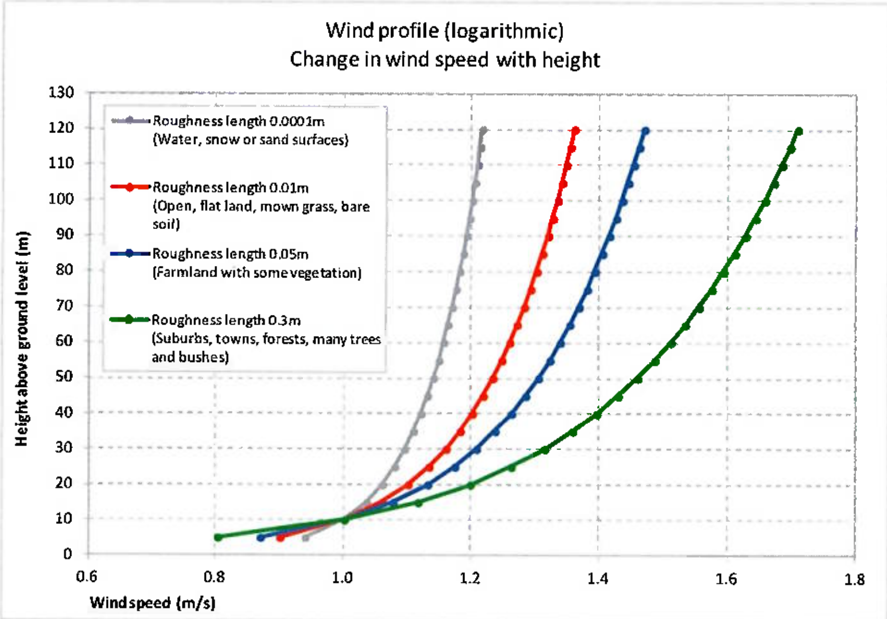


Figure 18: Example wind profiles

195 (van den Berg, Effects of the wind profile at night on wind turbine sound, 2004)

196 (International Electrotechnical Commission, 2012)

C2 Application to wind farm noise

Some methods of wind farm noise assessment, such as those detailed in ETSU-R-97, rely on a common 10m wind speed reference for both the measured background noise levels and the turbine noise emission data. In relation to background noise surveys, the 10m measurement height represented a practical requirement for the installation of temporary anemometry during the noise survey period. The 10m height wind speeds also generally tended to correspond more closely with wind conditions at surrounding receptor locations, enabling improved correlations between measured wind speeds and background noise levels, where these are necessary.

In relation to turbine emission data however, the reliability of a 10m height wind speed is dependent on an assumed shear profile. Specifically, manufacturers' noise emission data assessed according to IEC61400-11 must be referenced to 10m height wind speed and assumes a standard relationship between wind speeds at hub-height and 10m height. This relationship uses a reference surface roughness length (z_0) of 0.05m which equates to a wind profile near ground level for relatively open farmland with limited tree coverage and mild undulating terrain. The benefit of this method is a standardised reference which enables the comparison of noise emissions from different turbines with varying hub-heights.

The reliability of the 10m referenced turbine data is reduced if actual wind shear conditions where the turbine is installed significantly differ from the assumed wind shear applied to manufacturers' data. For example, if wind shear is lower than assumed by the standardised reference roughness length, as may occur during the day at sites with very flat ground and little or no tree coverage, the turbine's noise emissions will occur at relatively higher wind speeds than indicated by the 10m height standardised data, leading to potentially lower noise levels than expected for a given wind speed. Conversely, if wind shear is higher than assumed by the standardised reference roughness length, the turbine's noise emissions will occur at relatively lower wind speeds than indicated by the 10m standardised height, leading to potentially higher noise levels for a given wind speed.

Higher wind shear conditions than assumed manufacturers' IEC61400-11 noise emission data can occur as a result of increasing terrain complexity and ground coverage, or importantly as a result of wind shear conditions being dominated by atmospheric stability effects rather than ground roughness effects[197]. Stable atmospheric conditions may occur for a range of reasons such as the relative cooling of the air near ground level at night. The effect of stable atmospheric conditions and increased wind shear can therefore lead to situations where an assessment referenced to 10m wind speed heights will underestimate the level of turbine noise expected at surrounding locations for a given wind speed, a phenomenon reported in measurements published by Frits van den Berg[195] , and since occasionally referred to as the "van den Berg effect". The influence of increased wind shear was particularly relevant for older types of turbine design which utilised stall based speed regulation systems, characterised by noise profiles that continued to increase with wind speed. In contrast, modern pitch regulated machines tend to increase noise emissions up to a particular wind speed, above which noise levels do not generally increase with wind speed.

197 (van den Berg, Effects of the wind profile at night on wind turbine sound, 2004)

In some jurisdictions, current industry practice is to base wind farm noise assessments on hub-height wind speeds rather than the 10m height wind speeds. For example, the use of hub-height wind speed data has been detailed in recent guidance from Australia[198] and New Zealand[199] as it is considered to better account for the influence of site-specific wind shear conditions in the noise assessment.

Conversely, wind speeds continue to be referenced to 10m AGL in the UK. However, following criticism of assessments based on direct measurement of wind speeds at a height of ten metres, current good practice in the UK[200] recommends that all ten metre wind speed data is calculated from hub height wind speed assuming reference conditions.

198 SAG2009, AS4959:2010

199 NZS6808:2010

200 (Cand, Davis, Jordan, Hayes, & Perkins, 2013)

APPENDIX D GENERAL NOISE CONTROL METHODS

Most development, whether it involves construction of new dwellings or improving essential infrastructure, will generate noise.

General noise policies for infrastructure developments must therefore provide an acceptable level of amenity protection, whilst providing a viable framework that allows for essential development.

D1 Methods for policy control

The intent of many noise policies is to adequately control the effects that noise from one location has at another location. Most commonly, the control method is in the form of a *noise limit*, being the level of the sound that should not be exceeded at some location, typically that of the nearest noise sensitive receiver. There is, however, a range of control methods available, including several varying approaches to the use of a noise limit. These approaches are discussed briefly in Table 14.

Table 14: Summary of types of noise control method

Method		Comments
A	*Land Use Planning*	In the broadest terms, land use planning concerns the compatible and efficient arrangement of a variety of land uses: in a sense it's the starting point for any form of noise management. When the planning system achieves ideal outcomes, specific impact assessments aren't needed and land use planning can effectively address all possible issues relating to impact and effects. For example, zoning of land around airports often precludes/excludes potential development of residences as this type of noise sensitive land use is contradictory to the primary activities of an airport and the adverse noise impacts that it can potentially generate. By incorporating this style of buffer zone around an airport, the broader financial, social and in some cases security benefits of efficiently functioning airports can be better realised.
B	*Compensation to affected receivers*	In some cases it may not be possible to adequately control external noise levels at surrounding receptor locations. An alternative approach in these cases can be to compensate the affected receivers. For example, negotiating a mutually agreed outcome with the affected receptor(s). For example, building sound insulation upgrades could be provided as compensation for a property owner allowing higher noise limits at the property.
C	*Compulsory acquisition of affected receivers*	During major infrastructure projects, regularity bodies can in some cases have an option to acquire land in the vicinity of a project. This method is usually considered a last resort and only considered should other options not be viable. Generally, there is no set condition or rule which triggers the need for compulsory land acquisition. Rather, it involves weighing all relevant factors such as project benefits to the community, costs of acquisition, alternative site selection etc.

Method		Comments
D	*Minimum separation distances*	Requires a minimum separation distance between a noise source and noise sensitive receiver. For example the Ontario Ministry of the Environment's minimum setback between a wind project and a noise sensitive receiver of 550m. Setbacks allow a simple way of separating noise generating and noise sensitive development. However, they do not necessarily provide a consistent level of amenity protection. In some cases setbacks can be overly onerous as they fail to take account of terrain, shielding and meteorological affects on sound propagation. Conversely, unless the separation distance is impractically large, it fails to cope with any changes in source characteristics such as higher sound levels. Setbacks are addressed further in Section 5.2.4.
E	*Voluntary acquisition of affected receivers*	In some cases, typically involving major changes to an existing item of infrastructure which is going to cause adverse noise impacts, there can be an option to offer to acquire any affected properties.
F1 F2 F3	*Noise limits*	A cap on noise levels from one location received at another location, typically in the form of numerical noise limit values. Refer to Section 5.1 for further details.

D2 Noise control methods: Summary of advantages and disadvantages

Table 15 provides some key advantages and disadvantages of each noise limit derivation and regulatory approach.

Table 15: Advantage and disadvantages of each approach*

Method		Advantages	Disadvantages
A	Land use planning	Noise management based on (high level) consideration of different receiver sensitivities	There may not be enough land available for ideal land use planning at interfaces between zones. For example, ideal buffer between industrial and residential zones may not be realisable in practice.
B	Compensation to affected receivers	Shared financial benefit of the project.	Potentially costly and divisive
		Can allow a suitable internal amenity if building fabric is upgraded	Potential loss of amenity for neighbours irrespective of compensation received.
C	Compulsory acquisition of affected receivers	Prevents long term exposure to adverse noise impacts	Relocation of residents, additional cost

Method		Advantages	Disadvantages
D	Separation distance	Transparency and ease of understanding	No account of shielding or meteorological affects
		Simple to implement	Can result in inefficient use of resources
			May not cope well with changes in technology
			Limited or no incentive to use low noise technology
			Dispersed housing can make identifying appropriate sites difficult
E	Voluntary acquisition of affected receivers	Resident is provided with an option to relocate	Additional cost
			Residual impact on residents who chose not to move.
F1	Absolute noise limit	Easily derived	Doesn't take into account existing acoustic environment
F2	Relative noise limit	Takes into account existing acoustic environment	Requires a robust measurement procedure to establish representative ambient noise levels.
F3	Combination noise limit	Takes into account existing acoustic environment, provides a cap to limit continuing noise increase	See F2

* The extent of some of the advantages and disadvantages noted in the table will depend on the extent of control required by the relevant method. For example, the extent to which a separation distance may result in inefficient use of resources will depend on the magnitude of the setback or separation distance.

In relation to wind farms, as detailed in Table 16 in Appendix E, noise limits (F1, F2 & F3) are commonly encountered control methods in many jurisdictions. Alternatively methods of control such as acquisition (C, E) and setbacks (D) are much less commonly referenced in relation to wind farms.

APPENDIX E REVIEW OF WIND FARM NOISE REGULATIONS IN OTHER JURISDICTIONS

MARSHALL DAY Acoustics

t	Period[202]	Comment
	All	New South Wales, Queensland, Tasmania and Western Australia typically reference either South Australian wind farm noise guidance or the New Zealand standard on wind farm noise for assessments.
	All	
	All	
	Night	
	All	Site measurement of background level at receivers is not required. An assumed background level for wind speeds in the range 4-10m/s at 10m AGL is provided in the relevant Ministry guidelines, which state that the “[...] *wind induced background sound level reference* [values] ... *was determined by correlating the A-weighted ninetieth percentile sound level (L90) with the average wind speed measured at a particularly quiet site.*
	All	
	All	
	Night	
	Day	
	Night	Base limit varies depending on housing density in the receiving environment. The lower stated limit applies in an area with 1 - 8 dwellings, increasing to +3 dB for 9-160 dwellings and to +6 dB in noise affected areas with greater than 160 dwellings.
	Day	
	Night	
	Day	
	Night	
	Day	

i.

y related to the sound environment of a particular area”

ow ambient sound level, normally occurring only between 23:00 and 07:00 hours in Class 1 Areas, will typically be realizedas early

the urban hum

to frequent aircraft flyovers”

frequent aircraft flyovers”

t	Period[202]	Comment
	All	New South Wales, Queensland, Tasmania and Western Australia typically reference either South Australian wind farm noise guidance or the New Zealand standard on wind farm noise for assessments.
	All	
	All	
	Night	
	All	Site measurement of background level at receivers is not required. An assumed background level for wind speeds in the range 4-10m/s at 10m AGL is provided in the relevant Ministry guidelines, which state that the "[...] *wind induced background sound level reference* [values] ... *was determined by correlating the A-weighted ninetieth percentile sound level (L90) with the average wind speed measured at a particularly quiet site.*
	All	
	All	
	Night	
	Day	
	Night	Base limit varies depending on housing density in the receiving environment. The lower stated limit applies in an area with 1 - 8 dwellings, increasing to +3 dB for 9-160 dwellings and to +6 dB in noise affected areas with greater than 160 dwellings.
	Day	
	Night	
	Day	
	Night	
	Day	

;.

y related to the sound environment of a particular area"

ow ambient sound level, normally occurring only between 23:00 and 07:00 hours in Class 1 Areas, will typically be realizedas early

the urban hum

to frequent aircraft flyovers"

frequent aircraft flyovers"

t	Period[202]	Comment
	All	Limit applies at 6m/s at 10m AGL
-----	All	Limit applies at 8m/s at 10m AGL
	All	Limit applies at 6m/s at 10m AGL
-----	All	Limit applies at 8m/s at 10m AGL
	All Day Night	The relative thresholds inside dwellings apply across a range of single octave bands from 125 Hz to 4000 Hz. A minimum setback distance of 500m also applies[220].
	Day Night Day Night Day Night Day Night Day Night All	Germany does not have wind farm specific noise limit, and legislative noise limits for general noise sources apply. Peak limits also apply and the legislation states: *Individual short-term noise peaks may exceed binding immission values during the day by not more than 30 dB(A), and at night by not more than 20 dB(A).*
	All	Section 3.0 for further details.
ı)	All	

tutional, holiday home, camping or allotment purposes or areas designated in district plans or town planning regulations for noise-

·m), Joint Ministerial Gazette (GMBl) No. 26/1998, 26 August 1998, p. 503.

APPENDIX F EXAMPLE NOISE MODEL SUMMARY DETAILS

Table 17: noise model reference information

Item	Note
Sound power level data L_{WA} (dB)	2.3MW turbine

Octave Band Centre Frequency (Hz),									
31.5	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**	**Overall**
74.6	90.4	95.7	97.7	98.6	96.6	99.8	96.2	91.7	109.8

Item	Note
Sound power level data L_{WA} (dB)	3MW turbine

Octave Band Centre Frequency (Hz),									
31.5	**63**	**125**	**250**	**500**	**1000**	**2000**	**4000**	**8000**	**Overall**
83.1	95.7	95.6	103.2	104.9	101.7	102.3	95.4	85.9	105.8

Item	Note
Turbine wind speed	Nominally the wind speed of rated power

Turbine layout data

Setback example 1			Setback examples 2			Setback example 3		
X	**Y**	**Z (rel)***	**X**	**Y**	**Z (rel)***	**X**	**Y**	**Z (rel)***
700	0	100	700	0	100	700	0	100
			1200	0	100	1200	0	100
			1700	0	100	1700	0	100
			2200	0	100	2200	0	100
			2700	0	100	2700	0	100
			700	-300	100	700	-300	100
			1200	-300	100	1200	-300	100
			1700	-300	100	1700	-300	100
			2200	-300	100	2200	-300	100
			2700	-300	100	2700	-300	100
			500	350	100	500	350	100
			1000	350	100	1000	350	100
			1500	350	100	1500	350	100
			2000	350	100	2000	350	100
			2500	350	100	2500	350	100
			0	700	100	0	700	100
			500	700	100	500	700	100
			1000	700	100	1000	700	100
			1500	700	100	1500	700	100
			2000	700	100	2000	700	100

Receiver layout data	Setback example 1			Setback example 2			Setback example 3		
	X	Y	Z (rel)*	X	Y	Z (rel)*	X	Y	Z (rel)*
	0	0	1.5	-86	-33	1.5	-121	142	1.5
Prediction methodology	ISO 9613-2 1996 *Acoustics – Attenuation of sound during propagation outdoors –Part 2: General method for calculation* (ISO 9613-2:1996) implemented in SoundPLAN v7.2.								
Prediction input parameters	• Ground conditions – mixed ground characterised by a ground factor of G = 0.5 • Ground contours: Examples 1,2 – Flat ground Example 3 – Turbines are elevated relative to the receiver • Temperature – 10°C • Relative humidity – 70% • Source heights – 100m • Receiver heights - 1.5m AGL • Barrier effects – ISO 613-2:1996 Equation 12, Dz limited to no more than 20								

* relative heights express the height above ground level. Where ground contours are included in the noise prediction model, comparative heights between sources and receivers will vary.

APPENDIX G TENDER LITERATURE REVIEW DOCUMENTS

For informative purposed, brief comments are provided herein regarding each of the documents noted in Annex A of the *Request to Tender* documentation from SEAI[236].

Item	
1	Nissenbaum MA, Aramini JJ, Hanning CD (2012).Effects of industrial wind turbine noise on sleep and health. Noise Health;14:237-43 • Considers sleep and general health outcomes of people living close to wind turbines • A cross-sectional study involving two sites: Mars Hill (linear arrangement of 28 General Electric 1.5 megawatt turbines)and Vinalhaven (of three similar turbines sited on a low-lying, tree-covered island), Maine, USA. • A questionnaire was offered to all residents meeting the participant-inclusion criteria and living within 1.5 km of an industrial wind turbine (IWT) and to a random sample of residents, meeting participant inclusion criteria, living 3 to 7 km from an IWT between March and July of 2010. • Validated questionnaires were used to collect information on sleep quality (Pittsburgh Sleep Quality Index - PSQI), daytime sleepiness (Epworth Sleepiness Score - ESS), and general health (SF36v2), together with psychiatric disorders, attitude, and demographics. • Participants living within 1.4 km of an IWT had worse sleep, were sleepier during the day, and had worse SF36 Mental Component Scores compared to those living further than 1.4 km away. Significant dose-response relationships between PSQI, ESS, SF36 Mental Component Score, and log-distance to the nearest IWT were identified after controlling for gender, age, and household clustering. The adverse event reports of sleep disturbance and ill health by those living close to IWTs are supported.
2	Colby, WD.,.Dobie, R.; Leventhall, G.; Lipscomb, D.M.,. McCunney, R.J.,Seilo, Søndergaard, B.,(2009) Wind Turbine Sound and Health Effects, An Expert Panel Review. American Wind Energy Association and Canadian Wind Energy Association. • Considers health impacts of wind turbines • Study based on literature review • There is no evidence that the audible or sub-audible sounds emitted by wind turbines have any direct adverse physiological effects. • The ground-borne vibrations from wind turbines are too weak to be detected by, or to affect, humans. • The sounds emitted by wind turbines are not unique. There is no reason to believe, based on the levels and frequencies of the sounds and the panel's experience with sound exposures in occupational settings, that the sounds from wind turbines could plausibly have direct adverse health consequences

[236] It should be noted that the wider literature review included many more documents than the eight listed above. Refer to the Bibliography for a list of relevant literature.

3 IEA Task 28 relevant projects, http://www.socialacceptance.ch/WPrList.aspx?TR=E

Searched for 'abstract: noise' which identified the following documents:

A. Jeffrey M. Ellenbogen / Sheryl Grace / Wendy J Heiger-Bernays (Massachusetts Department of Environmental Protection), Wind Turbine Health Impact Study: Report of Independent Expert Panel January 2012, Prepared for: Massachusetts Department of Environmental Protection Massachusetts Department of Public Health

- Considers health impacts of wind turbines
- Study based on literature review
- There is limited evidence from epidemiologic studies suggesting an association between noise from wind turbines and sleep disruption.
- Whether annoyance from wind turbines leads to sleep issues or stress has not been sufficiently quantified. While not based on evidence of wind turbines, there is evidence that sleep disruption can adversely affect mood, cognitive functioning, and overall sense of health and well-being.
- There is insufficient evidence that the noise from wind turbines is directly (i.e., independent from an effect on annoyance or sleep) causing health problems or disease.

B. Delta, Low frequency noise from large wind turbines (Journal no. AV 1272/10, Project no. A401929, 21 November 2010)
http://www.madebydelta.com/delta/Business_units/TC/Services+by+technology/Acoustics/Low+frequency+noise/Low+frequency+noise+from+large+wind+turbines.page

- **Noise emission from wind turbines**
The emitted sound power from the wind turbines increases with the nominal power of the turbines. The increase in total A-weighted noise emission is slightly less than the increase in electrical power. In short, larger wind turbines are slightly quieter than smaller wind turbines, per kW of generated power.

- **Indoor noise levels at adjacent residences**
Calculation scenarios at the adjacent residences to wind turbines with determination of low frequency noise levels indoor have shown that the general differences between small and large wind turbines are small. For scenarios where the results for the total outdoor noise is close to the existing noise limits, the levels calculated for the indoor low frequency noise are close to the guidance limits applicable for industry in Denmark.

- **Annoyance from wind turbine noise**
Listening tests were carried out at the University of Salford. Here it was found that tones at lower frequencies in wind turbine noise was not perceived as more annoying than tones at higher frequencies when heard at the same prominence. This is a rather important result as when present, tones in noise from large wind turbines tend to occur at lower frequencies than for small wind turbines.

- **Infrasound**
A theoretical study from RISØ DTU together with the findings from the measurements on large wind turbines and a literature study, confirms that infrasound is imperceptible for this type of wind turbines. Even close to the wind turbines the sound pressure level is much below the normal hearing threshold. Thus infrasound is not considered a problem

C. Geoff Leventhal, *Infrasound From Wind Turbines – Fact, Fiction or Deception*, Canadian Acoustics Issue 29, Vol 34 no.2 (2006)

- A literature review with the following key findings:
  Infrasound from wind turbines is below the audible threshold and of no consequence.
  Low frequency noise is normally not a problem, except under conditions of unusually turbulent inflow air.
  The problem noise from wind turbines is the fluctuating swish

D. Eja Pedersen, Högskolan i Halmstad (Swedish EPA) , Noise annoyance from wind turbines a review (2013)

- Considers Noise annoyance from wind turbines
- Key findings include:
  Noise from wind turbines is not at all as well studied as for instance noise from road traffic. As the number of studies is low no general conclusions could be drawn. ...
  The reviewed studies above indicate that annoyance from wind turbine noise
  + Is to a degree correlated to noise exposure.
  + Occurs to a higher degree at low noise levels than noise annoyance from other sources of community noise such as traffic.
  +Is influenced by the turbines' visual impact on the landscape.
- It is also noted that wind turbine noise does not directly cause any physical health problems. There is not enough data to conclude if wind turbine noise could induce sleep disturbance or stress-related symptoms.
  Wind turbine noise is, due to its characteristics, not easily masked by background noise.
  Wind turbine noise is particularly poorly masked by background noise at certain topographical conditions.

E. EJA Pederson, Human response to wind turbine noise – perception, annoyance and moderating factors (Department of Public Health and Community Medicine, Göteborgs 2007)

- Considers noise annoyance from wind turbines
- Cross-sectional study carried out in a flat mainly rural area in Sweden. Examination of dose response relationship between wind turbine sound pressure levels and annoyance
- 513 surveys were collected with a response rate of 68%
- Key findings include:
  Dose response relationships were identified for perception and annoyance
  Risk of annoyance was enhanced by being able to see turbines and by resident living in as rural cf. Suburban area
  Noise was appraised as an intrusion to privacy
  Amplitude modulated sound was described as most annoying

4 UK institute of Acoustics relevant projects,http://www.ioa.org.uk/about-us/news-article.asp?id=260

Refer to comments about the IOA GPG throughout the body of this report.

5 Irish Wind Energy Association (2012) Noise Research Paper

This document was not retrievable online and has not been reviewed.

6	Hanning, CD.,Evans, A., (2012) British Medical Journal – Editorial and letter of response. Wind Turbine Noise, British Medical Journal Editorial. (Wind turbine noise Seems to affect health adversely and an independent review of evidence is needed Christopher D Hanning honorary consultant in sleep medicine 1, Alun Evans professor emeritus) • Considers sleep disturbance caused by wind turbine noise • Key findings *A large body of evidence now exists to suggest that wind turbines disturb sleep and impair health at distances and external noise levels that are permitted in most jurisdictions, including the United Kingdom. Sleep disturbance may be a particular problem in children, and it may have important implications for public health. When seeking to generate renewable energy through wind, governments must ensure that the public will not suffer harm from additional ambient noise. Robust independent research into the health effects of existing wind farms is long overdue, as is an independent review of existing evidence and guidance on acceptable noise levels.*
7	Referenced studies by Simon Chapman in his letter of response to the BMJ Editorial http://www.bmj.com/content/344/bmj.e1527/rr/572780 The following papers are referenced: A. Hanning CP, Evans A. Wind turbine noise. BMJ 2012;344:e1527 doi: 10.1136/bmj.e1527 (Published 8 March 2012) • See Item 6 of this table for comments. B. Chapman S, Simonetti T. Summary of main conclusions reached in 17 reviews of the research literature on wind farms and health. School of Public Health, University of Sydney. 30 Jan 2012 http://www.scribd.com/doc/79506148/Summary-of-main-conclusions-reached-in-17-reviews-of-the-research-literature-on-wind-farms-and-health • Key finding: insufficient evidence that the noise from wind turbines is directly causing health problems or diseases C. Chapman S, Simonetti T. Is there anything not caused by wind farms? A list of diseases and symptoms in humans and animals said to be caused by wind turbines. School of Public Health, University of Sydney. http://tobacco.health.usyd.edu.au/assets/pdfs/publications/WindfarmDiseases.pdf • Key finding: 216 difference diseases/symptoms claimed to be caused by exposure to wind turbine noise (intention to ridicule claims) D. Bartholomew RE, Wessely S. Protean nature of mass sociogenic illness: From possessed nuns to chemical and biological terrorism fears. Br J Psychiatry 2002 180: 300-306. http://bjp.rcpsych.org/content/180/4/300.full.pdf+html Issues considered • Considers mass sociogenic illness issues by way of literature review • Key finding: There has been a significant shift in the presentation of mass sociogenic illness E. Boss LP. Epidemic hysteria: a review of the published literature. Epidem Reviews 1997;19:233-243 • Literature review concerning reported instances of mass hysteria and mass psychogenic illness

F. Krogh CME. Industrial wind turbine development and loss of social justice. Bull Science, Technol and Society 2011;31:321-333.

- Argues that there has been a lack due diligence on the part of governments to investigate adverse health impacts of noise from wind turbines. In turn, the author contends that this demonstrates a failure to provide social justice.

---

8 **Submission by Simon Chapman to NSW Windfarm Guidance**

- Contends that *"...the sheer weight of evidence as adjudicated now in 17 separate reviews (see Appendix 1) underlines that claims that wind turbines can adversely affect health are not evidence-based."*
- Analysis and discussion addresses: Nina Pierpont and Wind turbine syndrome; Sarah Laurie, *Waubra Foundation;* Vibro-acoustic disease
- Also cites:

  Chapman S, Simonetti T. Summary of main conclusions reached in 17 reviews of the research literature on wind farms and health. School of Public Health, University of Sydney. 30 Jan 2012

  Chapman S, Simonetti T. Is there anything not caused by wind farms? A list of diseases and symptoms in humans and animals said to be caused by wind turbines. School of Public Health, University of Sydney.

APPENDIX H BIBLIOGRAPHY

Adcock, J., Bullmore, A. J., Jiggins, M., & Cand, M. (2007). Wind farm noise predictions – the risk of conservativsm. *Second International Meeting on Wind Turbine Noise.* Lyon: INCE.

Adcock, J., Bullmore, A., & Flindell, I. (2005). Balancing risks and uncertainties in environmental noise measurements. *Forum Acusticum 2005.* Budapest.

Alberola, J. (2004). *Predicting variability in environmental noise measurements (PhD thesis).* ISVR.

American Wind Energy Association. (2011). *Wind Energy Industry Manufacturing Supplier Handbook.* American Wind Energy Association.

Appeal Decision: Land to the south east of North Tawton and the south west of Bow, APP/Q1153/A/06/2017162 (2011).

Bass, J. (2011). Investigation of the 'Den Brook' amplitude modulation methodology for wind turbine noise. *Acoustics Bulletin*, pp. 18-24.

Bass, J. (2012, May). Response to Wind farms and the control of excess amplitude modulation (EAM) [Letter]. *Acoustics Bulletin*, p. 46.

Bass, J. H., Bullmore, A. J., & Sloth, E. (1998). *Development of a wind farm noise propagation prediction model. Final report Contract CEC/DTIJOR3-CT95-0051.*

Bass, J., Bowdler, R., McCaffery, M., & Grimes, G. (2011). Fundamental research into amplitude modulation - a project by RenewableUK. *Fourth International Meeting on Wind Turbine Noise.* Rome: INCE.

Berglund, B., & Lindvall, T. (1995). *Community noise.* Sweden: World Health Organisation.

Berglund, B., Lindvall, T., & Schwela, D. (1999). *Guidelines for community noise.* Geneva: World Health Organisation.

Bolin, K., Bluhm, G., Eriksson, G., & Nilsson, M. E. (2011). Infrasound and low frequency noise from wind turbines: Exposure and health effects. *Environmental Research Letters, 6*(035103). doi:10.1088/1748-9326/6/3/035103

Botha, P. (2005). The use of 10m wind speed measurements in teh assessment fo wind farm developments. *First International Meeting on Wind Turbine Noise.* Berlin: INCE Europe.

Bowdler, R., & Leventhall, G. (2011). *Wind turbine noise.* Brentwood: Multi-Science Publishing.

Bowdler, R., Bullmore, A. J., David, Hayes, M., Jiggins, M., Leventhall, G., & McKenzie, A. (2009). Prediction and assessment of wind turbine noise – agreement about relevant factors for noise assessment from wind energy projects. *Acoustics Bulletin, 34*(2).

Broner, N. (2011). A simple outdoor criterion for assessment of low frequency noise emission. *Acoustics Australia, 39*(1), pp. 7-14.

Bruel & Kjaer. (n.d.). *Sound, vibration, education 7: Audiology and psychoacoustics.* Retrieved October 17, 2013, from Bruel & Kjaer Web site: http://www.bksv.com/doc/sve/7.%20Audiology%20(0210).pdf

Bullmore, A. J., Adcock, J., Jiggins, M., & Cand, M. (2009). Wind farm noise predictions and comparison with measurements . *Third International Meeting on Wind Turbine Noise.* Aalborg: INCE.

Cand, M., Davis, R., Jordan, C., Hayes, M., & Perkins, R. (2013). *A good practice guide to the application of ETSU-R-97 for the assessment and rating of wind turbine noise.* St. Albans: Institute of Acoustics.

Casella Stanger. (2001). *Low frequency noise – Technical research support for DEFRA noise programme.* London: Department of Environment, Food & Rural Affairs (DEFRA) UK.

Colby, D., Dobie, R., Leventhall, G., lipscomb, D., McCunney, R., Seilo, M., & Sondergaard, B. (2009). *Wind turbine sound and health effects - An expert panel review.* American Wind Energy Association & Canadian Wind Energy Association.

Cooper, J., Evans, T., & Petersen, D. (2013). Tonality assessment at a residence near a wind farm. *Fifth International Meeting on Wind Turbine Noise.* Denver.

Crichton, F., Dodd, G., Schmid, G., Gamble, G., & Petrie, K. J. (2013). Can expectations produce symptoms from infrasound associated with wind turbines? *Health Psychology*. doi:10.1037/a0031760

Davis, R. A., & Lower, M. C. (1996). *Noise measurements in windy conditions (ETSU W/13/00386/REP)*. London: Department of Trade and Industry.

Delaire, C., Griffin, D., & Walsh, D. (2011). Comparison of predicted wind farm noise emission and measured post construction noise levels at the Portland Wind Energy Project in Victoria, Australia. *Third International Meeting on Wind Turbine Noise*. Rome: INCE.

Delarie, C., Griffin, D., Adcock, J., & McArdle, S. (2013). Widn farm noise commissioning methods: A review of methods based on measuring at receiver locations. *Fifth International Meeting on Wind Turbine Noise*. Denver.

Department of Health (Victoria). (2013). *Wind farms, sound and health - Technical information*. Melbourne: State Government of Victoria, Department of Health.

Deutsches Institut fur Normung. (1997, March). Deutsche Norm (DIN) 45680 Measurement and evaluation of low-frequency environmental noise. Berlin: Deutsches Institut fur Normung.

Doolan, C. (2011). Wind turbine noise mechanisms and some concepts for its control. *Acoustics 2011*. Gold Coast: Australian Acoustical Society.

Environment Protection Agency (Denmark). (2011, December 15). Statutory order on noise from wind turbines (Translation of Statutory order no. 1284(. Denmark.

Environment Protection Agency (Ireland). (2011). Guidance note on noise assessment fo wind turbine operations at EPA Licensed sites (NG3). County Wexford: Office of Environmental Enforcement (OEE).

Environment protection and heritage council. (2010). *National wind farm development guidelines - Draft July 2010*. Canberra: NEPC Service Corporation.

Evans, T., Cooper, J., & Lenchine, V. (2013). *Infrasound levels near wind farms and in other environments*. Adelaide: Environment Protection Authority (South Australia).

Evans, T., Cooper, J., & Lenchine, V. (2013). *Low frequency noise near wind farms and in other environments*. Adelaide: Environment Protection Authority (South Australia).

Fehily Timoney & Company. (2012). *Best Practice Guidelines for the Irish Wind Energy Industry*. Naas: Irish Wind Energy Association.

Gardner, P., Garrad, A., Jamieson, P., Snodin, H., & Tindal, A. (2003). Retrieved November 18, 2013, from European Wind Energy Association web site: https://www.google.com.au/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&ved=0CCsQFjAA&url=http%3A%2F%2Fwww.ewea.org%2Ffileadmin%2Fewea_documents%2Fdocuments%2Fpublications%2FWETF%2FFacts_Summary.pdf&ei=m5eKUpHfLeeZiQeqwoDQAw&usg=AFQjCNHbxlkVndSVtO06Oet

Griffin, D., Delaire, C., & Pischedda, P. (2013). Methods of identifying extraneous noise during unattended noise measurements. *20th International Congress of Sound & Vibration*. Bangkok.

Guidati, G., Bareiz, R., & Wagner, S. (1994). An investigation of blade-tower interaction (BTI) for horiztonal axis wind turbines in upwind and downwind configuration. First steps towards modelling of aeroelastic effects. *8th IEA Joint Action Symposium on Aerodynamics of Wind Turbines*. Lyngby.

Halstead, M., & Hunt, M. (2007). *Stakeholder Review & Technical Comments: NZS6808:1998 Acoustics - Assessment and measurement of sound from wind turbine generators*. Wellington: New Zealand Wind Energy Association and Energy Efficiency and Conservation Authority.

Haugen, K. M. (2011). *International Review of Policies and Recommendations for Wind Turbine Setbacks from Residences: Setbacks, Noise, Shadow Flicker, and Other Concerns*. Minnesota: Minnesota Department of Commerce: Energy Facility Permitting.

Hayes Mckenzie Partnership Ltd. (2006). *The measurement of low frequency noise at three UK wind farms (W/45/00656/00/00 06/1412).* London: Department of Trade and Industry.

Hessler, D., & Hessler, G. (2011). Recommended noise level design goals and limits at residential receptors for wind turbine developments in the United States. *Noise Control Engineering Journal, 59*(1), 94-104.

HGC Engineering. (2007). *Wind turbines and sound: Review and best practice guidelines.* Ottawa: Candian Wind Energy Association.

Hunerbein, S. V., King, A., Hargreaves, A., Moorhouse, A., & Plack, C. (2010). *Perception of noise from large wind turbines (EFP06 Project).* Manchester: The University of Salford.

Hunt, M. (2008). Criteria for sub 40dBA wind farm noise limits. *Proceedings of the XIXth biennial conference.* Auckland: New Zealand Acoustical Society.

International Electrotechnical Commission. (2005). IEC 60076-10:2005 Power transformers - Part 10: Determination of sound levels - Application guide. *1.0*. Geneva: International Electrotechnical Commission.

International Electrotechnical Commission. (2006). IEC61400-11:2006 Wind turbine generator systems - Part 11: Acoustic noise measurement techniques. *2.1*. Geneva, Switzerland: International Electrotechnical Commission.

International Electrotechnical Commission. (2012). IEC61400-11:2012 Wind turbine generator systems - Part 11: Acoustic noise measurement techniques. *3.0*. Geneva, Switzerland.

International Organisation of Standardisation. (1995). ISO 7196:1995 Acoustics - Frequency-weighting characteristics for infrasound measurements. Geneva, Switzerland: International Organisation of Standardisation.

International Organisation of Standardisation. (2003). ISO 226:2003 Acoustics - Normal equal-loudness-level contours. International Organisation of Standardisation.

International Standards Organisation. (1993). ISO 9613-1:1993 Acoustics - Attenuation of sound during propagation outdoors - Part 1: Calculation of the absorption of sound by the atmosphere. Geneva, Switzerland: International Standards Organisation.

International Standards Organisation. (1996). ISO 9613-2:1996 Acoustics - Attenuation of sound during propagation outdoors - Part 2: General method of calculation. Geneva: International Standards Organisation.

International Standards Organisation. (1996). ISO1996-1:2003 Acoustics - Description, measurement and assessment of environmental noise - Part 1: Basic quantities and assessment procedures. Geneva: International Standards Organisation.

International Standards Organisation. (2007). ISO1996-2:2007 Acoustics - Description, measurement and assessment of environmental noise - Part 2: Determination of environmental noise levels. Geneva, Switzerland: International Standards Organisation.

Jakobsen, J. (2001). Danish guidelines on environmental low frequency noise, infrasound and vibration. *Journal of low frequeny noise, vibration and active control, 20*(3), 141-148.

Jung, S. S., Cheong, C., Shin, S. H., & Chueng, W.-S. (2008). Experimental Identification of Acoustic Emission Characteristics of Large Wind Turbines with Emphasis on Infrasound and Low-Frequency Noise. *Journal of the Korean Physical Society, 53*(4), 1897-1905.

Kramers, R. (2008). *Do the right things II/III Step-by-step guidance book for planning of environmental inspections.* Brussels: Euorpean Union Network for the implementation and enforcement of environmental law (IMPEL).

Leventhall, G. (2004). *Notes on low frequency noise from wind turbines with special reference to the Genesis Power Ltd proposal, near Waiuku NZ.* Auckland: Genesis Power & Hegley Acoustic Consultants.

Leventhall, G. (2013, July). Concerns about infrasound from wind turbines. *Acoustics Today, 9*(3), pp. 30-38.

Leventhall, G. (2013). Infrasound and the ear. *Fifth International Meeting on Wind Turbine Noise.* Denver.

Ljunggren, S. (1997). *Expert group study on recommended practices for wind turbine testing: 10. Measurement of noise immission from wind turbines at noise receptor locations.* Stockholm: International Agency Programme for Research and Development on Wind Energy Conversion Systems.

Lundmark, G. (2011). Measurement of swish noise. A new method. *Fourth International Meeting on Wind Turbine Noise.* Rome: INCE.

Madsen, K. D., & Pedersen, T. H. (2010). *EFP-06 Project Low frequency noise from large wind turbines - Final report (AV 1272/10).* Delta Acoustics & Electronics.

Marshall Day Acoustics Pty Ltd. (2012, June 1). Retrieved October 8, 2013, from Hepburn Wind Web site: http://hepburnwind.com.au/downloads/Rp003%20R01%202011014ML%20-%20Hepburn%20Community%20Wind%20Farm%20-%20Post-construction%20noise%20assessment.pdf

McCabe, J. N. (2011). Detection and quantification of amplitude modulation in wind turbine noise. *Fourth International Meeting on Wind Turbine Noise.* Rome: INCE.

Moller, H., & Pedersen, C. S. (2011). Low frequency noise from large wind turbines. *Journal of the Acoustical Society of America, 129*(6), 3727-3744.

Moorhouse, A., Hayes, M., von Hunerbein, S., Piper, B., & Adams, M. (2007). *NANR223 Research into aerodynamic modulation of wind turbine noise: Final report.* London: Department of Environment, Food & Rural Affairs (DEFRA) UK.

Moorhouse, A., Waddington, D., & Adams, M. (2005). *Proposed criteria for the assessment of low frequency noise disturbance (NANR45).* London: Department of Environment, Food & Rural Affairs (DEFRA) UK.

National Health and Medical Research Council. (2010). *Wind turbines and health - A rapid review of the evidence.* Australian Government National Health and Medical Research Council.

National Institute of Deafness and other Communication Disorders (USA). (n.d.). *Common sounds.* Retrieved October 17, 2013, from National Institute of Deafness and other Communication Disorders Web site: http://www.nidcd.nih.gov/staticresources/health/education/teachers/CommonSounds.pdf

Nissenbaum, M. A., Aramini, J. J., & Hanning, C. D. (2012). Effects of industrial wind turbine noise on sleep and health. *Noise Health, 14*(60), 237-243. doi:10.4103/1463-1741.102961.

NSW Department of Planning and Infrastructure. (2011). *NSW planning guidelines: Wind farms (Draft for consultation).* Sydney: NSW Department of Planning and Infrastructure.

Oerlemans, S. (2009). *Detection of aeroacoustic sound sources on aircraft and wind turbines.* The Netherlands: University of Twente.

Oerlemans, S., Sijtsma, P., & Mendez-Lopez, B. (2007). Location and quantification of noise sources on a wind turbine. *Journal of Sound and Vibration, 299*(4-5), 869-883.

Ontario Ministry of Environment. (2008). *Noise Guidelines for Wind Farms: Interpretation for Applying MOE NPC Publications to Wind Power Generation Facilities.* Toronto: Queens Printer for Ontario.

Ontario Ministry of the Environment. (2009). *Development of Noise Setbacks for Wind Farms Requirements for Compliance with MOE Noise Limits.* Toronto: Ontario Ministry of the Environment.

Pedersen, E., & Larsman, P. (2008). The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines. *Journal of Environmental Psychology, 28.*

Pedersen, E., van den Berg, F., Bakker, R., & Bouma, J. (2009). Response to noise from modern wind farms in The Netherlands. *Journal of the Acoustical Society of America, 126*(2), 634-643.

Pedersen, T., Sondergaard, M., & Andersen, B. (1999). *Objective method for assessing the audibility of tones in noise: Joint Nordic method - Version 2 [AV1952/99].* Delta.

Pierpont, N. (2010). *Wind turbine syndrome: A report on a natural experiment.* K-selected books.

Plovsing, B. (2007). *Proposal for Nordtest Method: Nord2000 – Prediction of Outdoor Sound Propagation.* Delta Acoustics & Electronics.

Probst, F., Probst, W., & Huber, B. (2013). Large-scale calculation of possible locations for specific wind turbines under consideration of noise limits. *Fifth International Meeting on Wind Turbine Noise.* Denver.

Salt, A., & Lichtenhan, J. (2011). Responses of the inner ear to infrasound. *Fourth International Meeting on Wind Turbine Noise.* Rome: INCE.

Snow, D. J. (1997). *Low frequency noise and vibrations measuremetn at a modern wind farm (ETSU W/13/00392/REP).* London: Department of Trade and Industry.

Sondergaard, B., & Plovsing, B. (2009). *AV 1236/09 Validation of the Nord2000 propagation model for use on wind turbine noise.* Delta Acoustics & Electronics.

Sondergaard, L., & Pedersen, T. (2013). Tonality in wind turbine noise. IEC 61400-11 ver. 2.1 and 3.0 and the Danish/Joint Nordic method compared with listening tests. *Fifth International Meeting on Wind Turbine Noise.* Denver.

Sondergaard, L., & Sondergaard, B. (2008). *EFP-06 Project Low frequency noise from large wind turbines: Background noise measurement and evaluation (AV138/08).* Copenhagen: Delta Acoustics & Electronics.

Sonus Pty Ltd. (2010). *Infrasound measurements from wind farms and other sources.* Melbourne: Pacific Hydro. Retrieved from http://www.pacifichydro.com.au/media/192017/infrasound_report.pdf

South Australia Environment Protection Authority. (2009). Wind farms environmental guidelines. Adelaide: South Australia Environment Protection Authority.

Standards Australia. (1997). AS1055-1:1997 Acoustics - Description and measurement of environmental noise - General procedures. Standards Australia.

Standards Australia. (2010). AS 4959:2010 Acoustics - Measurement, prediction and assessment of noise from wind turbine generators. Sydney: Standards Australia.

Standards New Zealand. (1998). NZS6808: 1998 Acoustics - the assessment and measurement of sound from wind turbine generators. Standards New Zealand.

Standards New Zealand. (2010). NZS6808:2010 Acoustics - wind farm noise. Wellington: Standards New Zealand.

Stigwood, M. (2012, May). Wind farms and the control of excess amplitude modulation (EAM) [Letter]. *Acoustics Bulletin*, p. 46.

Stigwood, M., Large, S., & Stigwood, D. (2013). Audible amplitude modulation - Results of field measurements and investigations compared to psyco-acoustical assessment and theoretical research. *Fifth International Meeting on Wind Turbine Noise.* Denver.

Styles, P., Stimpson, I., Toon, S., England, R., & Wright, M. (2005). *Microsiesmic and infrasound monitoring of low frequency noise and vibrations from wind farms.* Keele: Keele University.

Tararua District Council and Masterton District Council. (2013, April 19). Castle Hill Wind Farm Land use consents. New Zealand: Tararua District Council and Masterton District Council. Retrieved November 18, 2013, from https://www.genesisenergy.co.nz/documents/10314/73728/CHWF+Masterton+%26+Tararua+District+Council+resource+consents.pdf/cf714d30-909b-400b-9dbe-594576046b3f

Tasmania Department of Primary Industries, Water and Environment. (2004). Noise measurement procedures manual. Hobart: Tasmania Department of Primary Industries, Water and Environment.

Technical Committee Grundlagen der Schallmessung/-bewertung. (1997). DIN 45680:1997 Measurement and evaluation of low-frequency environmental noise. Deutsche Norm.

The independent advisory group on non-ionising radiation. (2010). *Health effects of exposure to ulstrasound and infrasound.* London: Health Protection Agency.

The Working Group on Noise from Wind Turbines. (1996). *The assessment and rating of noise from wind farms (ETSU-R-97).* London: Department of Trade and Industry.

van den Berg, G. P. (2004). Effects of the wind profile at night on wind turbine sound. *Journal of sound and vibration, 277*, 955-970. doi:10.1016/j.jsv.2003.09.050

van den Berg, G. P. (2010). Rating of wind turbine noise using Lden. *Internoise*. Lisbon.

Victoria Department of Planning and Community Development. (2012). *Policy and planning guidelines for development of wind energy facilities in Victoria.* Melbourne: Victoria Department of Planning and Community Development. Retrieved from http://www.dpcd.vic.gov.au/__data/assets/pdf_file/0016/112750/Policy-and-planning-guidelines-for-development-of-wind-energy-facilities-in-Victoria-July-2012.pdf

Voklijk, D., & Dijkstra, M. (2011). 500MW on-shore wind part "NOP" the Netherlands. *Fourth International Meeting on Wind Turbine Noise.* Rome: INCE.

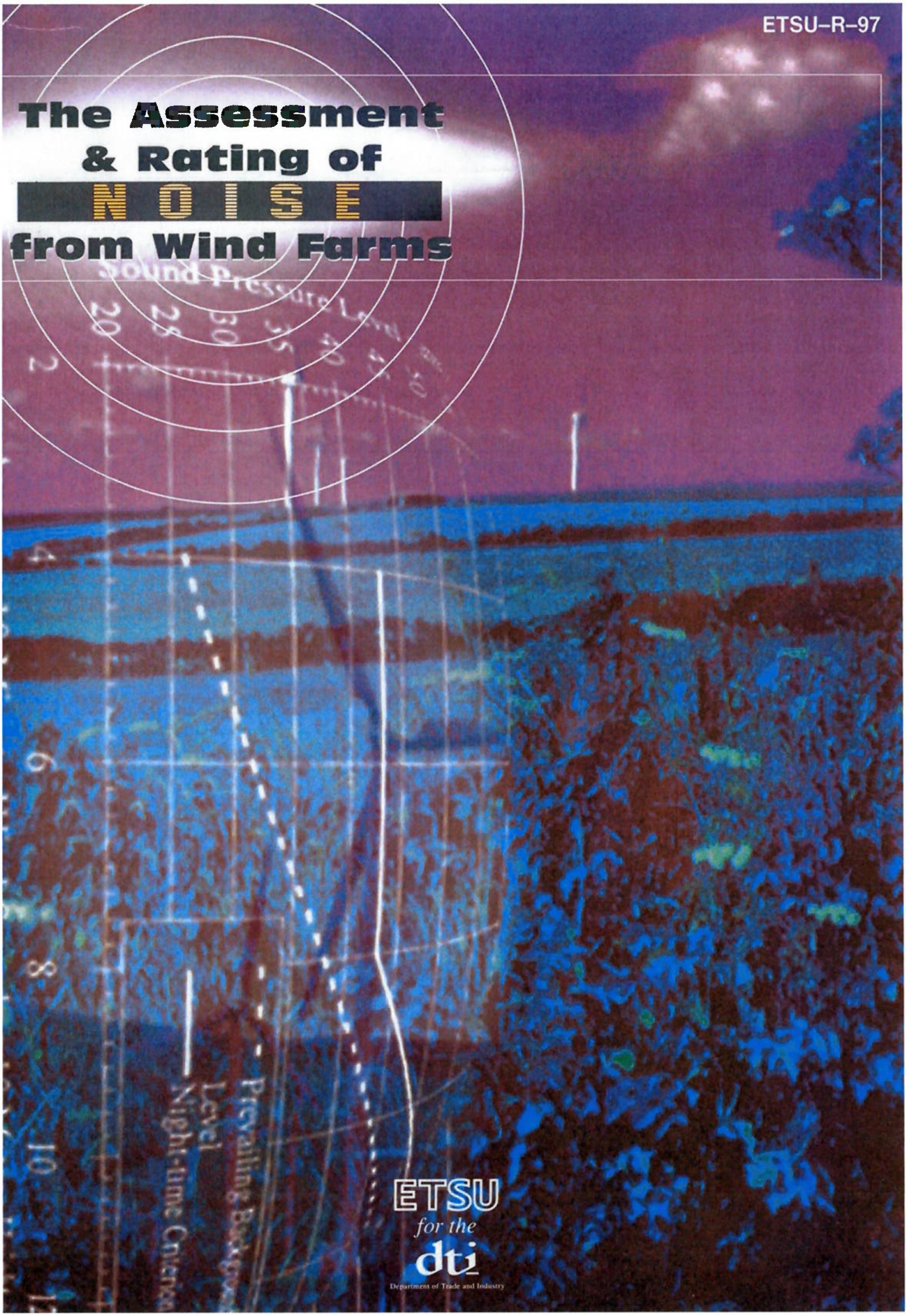
Waters-Fuller, T., MacKenzie, R., MacKenzie, R., & Lurcock, D. (2007). *NANR116: Open/closed window research: Sound insulation through ventilated domestic windows.* London: Department of Environment, Food & Rural Affairs (DEFRA) UK.

Watson, I., Betts, S., & Rapaport, E. (2011). Determining appropriate wind turbine setback distances: Perspectives from municipal planners in the Canadian provinces of Nova Scotia, Ontario and Quebec. *Energy Policy*. doi:10.1016/j.enpol.2011.11.046

Zwicker, E., & Fastl, H. (2010). *Psychoacoustics: Facts and models* (3 ed.). Springer.

ETSU-R-97

The Assessment & Rating of NOISE from Wind Farms



ETSU

for the

dti

Department of Trade and Industry

ETSU-R-97

THE ASSESSMENT AND RATING OF NOISE FROM WIND FARMS

The Working Group on Noise from Wind Turbines

Final Report
September 1996

PREFACE

This report describes the findings of a Working Group on Wind Turbine Noise. The aim of the Working Group was to provide information and advice to developers and planners on the environmental assessment of noise from wind turbines. While the DTI facilitated the establishment of this Noise Working Group this report is not a report of Government and should not be thought of in any way as replacing the advice contained within relevant Government guidance.

The report represents the consensus view of the group of experts listed below who between them have a breadth and depth of experience in assessing and controlling the environmental impact of noise from wind farms. This consensus view has been arrived at through negotiation and compromise and in recognition of the value of achieving a common approach to the assessment of noise from wind turbines.

Members of the Noise Working Group:

Mr R Meir, Chairman	DTI
Dr M L Legerton, Secretary	ETSU
Dr M B Anderson	Renewable Energy Systems
Mr B Berry	National Physical Laboratory
Dr A Bullmore	Hoare Lea and Partners
Mr M Hayes	The Hayes McKenzie Partnership
Mr M Jiggins	Carrick District Council
Mr E Leeming	The Natural Power Company Ltd
Dr P Musgrove	National Wind Power Ltd
Mr D J Spode	North Cornwall District Council
Mr H A Thomas	Isle of Anglesey County Council
Ms E Tomalin	EcoGen Ltd
Mr M Trinick	Bond Pearce Solicitors
Dr J Warren	National Wind Power Ltd

EXECUTIVE SUMMARY

INTRODUCTION

1. This document describes a framework for the measurement of wind farm noise and gives indicative noise levels thought to offer a reasonable degree of protection to wind farm neighbours, without placing unreasonable restrictions on wind farm development or adding unduly to the costs and administrative burdens on wind farm developers or local authorities. The suggested noise limits and their reasonableness have been evaluated with regard to regulating the development of wind energy in the public interest. They have been presented in a manner that makes them a suitable basis for noise-related planning conditions or covenants within an agreement between a developer of a wind farm and the local authority.

2. The noise limits suggested have been derived with reference to:

- existing standards and guidance relating to noise emissions
- the need of society for renewable energy sources to reduce the emission of pollutants in pursuance of Government energy policy
- the ability of manufacturers and developers to meet these noise limits
- the researches of the Noise Working Group in the UK, Denmark, Holland and Germany
- the professional experience of members of the Working Group in regulating noise emissions from wind turbines and other noise sources
- the discussion of the issues at meetings of the Noise Working Group and with others with appropriate experience.

3. The Noise Working Group has sought to protect both the internal and external amenity of the wind farm neighbour. Wind farms are usually sited in the more rural areas of the UK where enjoyment of the external environment can be as important as the environment within the home.

4. The guidance contained within this report refers to the operation of the wind farm and is not appropriate to the construction phase.

NOISE LIMITS

5. The Noise Working Group recommends that the current practice on controlling wind farm noise by the application of noise limits at the nearest noise-sensitive properties is the most appropriate approach. This approach has the advantage that the limits can directly reflect the existing environment at the nearest properties and the impact that the wind farm may have on this environment.

6. Given that one of the aims of imposing noise limits is to protect the internal environment, one might consider it appropriate to set these limits and hence monitoring locations at positions within the building. There are, however, some practicalities to take into consideration which lead us to believe that the current practice of setting external limits on noise is the more sensible approach; these factors are described in detail in Chapter 6 of the full report.

7. The noise limits applied to protect the external amenity should only apply to those areas of the property which are frequently used for relaxation or activities for which a quiet environment is highly desirable.

8. The Noise Working Group considers that absolute noise limits applied at all wind speeds are not suited to wind farms in typical UK locations and that limits set relative to the background noise are more appropriate in the majority of cases.

9. Only by measuring the background noise over a range of wind speeds will it be possible to evaluate the impact of turbine noise, which also varies with wind speed, on the local environment.

10. The Noise Working Group is of the opinion that one should only seek to place limits on noise over a range of wind speeds up to 12m/s when measured at 10m height on the wind farm site. There are four reasons for restricting the noise limits to this range of wind speed:

- Wind speeds are not often measured at wind speeds greater than 12m/s at 10m height
- Reliable measurements of background noise levels and turbine noise will be difficult to make in high winds
- Turbine manufacturers are unlikely to be able to provide information on sound power levels at such high wind speeds for similar reasons
- If a wind farm meets noise limits at wind speeds lower than 12m/s it is most unlikely to cause any greater loss of amenity at higher wind speeds

11. The recommendation of the Noise Working Group is that, generally, the noise limits should be set relative to the existing background noise at nearest noise-sensitive properties and that the limits should reflect the variation in both turbine source noise and background noise with wind speed. We have also considered whether the low noise limits which this could imply in particularly quiet areas are appropriate and have concluded that it is not necessary to use a margin above background approach in such low-noise environments. This would be unduly restrictive on developments which are recognised as having wider national and global benefits. Such low limits are, in any event, not necessary in order to offer a reasonable degree of protection to the wind farm neighbour.

12. Separate noise limits should apply for day-time and for night-time. The reason for this is that during the night the protection of external amenity becomes less important and the emphasis should be on preventing sleep disturbance. Day-time noise limits will be derived

from background noise data taken during quiet periods of the day and similarly the night-time limits will be derived from background noise data collected during the night.

Quiet day-time periods are defined as:

All evenings from 6pm to 11pm,
plus Saturday afternoon from 1pm to 6pm,
plus all day Sunday, 7am to 6pm.

Night-time is defined as 11pm to 7am.

13. Consideration has also be given to circumstances where a more simplified approach, based on a fixed limit, may be appropriate.

14. The Noise Working Group is agreed that the $L_{A90,10min}$ descriptor should be used for both the background noise and the wind farm noise, and that when setting limits it should be borne in mind that the $L_{A90,10min}$ of the wind farm is likely to be about 1.5-2.5dB(A) less than the L_{Aeq} measured over the same period. The use of the $L_{A90,10min}$ descriptor for wind farm noise allows reliable measurements to be made without corruption from relatively loud, transitory noise events from other sources.

15. The limits to be proposed relate to free-field (except for ground reflections) measurements in the vicinity of noise-sensitive properties.

16. The Noise Working Group is of the opinion that absolute noise limits and margins above background should relate to the cumulative effect of all wind turbines in the area contributing to the noise received at the properties in question. It is clearly unreasonable to suggest that, because a wind farm has been constructed in the vicinity in the past which resulted in increased noise levels at some properties, the residents of those properties are now able to tolerate higher noise levels still. The existing wind farm should not be considered as part of the prevailing background noise.

17. Wind turbines operate day and night dependent upon wind speeds. It will be necessary to acquire background noise data for both day- and night-time periods because:

- the absolute lower limit is likely to be different for day- and night-time operation
- the noise limits are to be related to the background noise levels
- background noise levels may be different in the day than during the night.

18. It is proposed that the background noise levels upon which limits are based and the noise limits themselves are based upon typical rather than extreme values at any given wind speed. An approach based upon extreme values would be difficult to implement as the difference in measurements between turbine noise and background would depend upon the length of time one is prepared to take data. A more sensible approach is to base limits upon typical or average levels but to appreciate that both turbine and background noise levels can vary over several dB for the same nominal conditions.

19. The variation in background noise level with wind speed will be determined by correlating $L_{A90,10min}$ noise measurements taken over a period of time with the average wind speeds measured over the same 10-minute periods and then fitting a curve to these data.

20. The wind farm noise limits proposed below refer to rating levels in a similar manner to that proposed in BS 4142 in respect that additions are made to the measured noise to reflect the character of the noise.

21. Noise from the wind farm should be limited to 5dB(A) above background for both day- and night-time (with the exception of the lower limits and simplified method described below), remembering that the background level of each period may be different.

22. In low noise environments the day-time level of the $L_{A90,10min}$ of the wind farm noise should be limited to an absolute level within the range of 35-40dB(A). The actual value chosen within this range should depend upon a number of factors:

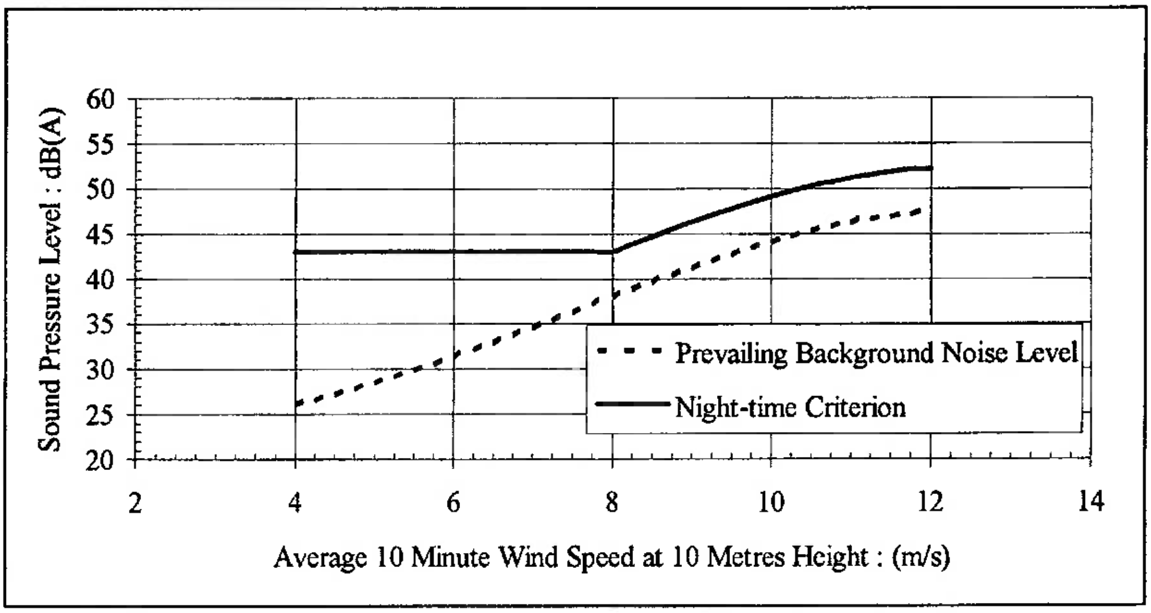
- the number of dwellings in the neighbourhood of the wind farm
- the effect of noise limits on the number of kWh generated
- the duration and level of exposure.

23. The Noise Working Group recommends that the fixed limit for night-time is 43dB(A). This limit is derived from the 35dB(A) sleep disturbance criteria referred to in Planning Policy Guidance Note 24 (PPG 24). An allowance of 10dB(A) has been made for attenuation through an open window (free-field to internal) and 2dB subtracted to account for the use of $L_{A90,10min}$ rather than $L_{Aeq,10min}$.

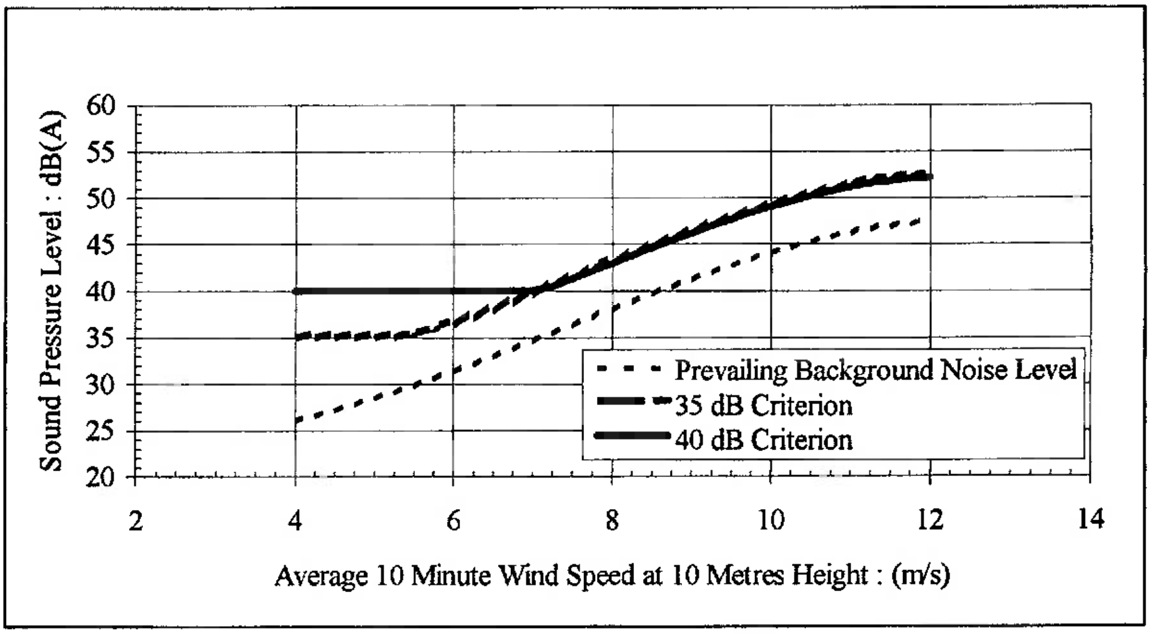
24. The Noise Working Group recommends that both day- and night-time lower fixed limits can be increased to 45dB(A) and that consideration should be given to increasing the permissible margin above background where the occupier of the property has some financial involvement in the wind farm.

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

26. Graphical representations of the recommended limits appear in the figures overleaf based upon a fairly typical background noise curve. Both background levels and turbine noise are determined by best-fit curves through representative data.



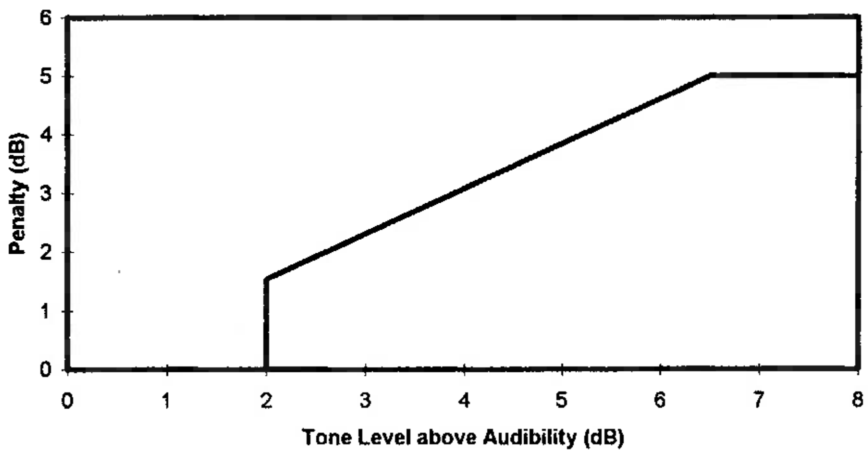
Example of night-time noise criterion



Example of day-time noise criterion

27. The noise levels recommended in this report take into account the character of noise described as blade swish. Given that all wind turbines exhibit blade swish to a certain extent we feel this is a common-sense approach given the current level of knowledge.

28. The Noise Working Group recommends that a tonal penalty is added to the measured noise levels in accordance with the figure below. The penalty incurred is related to the audibility of any tones produced by the wind turbines when measured using a prescribed method as represented graphically below.



Penalties for tonal noise

29. The Noise Working Group thought that it would be beneficial to present its recommendations in a form which might be useful to developers and planners. We therefore considered drafting planning conditions, but came to the conclusion that the necessary definitions of terms which would be required would make planning conditions too complicated. Therefore, it was decided to produce covenants for inclusion within an Agreement between a developer and a local authority. Conditions and Agreements (known as Planning Obligations) are discussed in Chapter 2. The Planning Obligation produced by the Noise Working Group is reproduced in Chapter 8 where it is supplemented by some Guidance Notes to which it refers. These Guidance Notes also serve as a useful summary of the proposed measurement procedure.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

A Planning Policy Guidance Note on Renewable Energy, PPG 22 [1], was published by the Department of the Environment and the Welsh Office on 3 February 1993. PPG 22 contains an Annex on Wind Energy which includes some discussion on noise from wind turbines. This annex includes a description of the sources of noise from wind turbines, a discussion on the limitations on the use of BS 4142: 1990, "Method for rating industrial noise affecting mixed residential and industrial areas" [2], and advice on noise-related information that could usefully accompany a planning application. At the time of writing there was insufficient relevant experience of noise from wind farms in the UK environment and public reaction to the noise to be able to provide more specific guidance.

A literal interpretation of how BS 4142 should be applied to wind turbine noise assessment is difficult and its use may be inappropriate and problematical. These difficulties are discussed in Chapter 6 of this report.

With no generally agreed procedure for determining noise levels that provide acceptable protection to the amenity of local residents, planners and developers have been required to use their own experiences to bring forward workable solutions by reference to the particular character and sensitivity of the area. Many wind farms, though not all, have had conditions relating to noise levels from the wind farm specified in the planning consents. These have varied in noise level and measurement units (eg L_{A90} or L_{A50}) from site to site but generally fall in to two classes: either an absolute noise level which shall not be exceeded at the nearest residences or a margin above the existing background noise which shall not be exceeded.

It was, however, recognised that there was still a degree of uncertainty among planners and developers. Planners did not have much experience of noise from wind turbines in rural areas. Developers had no noise targets for guidance when selecting sites for wind farms or deciding upon turbine layout. Therefore, in August 1993, the DTI facilitated the establishment of a Working Group on Noise from Wind Turbines, consisting of experts with experience in the environmental assessment of noise from wind turbines. The objectives of the Noise Working Group were:

- To review recent experience in the field of wind turbine noise. This was to include an attempt to relate measured data to complaints and provide an expert assessment of the issues relating to wind turbine noise.
- To define a framework which can be used to measure and rate the noise from wind turbines. This was to include parameters to be measured, measurement methods, units and measurement periods and was to fulfil all the necessary criteria required for planning conditions or covenants within Planning Conditions.
- To provide indicative noise levels thought to offer a reasonable degree of protection to wind farm neighbours and encourage best practice in turbine design and wind farm siting and layout.
- To encourage the widespread adoption of the Working Group's recommendations.

The Working Group was asked to address the issues of broadband noise, tonal content and blade swish (the modulation of broadband noise at blade passing frequency). The following report describes the findings and recommendations of the Noise Working Group. These recommendations are intended to serve as an informative guide to assessing the environmental impact of the noise from wind turbines.

The report was drafted in the light of the best information available at the time. However it is acknowledged that as more experience and information become available and as circumstances develop it may become necessary to revise and improve the contents of this report. The Noise Working Group therefore suggests this report and its recommendations are reviewed in two years time. To this end, any comments on the usefulness of the report would be most welcome, including any suggestions for improvement with any supporting evidence where possible. Any such suggestions should be sent to the Noise Working Group Secretariat at the following address:

Noise Working Group Secretariat
c/o Dr M L Legerton
ETSU
Harwell
Didcot
Oxfordshire OX11 0RA

2. THE PHILOSOPHY AND PRACTICE OF NOISE EMISSION CONTROL

Introduction

The way in which a society controls man-made noise sources reflects a variety of complex influences. These influences are social, economic, intellectual and political. They also reflect the limits of technical ability in the measurement of the noise source in question.

That the position is complex is reflected by the way in which those in the UK who live close to wind farms have reacted to noise generated by the wind turbines. An individual's reaction to the receipt of noise may reflect, at the same time, physical sensitivity to noise, local political attitudes to wind turbines, perceptions of the economic worth of wind energy generation, attitudes to wind energy development and development in the countryside, and the individual's own perception of wind turbines.

These complexities are not unique to the UK. Attitudes to noise emissions vary between and throughout all countries. However, certain patterns emerge both within Europe and within the UK. From the researches of the Working Party it seems that attitudes towards noise emissions, particularly with regard to wind turbines, are generally more rigorous in the northern countries of Europe where the most extensive deployment of wind turbines has taken place. In particular, Swedish and Dutch attitudes to the control of noise from wind turbines are strict, and the same could probably be said of the UK. Again, in Denmark there is a Statutory Order which specifically regulates noise from wind turbines, although perhaps less strictly than in Holland.

History of noise emission control in the UK

Modern noise control in the UK derives in spirit from the Wilson Report of 1964 [3]. One of the fundamental findings of the Wilson Report was that as a guiding principle noise regulation authorities should seek to control existing ambient noise at current levels. The existing noise environment should be maintained. This principle can be seen in DOE Circular 10/73 [4], now withdrawn in England in favour of Planning Policy Guidance: Planning and Noise, PPG 24, [5] issued in September 1994.

There can be little surprise at the findings of the Wilson Report or at the way it became transmitted into formal Government advice. The UK is relatively densely populated. Intensive and extensive developments in and adjoining towns and cities have over the years produced ambient noise levels much higher than might be desirable by any objective standard. At the same time, perhaps because of noise-generating development in towns and cities, those able to do so have sought the peace and quiet of the countryside for their leisure time. They have become commuters. It is to be expected that such persons will be exceptionally sensitive to any intrusions on the peace and quiet which they have obtained by moving to live in the countryside, whatever the reasons for the noise-generating activity which may prove to be such an intrusion.

Given the findings of the Wilson Report, and the advice in DOE Circular 10/73, it was logical that control of new noise emissions should have developed on the basis of a level of exceedence over the background noise level existing prior to the introduction of the new noise source. This approach is reflected in a well known advisory document on noise control, BS 4142. BS 4142 was first issued in 1967 and was most recently reissued in revised form in 1990. At the date of this report a further revision is in train.

PPG 24 and other advisory documents which include BS 4142: 1990 seek to control the noise environment by limits on the levels by which new development may cause the background noise level to be exceeded. However, there is a recognition that new development must take place because of the needs of the economy and of society. The aim of the guidance contained within PPG 24, as stated in the opening paragraph, is:

> *"..... to provide advice on how the planning system can be used to minimise the adverse impact of noise without placing unreasonable restrictions on development or adding unduly to the costs and administrative burdens of business."*

In the context of wind energy, the planning system must therefore seek to control the environmental impact from wind farms whilst at the same time recognising the national and global benefits that will arise through the development of renewable energy sources, and not be so severe that wind farm development is unduly stifled.

Special considerations are given to some types of development, such as road, rail and airport developments where the balance advised in PPG 24 is particularly difficult to achieve. In recognition that such developments must take place, but that they will cause significant changes to the noise environment of neighbours, a statutory compensation code has been developed. The statutory framework for this code is within the Land Compensation Act 1973. Developments covered by this Act possess a statutory immunity from action by regulatory authorities or by citizens who feel aggrieved at the noise created. Instead, citizens can claim compensation under the Act. The provisions of the Land Compensation Act 1973 do not apply to anything other than the sort of infrastructural development recorded in the previous paragraph.

The Government and planning authorities have also had to produce advisory standards for noise-generating developments which in the interests of the economy, society, and indeed the environment must take place. An example of a form of development falling into this category is mineral exploitation. Specific advice on noise emissions from mineral operations is contained in Mineral Planning Guidance Note 11 [6]. It is perhaps no coincidence that the Mineral Planning Guidance Notes issued by the Secretaries of State form an entirely separate body of advice from general Planning Policy Guidance Notes. Minerals are recognised in a variety of ways, not least noise emissions, to be a special case. Society requires a variety of minerals, and there is an inevitable environmental cost in their extraction and distribution.

Turning to wind energy, the Government has advised in a variety of documents, most recently Planning Policy Guidance Note 22 (February 1993) [1] and DTI Energy Paper 62 (March 1994) [7], that its policy is to encourage the exploitation of renewable energy resources in appropriate circumstances. The reasons for this advice relate to the need to promote a diversity of energy resources and to assist in meeting the UK's international environmental obligations. The Government's policy towards renewable energy development has been evidenced in the case of wind by over 30 planning permissions for wind farms, with many more planning permissions for single wind turbines. These developments have been permitted in rural areas where more established forms of development, except perhaps for mineral extraction, would be unlikely to be permitted.

No development is without an external cost. The external cost of wind energy generation derives mainly from the visual effect of the turbines, and such noise emissions that impact to any degree on those who live and work nearby.

Methods of noise control in the UK

While the Wilson Report was issued over 30 years ago, the emergence of noise emissions as a core environmental concern is relatively recent. While quite separate law relating to statutory nuisance derives from the Public Health Act 1936, the first relevant advice in a planning context can be seen within DOE Circular 10/73. At a statutory level the Control of Pollution Act 1974 contained detailed provisions concerning statutory nuisances. European Community (EC) Directives of the mid-1980s, and rapidly increasing concerns about a wide variety of environmental issues, culminated in the Environmental Protection Act 1990. Part I of the 1990 Act contains provisions (formerly within the Control of Pollution Act 1974) relating to the statutory nuisances which include noise. At the advisory level Planning Policy Guidance Note 24: Planning and Noise has replaced DOE Circular 10/73. In terms of renewable energy development the wind annex to Planning Policy Guidance Note 22 contains some fairly general thoughts on noise emissions.

Chapters 4 and 6 of this report include discussion on the difficulties in theory and in practice of applying the advisory documents recorded in the paragraph above to wind energy development.

There are three principal methods available to local authorities and to citizens who wish to control noise emissions from wind generators. Local authorities may secure compliance with planning conditions by serving a planning Enforcement Notice, by serving a Breach of Condition Notice, or by taking injunctive action in the Courts. Local authorities can enforce covenants given within Planning Obligations by taking injunctive action. Both local authorities and citizens can pursue complaints in the Magistrates Courts alleging statutory nuisance.

Planning conditions

When a local authority grants planning permission for a development they may impose such planning conditions as they think fit. This discretion is not unlimited. To be valid a planning condition has to satisfy certain tests, and these are advised in paragraph 14 of DOE Circular 11/95 (Welsh Office Circular 35/95) [8]. These tests are:

- relevance to planning
- relevance to the development in question

- necessity
- precision
- enforceability
- reasonableness in all the circumstances.

There is no doubt that the control of noise is relevant to planning, almost certainly relevant to any wind energy development and, if only for this reason, very probably necessary. It remains for a local authority to ensure that the condition as drafted is precise, enforceable and reasonable. If a planning condition fails any one of these three tests the local authority would have little prospect of successful enforcement.

The invalidity of a planning condition because of a failure to comply with any of the tests outlined above helps neither the developer nor the local authority if a problem should arise. With a well drafted and enforceable condition both parties know where they stand both against each other and, within the planning jurisdiction, with regard to any complainant. If a noise condition has been carefully thought out, correctly phrased, and is in all other respects valid then two beneficial consequences follow. Firstly, the wind farm operator will be able to establish if he is in breach of the condition, and what he has to do in order to secure compliance. Secondly, if despite a well drafted and reasonable condition, and compliance with that condition, a citizen brings a complaint before the Magistrates Court under the Environmental Protection Act 1990, the fact of compliance with a reasonable and well thought out condition may prove to be an effective defence to an action in the Magistrates Court. The defence of best practicable means is discussed below.

On the other hand, if the planning condition drafted does not secure the proper control of noise emissions, and could readily be perceived to be unfair to neighbouring occupiers, the Magistrates Court might have little hesitation in imposing a noise regime, through an abatement notice, under the statutory nuisance provisions of the Environmental Protection Act 1990. This regime would take precedence over the planning condition and would then be enforceable in the Courts even if more onerous than the planning condition.

Returning to the enforcement powers available to local planning authorities, the Enforcement Notice is a well established instrument used to proceed against breaches of planning control, including breaches of planning conditions. There is a right of appeal, and the appeal process may take a year or more. This position has for some years been extremely unsatisfactory for local authorities because irresponsible developers can flout the planning system, knowing that a considerable period of grace can be obtained by the lodging of an appeal.

It was and still is open to local authorities to serve Stop Notices. These require the immediate cessation of the activity alleged to be unlawful, but the Stop Notice has to be accompanied by an Enforcement Notice, and there is a right of appeal. Compensation for certain economic losses may be payable if the Stop Notice is withdrawn or quashed on appeal (unless quashed on the basis that the planning permission, which permitted increased noise levels, is granted).

Therefore local authorities very rarely use Stop Notices unless they are convinced of winning the appeal that may follow.

The Planning and Compensation Act 1991 introduced the Breach of Condition Notice. If local authorities detect a breach of a planning condition they can serve a notice requiring the developer to remedy the breach within the minimum period of 28 days. There is no right of appeal, and the only option for the developer is to make an application to vary or discharge the planning condition. This is a very effective means of control, and emphasises the need for developers to negotiate conditions that are not only comprehensible and valid, but to which they can adhere. Developers need to bear in mind the economic consequences of shutting down or restricting the operation of a wind farm in order to secure compliance with a Breach of Condition Notice.

Finally, local authorities may take injunctive action to secure a remedy for any breach of planning control, and therefore they may in theory take such action to secure an end to a breach of a planning condition. The principles for deciding such actions in the Court will broadly follow those in an action relating to breach of a covenant described below, but it is unlikely that the local authority would take injunctive action to prevent a continuing breach of the planning condition given the alternative, cheaper and equally effective remedies available, which are discussed above.

Planning Obligations

A Planning Obligation made under Section 106 Town and Country Planning Act 1990 (as amended) is a contractual document in which a developer gives covenants which are enforceable by the local planning authority. A Planning Obligation may take the form of an agreement between a developer and the local authority, or, a unilateral undertaking given by the developer to the local authority. The scope of a Planning Obligation is defined in Section 106 and guidance on the use of Planning Obligations is given in DOE Circular 16/91 (WO Circular 53/91). This Circular is under review at the time of writing. The present Circular 16/91 advises that Planning Obligations should be sought only where they are necessary to the granting of planning permission, relevant to planning, and relevant to the development to be permitted. Where a local planning authority seeks a Planning Obligation from a developer Circular 16/91 advises on the tests of the reasonableness of seeking a Planning Obligation.

If the developer breaches the covenants within the agreement then the local authority can take action through the Courts to secure an injunction requiring him to adhere to the terms of the Obligation. In such an action the burden of proof is on the planning authority to prove the breach alleged. However, once the breach has been proved there are severe limits to the mitigating circumstances which the developer can advance, and which may persuade the Court to stay its hand and refrain from granting an injunction. There is a substantial body of law relating to the limits of the Court's discretion in deciding whether or not to grant an injunction following an initial finding that a breach of covenant has occurred.

Statutory nuisance

As to the jurisdiction of the Environmental Protection Act any citizen who feels himself to be adversely affected by noise emission can bring an action in the Magistrates Court in order to secure what is known as a noise abatement order. Again, a local authority can act directly as a prosecutor and issue a noise abatement notice. An abatement notice or order may require the abatement of the alleged noise nuisance or prohibit or restrict its occurrence or recurrence. It may also require the execution of specified works and the taking of other specified steps. The abatement notice or order will specify the time within which the requirements are to be complied with. The wind farm operator can appeal, on specified grounds, to the Magistrates Court, and ultimately to the Crown Court and higher Courts, against noise abatement orders and notices.

It is not the role of this report to discuss in detail the defences available to a developer faced with an allegation of statutory nuisance under the Environmental Protection Act which has resulted in the issue of a noise abatement order or notice. However, it can be noted that the defence of "best practicable means" is available, can be very effective and may be essential. If a wind farm operator cannot reduce noise emissions without jeopardising the viability of the operation, then the defence of best practicable means will be the last line of defence against potentially disastrous economic consequences.

In considering the merits of the defence of best practicable means the Magistrates Court will have regard to three principal factors: local circumstances, the technology being deployed by the developer, and some sort of cost-benefit analysis. With regard to the first factor, the Court cannot require the developer to take abatement action which will involve the use of land not under his control. An acoustic barrier may be appropriate in a particular case, but if it can only be placed on land belonging to a third party, and which is not within the control of the developer, and that third party is not willing to cooperate with its placement, then the Court cannot enforce the remedy because of this local circumstance.

As to the technology available to the developer, the Court will expect to hear some evidence that the best available technology is being deployed, subject to a consideration of the third factor identified, a cost-benefit analysis. The limits to the use of the cost-benefit analysis within a defence of best practicable means will vary from case to case, and no firm lessons can be derived from past cases. This is partly because each case will be decided on its facts, but also because cases within the Magistrates Courts are not regularly reported and therefore the findings of the Justices are not readily accessible. Even if such were the case it must be noted that the Magistrates Courts are not courts of record, and that the findings of the Magistrates do not form a body of legal precedent.

Against this background certain extremes can be identified. Provided that the developer was able to show that at the time of deployment of the machines the best available technology was used in the design, manufacture and erection of the turbines then the Magistrates Court would be most unlikely to find that the replacement of those turbines would be a reasonable option open to the developer. In any event, planning permission would be required. However, extensive sound-proofing measures might well be felt to be reasonable even though at considerable cost. The equation to resolve in all cases will be the benefit to be extracted from a particular step when set against the cost of that step.

Summary

In summary a variety of measures are open to local planning authorities and to citizens who perceive detriment to the amenities of neighbouring occupiers because of noise emissions. Because each case will differ in its facts no firm conclusions, particularly in relation to any rating levels, can be derived from case studies. However, it is very clear that well drafted and fair planning conditions will tell a developer what must be achieved, will provide local authorities with an objective initial yardstick if a complaint is received, and will provide the starting point for any evaluation of a defence of best practicable means.

Regulating noise emissions in the public interest

It was noted in the introduction to this chapter that reactions to noise emissions from man-made sources vary widely, depending in part on the physical ability of the receptor to hear the noise and his perceptions of the source. Such factors do not admit readily to objective analysis. A noise which is to one person unbearable can be almost inaudible to another.

The Courts have historically adopted the standpoint of the reasonable man or, as in the cliché, the man on the Clapham omnibus. The Courts have not been prepared to make decisions to accommodate extreme perceptions in controlling noise from legitimate sources. They have adopted, so far as is possible, a reasonable approach.

Planning law follows the Courts. Planning Policy Guidance Note 1 advises that the basis of planning law and practice is that the use and development of land should be regulated in the public interest: the purpose of the planning system is not to protect private rights. It follows from this that extreme private perceptions will not be protected by the planning system. The objective is to promote the current concept, from time to time, of the public good.

With the factors that have been identified in this chapter in mind, it can be seen that to attempt to devise an assessment and rating standard for noise emissions from wind energy development is a difficult exercise. Wind energy remains a new form of development : its symbolic content remains a matter of debate. Opinions of wind energy fluctuate widely between people and over time. Nevertheless, as with minerals, there is an urgent need to assist local planning authorities by suggesting rating standards which would seem to be reasonable. Reasonableness in this case derives from: established standards and advisory notes relating to noise emissions; the need of society for clean energy in pursuance of Government energy policy; what can be achieved by the manufacturers of wind turbines; the researches of the Working Party in the UK, Denmark, Holland and Germany; the professional and career experience of members of the Working Group; and discussions between the members and various others with appropriate experience.

The purpose of this chapter has been to define and analyse the complicated background against which members of the Noise Working Group set out to suggest rating standards for noise emissions from wind turbines, standards which may themselves change with time. Such changes may arise as a result of technical improvements in noise suppression by the manufacturers, because of developing perceptions of clean energy development, because of changing patterns of settlement in the countryside, and due to a host of other factors which cannot be anticipated at present. This acknowledgement of continuing dynamics does not undermine the production of rating standards. It is hoped that, at the same time, they represent well researched assistance to developers, manufacturers and planning authorities as well as a firm basis for further research and guidance.

3. DESCRIPTION OF NOISE EMISSIONS FROM WIND TURBINES

Noise emitted by wind turbines can be associated with two types of noise source. These are aerodynamic sources due to the passage of air over the wind turbine blades and mechanical sources which are associated with components of the power train within the turbine, such as the gearbox and generator and control equipment for yaw, blade pitch, etc. These sources normally have different characteristics and can be considered separately.

Aerodynamic sources

Aerodynamic noise is emitted by a wind turbine blade through a number of sources which have been identified and studied by Lowson [9] and Lowson and Fiddes [10]. The key sources have been categorised as:

1. Self noise due to the interaction of the turbulent boundary layer with the blade trailing edge.

2. Noise due to inflow turbulence (turbulence in the wind interacting with the blades).

3. Discrete frequency noise due to trailing edge thickness.

4. Discrete frequency noise due to laminar boundary layer instabilities (unstable flow close to the surface of the blade).

5. Noise generated by the rotor tips.

Noise due to aerodynamic instabilities, mechanisms 3 and 4, can be reduced to insignificant levels by careful design. The other mechanisms are an inescapable consequence of the aerodynamics of the turbine which produce the power and between them they will make up most if not all of the aerodynamic noise radiated by the wind turbine. The relative contribution of each source will depend upon the detailed design of the turbine and the wind speed and turbulence at the time. The mechanisms responsible for tip noise are currently under investigation but it appears that methods for its control through design of the tip shape may be available. Self noise, mechanism 1 above, is most significant at low wind speeds whereas noise due to inflow turbulence becomes the dominant source at the higher wind speeds. Both mechanisms increase in strength as the wind speed increases, particularly inflow turbulence. The overall result is that at low to moderate wind speeds the noise from a fixed speed wind turbine increases at a rate of 0.5-1.5 dB(A)/m/s.

The experience of some residents who neighbour wind farms in the UK would indicate that the assumption that aerodynamic blade noise sounds like the wind in the trees is perhaps an over-simplification, although the frequency content of this source can be similar to that of wind turbines. It is the regular variation of the noise with time that, in some circumstances, enables the listener to distinguish the noise of the turbines from the surrounding noise. Onomatopoeic descriptions of these noises include swishing, whooshing, chomping and thumping.

Blade swish is an amplitude modulation of noise in the frequency range which is associated with trailing edge noise radiated from the outer portion of the turbine blade and discrete frequencies associated with trailing edge thickness. This rhythmic swishing sound, dependent upon tip speed and blade profile, is normally centred around the 800-1000Hz region of the frequency band for trailing edge noise and at higher frequencies for trailing edge discrete frequencies depending on edge thickness. Measurements of the emitted sound power level of a wind turbine are normally performed using the A-weighting network and a time-averaging period of a minimum of 2 minutes, [11] [12]. This modulation might be expected to be clearly apparent when performing noise measurements close to wind turbines. However, the modulation of the A-weighted noise level is of the order of 2-3dB(A) for typical wind turbine configurations. Measurements performed in Denmark [13] and at some locations in the UK indicate that this level of amplitude modulation may be greater if analysis is performed using third octave or narrow band analysis of the radiated noise from a wind turbine. This modulation may be caused by directivity effects associated with the generation of the noise at the blade and is most apparent when standing close to a wind turbine, less than 50 metres from the base of a supporting tower.

As observer distance increases from the turbine, the rhythmic swishing becomes less pronounced. This may be due to a number of single effects or a combination. As distance increases, the modulation caused by the directivity of the radiated sound wave emitted by a turbine blade will become less significant. Therefore, it would be expected that any directivity effects which may be audible close to the turbine will be reduced in audibility. Atmospheric attenuation will cause a reduction of high frequency blade noise relative to lower frequency blade noise. This removes the high frequency "swish" spectral content which increases its distinguishing character. As the observer distance increases, the level of sound from the turbine incident at the observer position will decrease. However, in exposed locations, it should be expected that the background noise level will remain, in general, the same. Therefore, increased masking by the background noise will reduce the subjective impact of the turbine noise. This rhythmic swishing has been noted to vary between turbine types and between sites where similar turbines have been installed.

Current research projects aimed at more fully characterising the aerodynamic noise emissions from wind turbines are described in Chapter 9 on Further Work. These projects include measurements of blade swish and low frequency noise and vibration emissions.

Mechanical sources

Mechanical noise is normally perceived within the emitted noise from wind turbines as an audible tone(s) which is subjectively more intrusive than a broad band noise of the same sound pressure level. Sources for this noise are normally associated with: the gearbox and the tooth mesh frequencies of the step up stages; generator noise caused by coil flexure of the generator windings which is associated with power regulation and control; generator noise caused by cooling fans; and control equipment noise caused by hydraulic compressors for pitch regulation and yaw control.

Where complaints have been received due to the operation of wind farms, tonal noise from the installed wind turbines appears to have increased the annoyance perceived by the complainants and indeed has been the primary cause for complaint.

Mechanical noise may be radiated by the containing structure of the source, ie the gearbox casing, or by parts of the turbine structure which have a direct mechanical linkage to the source. Where gearbox noise has been perceived as a tonal noise problem, the acoustic energy has normally been found to be radiated by the supporting tower structure upon which the turbine nacelle containing the gearbox is mounted and/or by the wind turbine blades themselves. Vibrational energy is transmitted from the drive train within the gearbox and the drive shafts and enters the gearbox supporting structure. This then travels through the supporting structure and may be re-radiated as sound at any position where the structure is exposed to atmosphere. Supporting towers are normally large, between 25 and 45 metres in height, from which acoustic energy may be radiated. These large radiating surfaces can result in the efficient transmission of the vibrational energy into the external environment surrounding a wind turbine.

Most turbine manufacturers have started to ensure that sufficient forethought is given to the design of quieter gearboxes and the means by which these vibrational transmission paths may be broken. Through the use of careful gearbox design and/or the use of anti-vibration techniques, it is possible to minimise the transmission of vibrational energy into the turbine supporting structure. The benefits of these design improvements have started to filter through into wind farm developments which are using these modified wind turbines. It is possible to obtain turbines which do not emit any clearly distinguishable tones.

Vibrational energy that enters the wind turbine blade may be reduced by the placing of a resilient coupling on the low-speed shaft and/or by treating the blade itself. Foam filling of the blade would provide significant additional damping to the blade skin, thereby reducing the transmitted vibrational energy within the blade.

4. REVIEW OF CURRENT PRACTICE AND GUIDANCE

Introduction

Much work has been carried out and is still current in relation to the measurement of noise from wind generators. However, there is as yet no primary or secondary legislation in the UK relating specifically to the rating of noise from wind generators. This corresponds with the position in all European Community member states which have seen wind energy development, except Denmark where a statutory instrument of 1991 [12] specifically regulates maximum levels of noise emissions from wind generators. There are statutory noise controls in Holland and Germany but these are not specifically related to wind generators.

The only current advice in the UK specifically relevant to wind energy development is contained within the wind energy annex to Planning Policy Guidance Note 22 (PPG 22) [1] which advises on renewable energy development. However, there are numerous elements of advice more or less pertinent to the subject and these are recorded in this section of the report. Advice continues to emerge, and in particular it is noted that Planning Policy Guidance Note 24: Planning and Noise [5], which superseded DOE Circular 10/73 [4] in England (Welsh Office 16/73 is still in effect at time of writing), was issued in September 1994 and a revision to BS 4142: 1990 [2] relating to industrial noise in mixed residential and industrial areas is currently being prepared.

This chapter of the report records and discusses legislation and advice which is current, and either potentially or directly pertinent to noise emissions from wind generators. Chapter 6 of this report discusses the difficulties in theory and in practice of applying the advisory documents described in this chapter to wind energy development and proceeds to recommend a framework for the measurement and assessment of noise from wind farms.

The use of planning conditions

As a result of this lack of direct guidance for the assessment of wind turbine noise, several methods have evolved to limit the noise levels which are incident from a wind turbine or farm. These methods can be summarised as follows:

- The setting of noise limits (maximum limit not to be exceeded or limit at a specified wind speed, typically 5m/s at hub height, the cut-in wind speed for a wind turbine) which are independent of the existing background noise levels. This is like the planning condition for Rhyd-y-Groes on Ynys Mon/Anglesey and some sites in Dyfed.

- The setting of a limit based on measurements of the background noise before the construction of the wind farm. The planning conditions agreed for Four Burrows in Cornwall are of this type.

- The setting of a limit permitting the noise level of the wind farm to the exceed the prevailing background noise level when the wind farm is not operating by a specified amount. This is like the planning condition agreed for Carland Cross in Cornwall.

Furthermore, the methods by which these conditions or obligations are to be tested are different. Some propose the measurement of the L_{Aeq} of the background and incident turbine noise at a property, some propose the measurement of the L_{A90} of the background and incident noise from the wind turbines and some consider the noise in terms of the L_{A50}. The reasons for this can be summarised as follows:

- The use of L_{Aeq} follows the guidance that is contained within BS 4142: 1990 (Method for rating industrial noise affecting mixed residential and industrial areas) which was updated to align itself with ISO 1996: Parts 1 to 3. This proposes that measurements and an assessment of a new noise source be performed using the L_{Aeq} index.

- The use of L_{A90} was proposed by some local district councils in Cornwall because transitory, high-energy effects such as aircraft fly-overs and wind upon the microphone could increase the measured L_{Aeq} such that the measured noise levels from the turbines would be masked. As a wind turbine is a fairly constant noise source it was considered that the L_{A90} would be a reasonable approximation to the L_{Aeq} of a wind turbine. However, at a receiver position, where short-term, high-energy events may result in a higher L_{Aeq} than would be expected from just the operation of wind turbines, the L_{A90} was considered to be less affected by these transitory, high-energy events.

- The use of L_{A50} was adopted during early work by the CEGB at the demonstration test facility at Carmarthen Bay. The reasoning for the use of the L_{A50} follows that described in the previous paragraph.

Therefore, there currently exist several methods by which conditions and obligations have been written and by which developers have considered the effects of their developments upon neighbouring dwellings and noise-sensitive buildings. The purpose of this Working Group is to consider the merits of these and other methods with respect to existing primary and secondary legislation, Planning Policy Guidance Notes, Mineral Planning Guidance and British Standards. This investigation has also taken into account recommendations made by the World Health Organisation (WHO), the European Community (EC) and the Organisation of Economic Co-operation and Development (OECD). Reference has also been made to the experiences of other countries where the development of wind energy has already been underway for a number of years.

Primary and secondary legislation in the UK

The emergence of noise emissions as a core environmental concern is relatively recent. While quite separate law relating to statutory nuisances derives from the Public Health Act 1936, the first relevant advice in a planning context can be seen in the DOE Circular 10/73 (Welsh Office Circular 16/73), now replaced in England by Planning Policy Guidance Note 24. At a statutory level the Control of Pollution Act 1974 contained detailed provisions concerning statutory nuisances. EC Directives of the mid-1980s, and rapidly increasing concerns about a wide variety of environmental issues, culminated in the Environmental Protection Act 1990. A brief summary of relevant provisions in primary legislation of relevance to noise emission control is given below.

Planning juridictions

Section 70 Town and Country Planning Act 1990:

"Where an application is made to a local planning authority for planning permission

a) Subject to (other sections) they may grant planning permission, either unconditionally or subject to such conditions as they think fit; or

b) They may refuse permission."

Section 106 Town and Country Planning Act 1990:

"Any person interested in land in the area of a local planning authority may, by agreement or otherwise, enter into an Obligation (..."a Planning Obligation"):

a) restricting the development or use of the land in any specified way;

b) requiring specified operations or activities to be carried out in, on, under or over the land;

c) requiring the land to be used in any specific way; or

d) requiring a sum or sums to be paid to the authority on a specified date or dates or periodically."

Statutory nuisance

Section 80 Environmental Protection Act 1990:

"Where a local authority is satisfied that a statutory nuisance exists, or is likely to occur or to recur, in the area of the authority, the local authority shall serve a notice ("an abatement notice") imposing all or any of the following requirements -

a) Requiring the abatement of the nuisance or prohibiting or restricting its occurrence or reoccurrence;

b) Requiring the execution of such works, and the taking of such other steps, as may be necessary for any of those purposes, and the notice shall specify the time or times within which the requirements of the notice are to be complied with."

Section 82 Environmental Protection Act 1990:

"A magistrates court may act under this section on a complaint made by any person on the ground that he is aggrieved by the existence of a statutory nuisance. If the

magistrates court is satisfied that the alleged nuisance exists, or that although abated it is likely to recur on the same premises, the Court shall make an order for either or both of the following purposes -

a) Requiring the Defendant to abate the nuisance within a time specified in the order, and to execute any works necessary for that purpose;

b) Prohibiting a reoccurrence of the nuisance, and requiring the Defendant, within a time specified in the order, to execute any works necessary to prevent the reoccurrence,

and may also impose on the Defendant a fine not exceeding ..... on the standard scale."

Town and Country Planning (Assessment of Environmental Effects) Regulations 1988

By virtue of the Town and Country Planning (Assessment of Environmental Effects) (Amendment) Regulations 1994, which came into force on 6 April 1994, the provisions of the 1988 Regulations now apply to wind energy development. Wind generators are listed within Schedule 2 to the 1988 Regulations as a form of development for which environmental assessment may be appropriate, depending on such factors as the nature, size and location of proposal.

Planning Policy Guidance Notes

PPG 22 Renewable Energy

PPG 22 sets out Government planning policy advice concerned with developing renewable energy sources, against the background of the Government's policies for the environment, and for developing these renewable energy sources. For ease of reference the Government's policy on new and renewable energy as stated in Energy Paper No 62 is:

"To stimulate the development of renewable energy sources wherever they have prospects of being economically attractive and environmentally acceptable in order to contribute to:

- *diverse, secure and sustainable energy supplies*
- *reduction in the emission of pollutants*
- *encouragement of internationally competitive industries.*

In doing this it will take account of those factors which influence business competitiveness and work towards 1500MW DNC of new electricity generating capacity from renewable sources for the UK by 2000."

The main principle running through PPG 22 is the requirement to balance the local environmental impact of renewable energy generation against global environmental benefits.

This is best illustrated by reference to extracts from paragraphs 21 and 26, the first considering land use planning matters and the second advising on development plans.

> *"Sites proposed for the development of renewable energy sources will often be in rural areas or on the coast, and such development will almost always have some local environmental effects. The Government's policies for developing renewable energy sources must be weighed carefully with its continuing commitment to policies for protecting the environment."*

> *"Authorities will need to consider both the immediate impact of renewable energy projects on the local environment and their wider contribution to reducing emissions of greenhouse gases."*

The PPG specifically considers noise issues within paragraphs 39-51 of its wind annex. The document provides an overview of the issues to be addressed but as it admits, there was insufficient information available at the time of writing for more quantitative general guidance to be given.

PPG 24: Planning and Noise

PPG 24 Planning and Noise, issued in September 1994, gives guidance to local authorities in England and replaces Circular 10/73. This document too highlights the potential conflicts of interest which have to be considered as part of the planning process. The aim of the guidance contained within PPG 24, as stated in the opening paragraph. is:

> *"..... to provide advice on how the planning system can be used to minimise the adverse impact of noise without placing unreasonable restrictions on development or adding unduly to the costs and administrative burdens of business."*

Paragraph 10 continues:

> *"Much of the development which is necessary for the creation of jobs and the construction and improvement of essential infrastructure will generate noise. The planning system should not place unjustifiable obstacles in the way of such development. Nevertheless, local planning authorities must ensure that development does not cause an unacceptable degree of disturbance. They should also bear in mind that a subsequent intensification or change of use may result in greater intrusion and they may wish to consider the use of appropriate conditions."*

Within Annex 1 of PPG 24 the concept of noise exposure categories (NECs) is developed. These categories are to help identify whether noise is an important issue in the development of residential dwellings within an existing noise environment. However, it identifies that when a new noise source is brought to sensitive properties this guidance is not to be used:

> *"The NEC procedure is only applicable where consideration is being given to introducing residential development into an area with an existing noise source, rather*

than the reverse situation where new noise sources are to be introduced into an existing residential area."

This is because:

"...the planning system can be used to impose conditions to protect incoming residential development from an existing noise source but, in general, developers are under no statutory obligation to offer noise protection measures to existing dwellings which will be affected by a proposed new noise source."

It is also stated that where industrial noise is the dominant noise source rather than transportation noise sources, the NEC noise levels should not be used because:

"...there is insufficient information on people's response to industrial noise to allow detailed guidance to be given."

However, if industrial noise is present but not dominant in a noise environment, then its contribution should be included when establishing the NEC category. The discussion on the setting of noise limits for the various NECs makes reference to sleep disturbance criteria and attenuation of noise through open and closed windows. The approach of PPG 24 is discussed in Chapter 6 for the purposes ofconsidering the setting of noise limits for wind farms.

However, the derivation of the night-time noise limits contained within the NEC table is based upon the concept of sleep disturbance and the protection of the restorative process of sleep. The setting of these criteria has assumed a reduction of the noise from outside the building through to the inside within bedrooms such that the internal noise level is at or below 35dB L_{Aeq}. (Reference is made to the WHO document Environmental Health Criteria 12 - WHO, 1980 [14]. It should be noted that there is currently a review of the criteria contained within this report. The new draft is discussed later in this chapter.) The reduction through a window that has been assumed for the calculation of acceptable external noise levels is 13dB(A) from internal noise level to facade noise level. (It is stated within PPG 24 that this figure is usually taken to be 10-15dB(A) and that for the purpose of deriving the NEC table it has been assumed to be 13dB(A).)

When advising on the assessment of noise from industrial and commercial developments the PPG comments that the likelihood of complaints about noise from industrial development can be assessed, where the Standard is appropriate, using guidance in BS 4142: 1990. It goes on to say that the "rating level" shall be used when stipulating the level of noise that can be permitted.

Planning and Noise Circular (W.O. 16/73)

Welsh Office Circular 16/73 contains guidance for planning authorities concerning new noise sources. This is equivalent to DOE Circular 10/73 recently cancelled by PPG 24 in England. Although the circular does not directly deal with wind turbine-generated noise it provides some guidance as to what might be considered as acceptable noise levels for the incident noise levels from such development.

Noise from fixed installations and industrial premises is considered within paragraphs 24-36 of the Circular. Within paragraph 24 it is recommended that local planning authorities consult their Environmental Heath Departments at an early stage to minimise the noise effects of developments.

Paragraph 27 proposes a method by which noise from a new noise source introduced into an existing residential environment may be assessed. It states:

> *"Where, by the standards established in BS 4142, the noise from the proposed development "is likely to give rise to complaints" even if reasonable sound insulation is required and provided, it will hardly ever be right to give permission. In predicting noise levels from new developments it will be necessary to take account of those which can be expected when the plant is operating at maximum capacity, even if this presupposes a higher level of activity than that initially proposed by the developer."*

Paragraph 28 considers that, where possible, the authorities should operate their development control powers in such a way as to avoid an increase in the ambient noise affecting residential and other noise-sensitive development. It also recognises within this paragraph that this will not always be possible for certain types of development.

Where industrial noise is incident upon a residence, the Circular proposes that the CNL (Corrected Noise Level) for a stationary source to provide a "good standard" of noise within a dwelling with windows closed is 45dB(A) during the day-time and 35dB(A) during the night-time. These are internal noise levels, with windows closed.

MPG 11 The Control of Noise at Surface Mineral Workings

The aim of Mineral Planning Guidance Note 11 is to provide advice on how the planning system may be used to keep noise emissions from surface mineral workings within environmentally acceptable limits without imposing unreasonable burdens upon minerals operators.

Paragraphs 31-35 consider the setting of absolute noise limits for such developments, which are linked to day-time and night-time working periods. MPG 11 states:

> *"The Government takes the view, except in the circumstances outlined below, the day-time nominal limit at properties used as dwellings should normally be 55dB $L_{Aeq,1h}$ (free field)...."*

MPG 11 goes on to say that this level is generally found to be a tolerable noise level and that above this noise level continuous noise starts to cause annoyance.

The suggested night-time noise limit is 42dB $L_{Aeq,1h}$ at a noise-sensitive dwelling. It also recognises that lower nominal noise limits may be appropriate in quiet rural areas if the mineral working threatens to disturb exceptionally low background noise levels.

Paragraphs 37 and 38 discuss the setting of noise limits relative to the existing background noise level. However, MPG 11 recognises the difficulties of this approach when applied to sites where quiet background noise levels exist:

> *"In exceptionally quiet rural areas where the day-time background noise level is below 35dB(A), a condition limiting mineral operators to a 10 decibel excess over the existing background noise level is likely to be both difficult to achieve and unduly restrictive. It would not normally be appropriate to require a day-time limit below 45dB $L_{Aeq,1h}$, as such a limit should prove tolerable to most people in rural areas. The exercise of care and some flexibility are important in addressing these issues."*

Paragraph 39 states:

> *"In the case of night-time working, MPAs and operators should have particular regard to the needs of local people, and discussion with local Environment Health Officers may well be appropriate as to whether the night-time limit stated at paragraph 34 is reasonable. This may be a particular issue in quieter rural areas."*

These comments indicate that for very quiet background noise environments, the operation of mineral extraction plant should not be allowed to exceed 42dB $L_{Aeq,1h}$ during the course of a night, but that a lower limit may be appropriate after discussions with the local Environmental Health Officer.

British Standards

BS 4142: 1990: Method for rating industrial noise affecting mixed residential and industrial areas

It is stated within the foreword of this British Standard that:

> *"The standard is intended to meet the need for rating various noises of an industrial nature affecting persons living in the vicinity. It gives a method of determining a noise level, together with procedures for assessing whether the noise in question is likely to give rise to complaints. Although, in general, there will be a relationship between incidence of complaints and the level of general community annoyance, quantitative assessment of the latter is beyond the scope of this standard as is the assessment of nuisance."*

This indicates that although the standard may be used for the rating of a noise incident upon a receiver position, it is not appropriate for either the quantitative assessment of general community annoyance or the assessment of nuisance.

The foreword continues:

> *"In general, a noise is liable to provoke complaints whenever its level exceeds the background noise by a certain margin; or when it attains a certain absolute level."*

This indicates that complaints may occur if the incident noise level exceeds the background noise level by a margin or if the incident noise exceeds an absolute level that may not be related to the background noise level.

The foreword to BS 4142 also states:

> *"This standard is intended to be used for assessing the measured noise from existing premises or the calculated (or measured) noise levels from new or modified premises. It may be found helpful in certain aspects of environmental planning and may be used in conjunction with recommendations on noise levels and methods of measurement published elsewhere."*

The scope explains that the standard provides a method for assessing whether noise measured at the outside of a building is likely to give rise to complaints from people residing inside the building.

BS 4142 itself acknowledges that it is not suitable for assessing noise in situations where the background noise level is very low, ie below an A-weighted sound pressure level of 30dB.

The rating method described within BS 4142 compares the incident noise from an industrial source, be it calculated or measured, with the measured background noise at the position where the new noise source is incident. The noise levels of the source are measured in terms of $L_{Aeq,T}$ but for background noise level, $L_{A90,T}$ is used. When performing an assessment using BS 4142, not only is the level of incident noise from the new noise source of concern but also the character of the source. BS 4142 proposes that a penalty be applied if the noise has the following characteristics:

> *"7.2 If the noise contains a distinguishable, discrete, continuous note (whine, hiss, screech, hum, etc), or if there are distinct impulses in the noise (bangs, clicks, clatters, or thumps), or if the noise is irregular enough in character to attract attention, add 5dB to the specific noise level to obtain the rating level. Make only a single 5dB correction if one or more of the above characteristics is present."*

The method of assessment then subtracts the measured background noise level from the rated noise level. A difference of 10dB(A) or greater is considered to indicate that complaints are likely. A difference of around 5dB is of marginal significance. The lower the value the less likelihood there is of complaints.

The issues associated with the application of BS 4142 to noise from wind farms in rural areas are discussed in Chapter 6.

BS 5228: Part 1: 1984 Noise Control on construction and open sites. Part 1: Code of Practice for basic information and procedures for noise control

The scope of BS 5228 Part 1 [15] covers recommendations for basic methods of noise control relating to construction sites and other open sites where noisy work activities and operations are carried out. It describes the legislative background to noise control and provides guidance concerning methods of predicting and measuring noise. It also contains recommendations on how the impact of noise on people living nearby and on-site workers can be minimised.

Section 11 within the British Standard discusses the setting of noise criteria. When setting target noise levels at sensitive dwellings adjacent to a site, it is recognised that the period of falling asleep and just before awakening are the most sensitive. It is suggested that site noise will be required to be limited to $L_{Aeq,1h}$ of 40-45dB at the facade to avoid sleep disturbance; this is equivalent to a free field sound pressure level of 37-42dB. The free field sound pressure level is that which is measured when the measurement position is situated further than 3.5 metres from a reflecting surface.

BS 7445: Parts 1-3: 1991 Description and measurement of environmental noise

Part 1. Guide to quantities and procedures
Part 2. Guide to the acquisition of data pertinent to land use
Part 3. Guide to application to noise limits

BS 7445: Parts 1-3: 1991 [16] is the equivalent British Standard to ISO 1996/1-3: 1982 and is identical to this ISO standard. This International Standard does not specify limits for environmental noise. The stated aim of these standards is to:

> *"...provide authorities with material for the description of noise in community environments. Based on the principles described in this International Standard, acceptable limits of noise can be specified and compliance with these limits can be controlled."*

Part 1 of the standard describes the preferred measurement units which should be used, the type of equipment that should be used for determining the noise level and measurement positions. The standard introduces the concept of measurements performed within a building when assessing the impact upon a nearby receiver. Section 5.2.3 of the standard states that the preferred measurement position within a building is:

> *"at least 1 metre from the walls or other major reflecting surfaces, 1.2 to 1.5 metres above floor level and about 1.5 metres from windows."*

Section 5.3 of the standard discusses the possible meteorological effects upon the measurements that may be undertaken. It does not specify that there are weather conditions during which measurements are unacceptable. However, it recommends that measurements be made when conditions will be those that will allow the most stable propagation of the noise from the source to the receiver, with a significant wind component from the source to the receiver.

The purpose of Part 2 of the British Standard is:

> *"To provide methods for the acquisition of data describing environmental noise. Using these data as a basis, authorities may establish a system for selecting the appropriate*

land use, as far as levels of noise - existing or planned - which are acceptable with respect to land use, existing or planned."

This part of the British Standard gives some guidance as to the method by which a rating may be made of the noise source, taking into account whether it has an impulsive character or whether it contains any tonal components. The control of such acoustic emissions from a wind turbine are normally addressed through the warranty provided by the manufacturer of the wind turbines and the planning permission for the development.

The tonal adjustment as described below is proposed within BS 7445 in order to take into account the effects of tonal noise:

> *"A prominent tonal component may be detected in 1/3 octave spectra if the level of a 1/3 octave band exceeds the level of adjacent bands by 5dB or more, but a narrow band frequency analysis may be required in order to detect precisely the occurrence of one or more tonal components in a noise signal. If tonal components are clearly audible and their presence can be detected by a 1/3 octave analysis, the adjustment may be 5 or 6dB. If the components are only just detectable by the observer and demonstrated by narrow band analysis, an adjustment of 2 to 3dB may be appropriate."*

Part 2 also states that the measurement of the noise source should be undertaken when the propagation conditions are stable and when the meteorological conditions will enhance propagation towards the receiver position. BS 7445 states that wind conditions should be from the source to the receiver and within an angle of ± 45° of a line connecting the centre of the source with the centre of the receiver position. It also states the wind speeds for this assessment should not exceed an average wind speed of 5m/s between the heights of 3 and 11 metres. This typically equates to average wind speeds of 7.8m/s and 5.9m/s respectively, when measured at a height of 30 metres, which are low to moderate wind speeds for turbine operation (see "wind shear" entry in Glossary). It is also stated within BS 7445 Part 2, Paragraph 5.4.3.3, Note 1, that it should always be ascertained that the wind noise at the microphone does not interfere with the measurements.

Part 3 of BS 7445 describes the application of noise limits and the elements which are necessary in any setting of noise limits. These include:

- the noise descriptor to be used
- the relevant time intervals
- the sources and their conditions of operation, where appropriate
- the locations where the noise limits have to be verified
- meteorological conditions, where appropriate
- criteria for assessment of compliance with the set limits.

Guidance is given within this section of the standard as to how to set the conditions for any noise limits and for checking compliance with any of the noise limits that might have been agreed or imposed by the local authority.

BS 7135: Part 1: 1989: Noise emitted by computer and business equipment Part 1. Method of measurement of airborne noise

BS 7135: Part 1 [17] is a measurement method for noise emitted by computer and business equipment. The methods described within the standard are only relevant to the measurement of these noise sources. However, within Annex D (Measurement of impulsive sound pressure levels and discrete tones at the operator position) are methods for the determination of the impulsiveness of the noise and the tonality of the noise.

Measurement of the impulsive sound is performed by aural examination of the noise source at the operator positions. If the noise emitted is perceived to include short-duration high-amplitude sound, then the following test shall be performed:

> *"The A-weighted impulse sound pressure level, L_{pAI}, shall be measured for the same modes of operation and measurement conditions used for the measurement of the A-weighted sound pressure level, L_{pA}, according to 7.7. The difference in decibels between the A-weighted impulse sound pressure level, L_{pAI}, and the A-weighted sound pressure level, L_{pA}, shall be obtained. The difference ($L_{pAI} - L_{pA}$) is the impulse parameter ΔL_I, which may be considered a measure of the impulsive content of the noise; if $\Delta L_I \geq 3dB$, the noise is considered to be impulsive."*

The impulsive response of a sound level meter is defined by the time constant for the input signal. An impulse sound level meter has a time constant of 35ms compared with a fast time weighting network of 125ms. The measurement method described within BS 7135 (Section 7.7 of the Standard) to determine the L_{pA} sound pressure level requires that a measurement be performed for a period of at least 8 seconds. Although it is not clearly identified within the standard as to whether the measurement is an L_{Aeq} level or a mean level, it is assumed that the L_{Aeq} level should be recorded.

Section D.4 of the annex describes a method for the detection of a tone within a broad band noise. Section D.4.1 states the following:

> *"A discrete tone which occurs in a broad-band noise is partially masked by the noise contained in a relatively narrow frequency band, called the critical band, that is centred at the frequency of the tone. Noise at frequencies outside the critical band does not contribute significantly to the masking effect. The width of the critical band is a function of the frequency. In general, a tone is just audible when the sound pressure level of a tone is about 4dB below the sound pressure level of the masking noise contained in the critical band centred around the tone. For the purpose of this annex, a discrete tone is defined as being prominent if the sound pressure level of the tone exceeds the sound pressure level of the masking noise in the critical band by 6dB. This corresponds, in general, to a tone being prominent when it is more than 10dB above the threshold of audibility."*

The standard then proceeds to describe a method of assessment to determine the existence of discrete tones within the emitted noise from a computer. This method employs the concept of Zwicker critical bands. When considering critical band theory for the masking of discrete tones within broad band noise, it is clear that the detection of a tone is related to the frequency and level of the tone compared to the critical band masking level. The defined criteria for the threshold of audibility and prominence is a simplification of these criteria as the detection threshold is frequency-dependent.

The British Standard is designed for the assessment of tones that are emitted from computer equipment. Most tones that are emitted by computers are related to the cooling fans and the scanning frequency of the CRT (cathode ray tube). These frequencies are normally found above 1kHz and for a CRT 15-25kHz. At these frequencies the likelihood of a tone being detected is high when the audibility threshold level is 4dB below the critical masking level. However, at lower frequencies, especially below 500Hz, the audibility threshold for a tone is measured as being 2dB below the critical masking band noise level. Therefore, the criterion that is described within the British Standard is a simplification of the detection thresholds of a normal ear due to the assumptions made with respect to the normal range of discrete frequencies that are emitted by computer equipment.

The critical bandwidths are defined within the British Standard as follows:

The width of the critical band, Δf_c, centred at any frequency, f, is given by the following equation:

$$\Delta f_c = 25 + 75 \left[1 + 1.4 \, (f/1000)^2 \right]^{0.69}$$

(e.g. $\Delta f_c = 162.2$Hz at f = 1000Hz)

For the purposes of determining the value of L_n, the critical band is modelled as a rectangular filter with centre frequency, f_0, the lower band edge frequency f_1, and the upper band edge frequency, f_2, where

$$f_1 = f_0 - \Delta f_c/2$$

and

$$f_2 = f_0 + \Delta f_c/2$$

The British Standard also states that the measurements should be performed using the A-weighting network. However, if measurements are performed using linear quantities then the threshold of audibility should be defined as when a tone is 6dB below the masking band level.

The measurement period that should be used for determining the tone levels is defined as a minimum of 8 seconds, following the measurement methodology used for the impulsive noise assessment. However, performing a narrow band analysis on a signal using an FFT (Fast Fourier Transform) Analyser results in blocks of data, between 125 ms and 1 second in length, being analysed, rather than a continuous stream. To derive the sound pressure level for each narrow band over a longer time period, such as 8 seconds, requires that the average level is obtained from a number of shorter measurements.

The determination of the masking band level within the critical band is dependent upon this averaging of the measured noise. However, for a single spectrum using a Hanning window it is expected that the broad band level calculated would have a 68.3 % chance of being within 4.34dB of the true level, a 95.5 % chance of being within 8.68dB and a 99.7 % chance of being within 13.02dB. However, as the number of averages increases, the standard error will become less due to the greater number of samples. Table 1 details the expected error with increase in the number of samples used to determine the average level of each narrow band.

Table 1 Expected error bands using FFT analysis

Number of Samples	Standard Deviation	2 × Standard Deviation	3 × Standard Deviation
1	4.34	8.68	13.02
2	3.07	6.14	9.21
4	2.17	4.34	6.51
8	1.53	3.07	4.60
16	1.09	2.17	3.26
32	0.77	1.53	2.30
64	0.54	1.09	1.63
128	0.38	0.77	1.15
256	0.27	0.54	0.81
512	0.19	0.38	0.58
1024	0.14	0.27	0.41

Therefore, to undertake measurements that have a high degree of accuracy requires that a significant number of measurements are averaged before the level can be confidently predicted to be within 1dB of the level recorded by the analyser. This compares with the advised minimum measurement period of 8 seconds proposed within the standard. As an example, if the highest frequency of interest is 2kHz and the narrow band bandwidth is 2.5Hz, equivalent to 800 lines, then the sampling frequency will require to be 2.56 times the frequency of highest interest, ie 5120Hz. To obtain sufficient data to perform the FFT analysis will require 2048 data points. Therefore, the time that is required to obtain sufficient data for a single spectrum is 2048 × (1/5120Hz) = 0.4 seconds. If it is assumed that the data is collected as a continuous stream, then in the space of 8 seconds it would be expected that 20 spectra are available for averaging. From Table 1 it may be seen that this would lead to an expected accuracy of the measurement of about 1dB for a single standard deviation. For an accuracy of ± 0.2dB, 470 measurements would be required, resulting in an overall measurement period of 188 seconds, approximately 3 minutes.

International Guidance

European Community Directives

Council Directive 85/337 of the European Community requires the assessment of the environmental impact of certain projects in the public and private domain. The terms of this Directive must be implemented by member states. In the UK most of the Directive's terms have been implemented through the Town and Country Planning (Assessment of Environmental Effects) Regulations 1988, reference to which has already been made.

CEC Report EUR 5398 e: 1975

The Commission of the European Communities report EUR 5398 e: Environment and Quality of Life: Damage and Annoyance Caused by Noise [18], contains a number of recommendations for the setting of external and internal noise criteria which will not affect sleep or relaxation in external environments.

The report states within its conclusions that internal L_{Aeq} noise levels within a bedroom of 30-35dB would not affect sleep at all, while a maximum sound level should not exceed the L_{Aeq} level by more than 10dB. The setting of a maximum noise level above the average L_{Aeq} level is due to the human startle response function which results in a sleeper awakening as a result of a short period, high level noise. The report states that a certain safety margin has been taken into account for more susceptible elderly persons when stating this figure. It is proposed within the report that as these levels will result in no sleep disturbance, achieving these noise levels for other rooms within a dwelling will result in no interference in relaxation. Again, the limit for a maximum level 10dB above the continuous L_{Aeq} level applies. However, the report does note that public authorities may be led to decide that such protection should be restricted to specific and particularly sensitive groups, such as invalids, convalescents and residents of old peoples' homes, thereby indicating that this may also be a very safe criterion for most members of the population.

Noise criteria for relaxation in areas external to the dwelling are not so clearly defined. The recommended noise levels contained within Report EUR 5398 e state that L_{Aeq} levels of 50-55dB will result in slight annoyance. However, reference is made within the report that acceptable guide levels for external areas based upon average L_{Aeq} levels are as follows: 45dB during day-time and 35-40dB during the night time. It is stated that:

> *"This would seem to provide an adequate safeguard for night-time and day-time sleep, relaxation and also for the use for relaxation of open-air facilities such as balconies, terraces and gardens."*

OECD Report: Reducing Noise in OECD Countries: 1978

The OECD report Reducing Noise in OECD Countries [19] provides guidance and decision criteria for noise abatement policies. Within this document three criteria are quoted, which are used in some countries not identified within the report, to set internal noise levels. These are as follows:

The extension of time to fall asleep	L_{Aeq} = 35dB
The shortening of light sleep	L_{Aeq} = 45dB
The shortening of deep sleep	L_{Aeq} = 50dB

The three categories of sleep noise criteria reflect the sensitivity which has been found in the average person to noise at various stages of the sleep cycle. It is considered that the most sensitive period for sleep being affected by noise is when a person is falling asleep. Therefore, it is during this period that the lowest noise levels should be achieved within a dwelling and thereby any criteria set. Light sleep or REM (rapid eye movement) sleep is less affected by noise. This sleep period is when most dreaming occurs. Deep sleep is the least sensitive sleep category in the nightly sleep cycle. As such, a level 15dB(A) higher than the falling asleep level may exist without any adverse affect upon a sleeping subject.

It is also stated within this document that maximum peak levels should not exceed the background noise level by 10-15dB(A) to ensure that no sleep disturbance occurs. All the noise levels stated above are internal noise levels.

WHO Environmental Health Criteria 12 - Noise: 1980

The World Health Organisation Environmental Health Criteria [14] recommends an internal noise level of about 35dB(A) L_{eq} during the night in order to prevent sleep disturbance. Some effects of noise level on sleep are described within the main body of the report:

> "*The effects of noise on sleep appear to increase as the ambient noise levels exceed 35dB(A) L_{eq} (Berland et al, 1972). In one study , the probability of subjects being awakened by a peak sound level of 40dB(A) was 5%, increasing to 30% at 70dB(A). When changes in sleep changes were taken as an indication of disturbance, the proportion of subjects affected was 10% at 40dB(A) and 60% at 70dB(A) (Thiessen, 1969).*"

It is to this document that PPG 24 refers when establishing noise exposure categories for the night-time.

WHO Environmental Health Criteria Document on Community Noise, External Review Draft, 1993

There is currently a review of existing research of environmental health noise criteria being undertaken by the World Health Organisation [20]. The final report of the temporary advisors was submitted to the WHO in 1995 but at the time of writing has yet to be published as a replacement of the 1980 document. The external review draft includes a review of current work being performed with respect to sleep disturbance and noise. Section 11.1.1.3 dealing with sleep disturbance effects states:

"Sleep disturbance due to continuous, as well as intermittent noise, has been demonstrated by electrophysical and behavioural methods. The more intense the background noise is, the more disturbing is its effect on sleep. Measurable effects start from about 30dB(A) L_{eq}. Physiological sleep effects include changes in the pattern of sleep stages, especially a reduction in proportion of REM-sleep. Subjective effects have also been identified such as difficulties in falling asleep, subjective sleep quality and adverse after-effects like headaches and tiredness. The sensitive groups will mainly include elderly persons, shift workers, persons who are especially vulnerable due to physical or mental disorders and other individuals who have sleeping difficulties.

Sleep disturbance increases with increased maximum noise level. Even if the total equivalent noise is fairly low, a small number of noise events with a high maximum sound pressure level will affect sleep. Therefore, guidelines for community noise to avoid sleep disturbance should be expressed in terms of equivalent noise level as well as maximum levels and number of noise events. It should be noted that low frequency noise, for example, from ventilation systems, can disturb rest and sleep even at low intensity.

Where noise is continuous, the equivalent noise level should not exceed 30dB(A) indoors, if negative effects on sleep are to be avoided. In the presence of a large proportion of low frequency noise a still lower guideline value is recommended. It should be noted that adverse effect of noise partly depends on the nature of the source."

The comments with respect to low frequency noise reflect the effect of using an A-weighted sound pressure level. If most of the acoustic energy was concentrated at a very low frequency, then high levels of acoustic energy might exist but an A-weighted level may still only be 30dB(A). As an example, the A-weighting network applies a correction of 50dB at a frequency of 20Hz. Therefore, a level of 80dB at 20Hz would meet this 30dB(A) requirement.

Section 11.1.1.6 dealing with annoyance responses states that:

"Community annoyance varies with activity (speech communication, relaxation to radio and TV, etc). The threshold of annoyance for steady continuous noise is around 50dB(A)L_{eq} outdoors. Few people are seriously annoyed during the day time at noise levels below around 55dB(A)L_{eq} outdoors. Noise levels during the evening and night should be 5 to 10dB lower than during the day."

Section 11.1.2.1 deals with internal noise criteria for dwellings. It states:

"For dwellings, the critical effects are sleep disturbance, annoyance and speech interference. Specifically, for bedrooms the critical effect is sleep disturbance. Recommended guideline values inside bedrooms are 30dB(A)L_{eq} for steady-state continuous noise and for a noise event 45dB(A)L_{MAX}. Lower levels may be annoying depending on the nature of the noise source. The maximum level should be measured with the instrument set at 'fast'.

To protect the majority of the people from being seriously annoyed during the day time, the sound pressure level from steady, continuous noise on balconies, terraces and in outdoor living areas should not exceed 55dB(A)L_{eq}. To protect the majority of people from being moderately annoyed during the day time, the noise level should not exceed 50dB(A) L_{eq}. Where it is practical and feasible the lower sound pressure level should be considered the maximum desirable sound pressure level for decisions in relation to new development.

At night-time outdoors, sound pressure levels should not exceed 45dB(A)L_{eq}, so that people may sleep with bedroom windows open. This value has been obtained by assuming that the reduction from outside to inside with the window open is 15dB."

It should be noted that an assumption of 15dB(A) level reduction between external and internal noise levels has been assumed. This is quite a high level of attenuation through a building envelope if large glazed areas exist within the building facade of a neighbouring residence. The actual level difference between external and internal noise levels (free field to internal) is typically 10-5dB(A) for a face with 25 - 40 % glazed facade area, respectively. Large glazed areas are not uncommon when patio doors or large picture windows exist in a dwelling but are less common for bedrooms.

Summary of noise limits and criteria in published guidance

Table 2 Summary of sleep disturbance criteria and internal noise levels

Source of Proposed Criteria	**Falling Asleep**	**Light Sleep**	**Deep Sleep**	**Max. Level**
CEC Report EUR 5398 e: 1975 Environment and Quality of Life: Damage and Annoyance Caused by Noise		L_{Aeq} = 30 to 35		L_{Aeq} + 10
OECD Report: Reducing Noise in OECD Countries: 1978	L_{Aeq} = 35	L_{Aeq} = 45	L_{Aeq} = 50	L_{Aeq}+10 to 15
WHO Environmental Health Criteria 12 - Noise: 1980	L_{Aeq} = 35	L_{Aeq} = 35	L_{Aeq} = 35	
WHO Criteria Document: Community Noise: Environmental Health Criteria: External Review Draft 1993	L_{Aeq} = 30	L_{Aeq} = 30	L_{Aeq} = 30	L_{AMAX}< 45dB
PPG 24 Planning and Noise	L_{Aeq} = 35 (Based on WHO Environmental Health Criteria 12)			
Planning and Noise Circular W.O. 16/73	Good Standard Internal Noise Level CNL (Corrected Noise Level) Day = 45dB(A) Night = 35dB(A)			

Table 3 Summary of external noise criteria

Source of Criterion	External Noise Limit dB
CEC Report EUR 5398 e: 1975 Environment and Quality of Life: Damage and Annoyance Caused by Noise	L_{Aeq} = 50 - 55
British Standard BS 5228: Part 1: 1984 Noise Control on Construction and Open Sites. Part 1. Code of practice for basic information and procedures for noise control	$L_{Aeq,1\ Hour}$ at facade = 40 - 45
PPG 24 Planning and Noise	BS 4142 where appropriate
MPG 11 Control of Noise at Surface Mineral Workings	Day $L_{Aeq,1h}$= 55, (No less than 45 in quiet area) Night $L_{Aeq,1h}$ = 42 Gardens/open spaces $L_{Aeq,1h}$= 55-65
WHO Criteria Document: Community Noise: Environmental Health Criteria: External Review Draft 1993	Day-time L_{Aeq}= 50 Moderate Annoyance Night-time L_{Aeq}= 45

Experience in other countries

USA

The largest concentration of wind turbines in the world is situated in California, USA. Three main groups of turbines exist at Altamont, Palm Springs and Mojave Desert. Some work has been performed to provide noise criteria for these sites such that a minimum of disturbance is caused to neighbouring properties.

The most recent revisions have been performed under the title "*Tri-County Wind Energy: Mitigation Compliance Monitoring Program*" which has been performed for the Alameda, Contra Costa & Solano Counties and the California Energy Commission. Within this document is a section dealing specifically with noise which contains a brief description of the sources of noise from wind turbines. It also provides a summary of existing policies and regulations for wind turbines and makes a recommendation for adoption by the counties sponsoring the report. Extracts from this and other guidance from the USA are contained in Appendix B.

Denmark

The development of wind turbines and wind farms in Denmark has been under way for at least 15 years. During this time, work has been performed to assess the potential for noise emissions from wind turbines and also the level of ambient noise due to wind in trees and grasses. This work was used, to a degree, to formulate policy for wind turbines with respect to noise. This has been issued by the Ministry of the Environment, Denmark, National Agency of Environmental Protection, and is called *Statutory Order from the Ministry of the Environment No.304 of May 14, 1991 on Noise from Windmills.*

Part 2 of this document states the following:

> *"Establishment and Operation of Windmills*
>
> *Section 2. The noise load from windmills shall not exceed 45dB(A) at outdoor open spaces in the immediate vicinity of neighbouring properties in open country.*
>
> *Subsection 2. For the purposes of this order neighbouring properties means all residential buildings other than the private house of the windmill owner.*
>
> *Subsection 3. The noise load from windmills shall not exceed 40dB(A) in the most noise-inflicted spot at outdoor open spaces in residential areas and other noise-sensitive land uses.*
>
> *Subsection 4. For the purposes of this Order noise-sensitive land uses means areas used or reserved for the purposes of institutions, week-end houses, allotment gardens or recreation.*
>
> *Section 3. The noise load shall be determined according to the guidelines laid down in the Annex to this order as the equivalent corrected A-weighted noise level at a height of 1.5 metres at a wind speed of 8m/s at 10 metres above ground height."*

This statutory order defines the measurement position, the wind conditions and the level which should not be exceeded. The determination of the sound power level (SWL) from the wind turbines has also be defined within the Annex and is the method reported by most Danish manufacturers of wind turbines. The quoted SWL is that which is emitted by the turbine when operating at 8m/s wind speed measured at a height of 10 metres above ground level.

In the UK the level which must be achieved by a wind farm site has sometimes been set at the cut-in wind speeds of the wind turbines, the expectation being that wind-induced noise at the receiver position will increase at a greater rate than the emitted noise from the turbine. Therefore, for a comparison of agreements and conditions which have already been undertaken by some developers in the UK it is better to compare directly these levels at cut-in.

The emitted noise from a wind turbine increases with wind speed. This increase is typically about 1dB(A)/m/s. Different wind turbines have different rates of increase but this figure is fairly average for most commercially available wind turbines. Allowing for the height difference between the hub height (sometimes used for specifying the wind conditions when undertaking a noise test for compliance to any agreed noise level in the UK) and the wind speed and height used for the Danish Statutory Order of 8m/s at 10 metres height, Table 4 details the equivalent L_{Aeq} level which might be expected to meet the Danish Statutory Order at the cut-in wind speed of the wind turbines. A range is indicated to reflect the effects of varying ground roughness (0.01-0.05m) and rate of increase of noise with wind speed (0.75-1.0dB/m/s).

Table 4 Comparison of Danish limits to noise levels at cut-in

L_{Aeq} @ 8m/s @ 10m height dB(A)	Equivalent L_{Aeq} @ 5m/s @ 30m height dB(A)
45	40-42
40	35-37

The determination of the character of the noise emitted by wind turbines is performed by both a subjective and an objective test. This takes the form of listening to the emitted noise at the affected property and/or performing objective measurements of the incident noise at the property. The method by which tones are evaluated is the Joint Nordic Method for the Evaluation of Tone in Broadband Noise [21]. This method applies a 5dB(A) penalty to the incident noise from the wind turbine when the tone is deemed "prominent" using the objective test method.

The determination of when a tone is "prominent" is the result of laboratory tests of different tone and masking levels and different tone frequencies. (There is current work being performed for the DOE by NPL & ISVR to determine a more appropriate correction method for tonal noise. It is expected that this will not be included within a revision to BS 4142 for a number of years.)

The audibility criterion that is defined within the Joint Nordic Method is based upon Zwicker critical bands. The audibility criterion is frequency-dependent unlike the criterion defined within BS 7135 which is not frequency-dependent. The audibility threshold is defined as:

ΔL_t Audibility Criterion = $- 2 - \text{Log} (1 + (f_t / 502)^{2.5})$

where f_t = tone frequency.

The Joint Nordic Method also defines a method for the analysis of tones in non-stationary conditions, ie if the level or frequency of the tone is varying.

The details of the Joint Nordic Method are discussed further in Chapter 6.

Netherlands

The Netherlands has no specific legislation concerning noise from wind turbines but has noise regulations for industrial noise which state the following:

$L_{Aeq,24hr}$ = 40dB(A) for rural areas without traffic
L_{Aeq} = 45dB(A) for quiet residential neighbourhoods in the city
L_{Aeq} = 50dB(A) for residential neighbourhoods in the city

The 45dB(A) and 50dB(A) limits are day-time values and should be reduced by 5dB(A) for evening periods and by 10dB(A) during the night. It should be noted that this implies that quiet residential neighbourhoods will, at night, have stricter noise limits than rural areas without traffic. It is understood that these are only recommendations and municipalities may use other standards when they issue a Nuisance Act permit.

Where a noise zone has not been proposed, the quality of the environment around the proposed wind farm will be considered. For example, if a wind farm were to be developed and dwellings were located nearby, background noise measurements would be undertaken to assess the prevailing background noise levels at the dwellings, the background noise level being defined as the L_{A95} level. Turbine noise would then not be allowed to exceed this level, ie the wind farm would be designed to not exceed the existing background noise levels.

Germany

German recommendations for acceptable noise levels are given in documents covering "The law for the protection against any emissions" and detailed under Technical Instructions for Noise.

The sound pressure levels, measured as $L_{Aeq,T}$, which must not be exceeded, are as follows:

	Day-Time	Night-Time
Commercial Areas	65dB(A)	50dB(A)
Mixed Areas	60dB(A)	45dB(A)
General Residential	55dB(A)	40dB(A)
Pure Residential	50dB(A)	35dB(A)

There currently exists a method for the determination of the audibility of tones , Draft DIN 45 681 [22]. This method is in draft form and is based upon ISO 7779 which forms the basis of BS 7135 Part 1 Annex D. This Draft DIN standard proposes a penalty rating method that follows the guidance contained within ISO 1996 (BS 7445) which gives a tonal penalty to the noise, that is related to the audibility of the tone. The penalty varies from 0-6dB depending upon the exceedence of the tone above the tone detection threshold. However, the penalty system is based upon the tone detection thresholds that are described in ISO 7779, and like BS 7135, the detection thresholds do not follow classic critical band theory. The audibility threshold described in DIN 45 861 is 6dB below the critical band masking level. Classic theory would indicate that this is 4dB over-sensitive at frequencies below 500Hz. Experience through the application of the tonal assessment method described in DIN 45 681 would indicate that a tonal penalty would be, and is, applied even when a tone is not audible but the assessment method indicates that one exists.

DIN 45 681 usefully defines which lines in the spectrum should be counted as contributing to the tone energy. Section 4.3.2 explains:

> *"It is not always obvious whether sidebands contribute to tone energy. A sideband should be included in the sum if the difference with respect to the maximum narrowband level is less than 10dB, and the difference with respect to the average narrowband of the masking noise in the critical band about the tone is larger than 6dB."*

5. SURVEY OF PUBLIC REACTION TO NOISE FROM WIND FARMS

Introduction

One element of the work of the Working Group was to assess the circumstances which have or have not resulted in complaints by the public over noise from wind farms. A survey of public reaction to noise from wind turbines as reported to Environmental Health Departments was therefore conducted, based upon the operational wind farms in England and Wales as of February 1994. A list and brief description of the wind farms used in the survey is given in Table 5 and Fig 1 shows their location.

Table 5 Operational wind farms in England and Wales (Feb 1994)

Wind Farm	Turbine Manufacturer	No.	Rated Power kW	Total Capacity kW
Cemmaes, Powys	WEG	24	300	7200
Kirkby Moor, Cumbria	Vestas	12	400	4800
Chelker, Yorkshire	WEG	4	300	1200
Ovenden Moor, Yorkshire	Vestas	23	400	9200
Delabole, Cornwall	Vestas	10	400	4000
Penrhyddlan and Llidiartywaun, Powys	Mitsubishi	103	300	30900
Rhyd-y-groes, Anglesey	Bonus	24	300	7200
Blyth Harbour, Northumberland	HMZ	9	300	2700
Orton Airport, Cumbria	Carters	10	300	3000
Goonhilly Downs, Cornwall	Vestas	14	400	5600
Cold Northcott, Cornwall	WEG	22	300*	6700
Blood Hill, Norfolk	Vestas	10	225	2250
Taff-Ely, Mid Glamorgan	Nordtank	20	450	9000
Carland Cross, Cornwall	Vestas	15	400	6000
Coal Clough, W Yorkshire	Vestas	24	400	9600
Llangwyryfon, Dyfed	WEG	20	300	6000
Haverigg, Cumbria	Vestas	5	225	1125
Royd Moor, S Yorkshire	Bonus	13	450	5850

* Includes 1x400 kW Turbine

A questionnaire was sent to local authorities having wind farms in their areas. A summary of the results of this survey appears in Table 6 and a more detailed discussion follows.

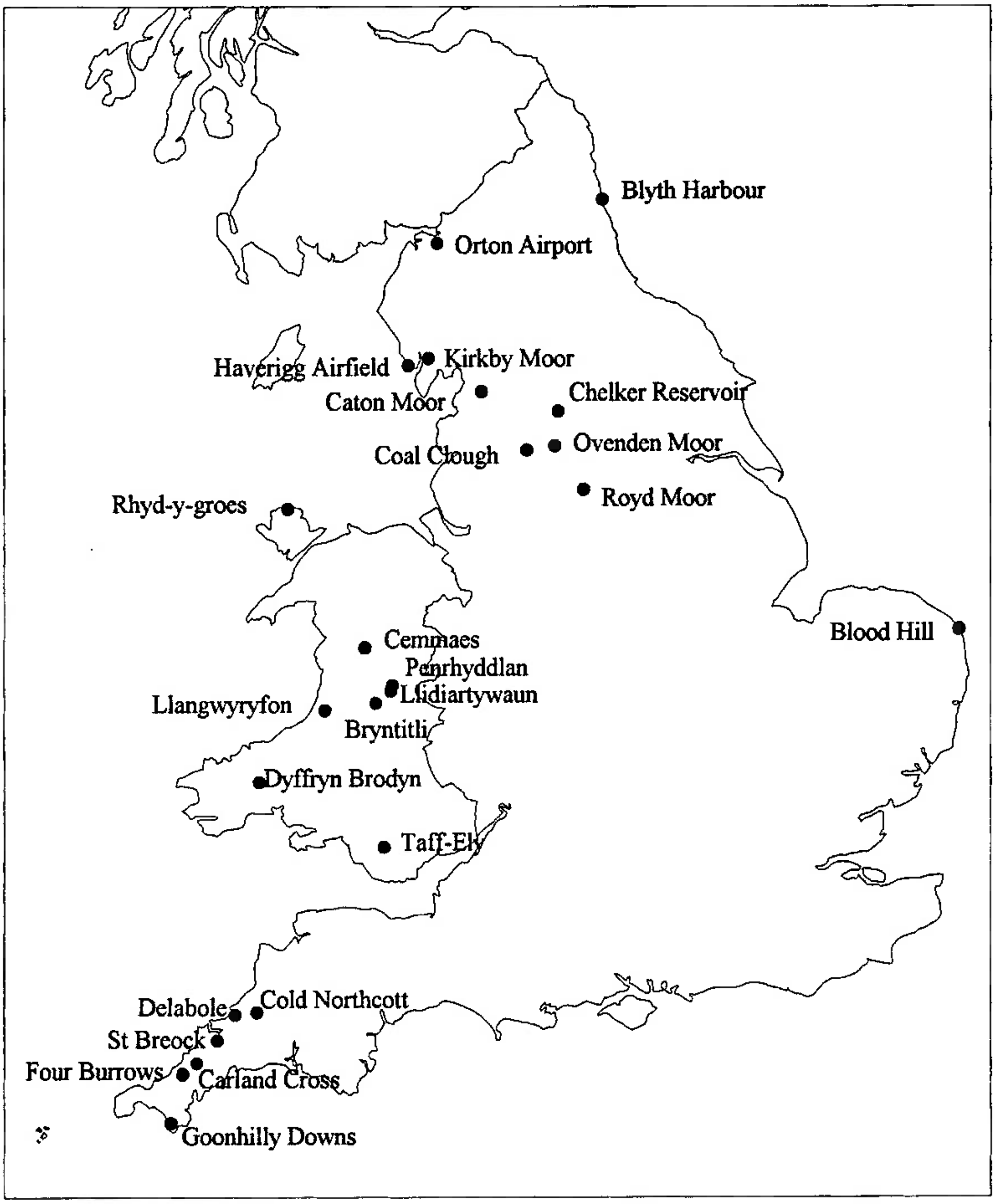


Figure 1 Wind farms constructed under NFFO-1 and -2

Table 6 Summary of complaints from wind farms
(figures in italics are from conversations on phone rather than from the questionnaire)

Wind Farm	Distance from residences to wind farm (m)	Number of complaints			Aspects of noise leading to complaints			
		Verbal	Written	Distant	Overall	Tones	Swish	Other
Cemmaes		*0*	*0*	*0*	*n/a*	*n/a*	*n/a*	*n/a*
Kirkby Moor	*700*	*0*	*0*	*0*	*n/a*	*n/a*	*n/a*	*n/a*
Chelker	350-500	0	0	0	n/a	n/a	n/a	n/a
Ovenden Moor	320-630	0	0	0	n/a	n/a	n/a	n/a
Delabole	350-1380	15	7	5	No	Yes	No	Yes
Penrhyddlan and Llidiartywaun	700-1200		5	2	Yes	Yes	Yes	No
Rhyd-y-Groes	400-600	1	1	0	Yes	No	No	Yes
Blyth Harbour		*0*	*0*	*0*	*n/a*	*n/a*	*n/a*	*n/a*
Orton Airport								
Goonhilly Downs								
Cold Northcott	380-500	10+	5	1	Yes	Yes	Yes	No
Blood Hill	400-450	0	0	0	n/a	n/a	n/a	n/a
Taff-Ely		*1*	*1*	*0*				
Carland Cross	370-410	2	2	2	Yes	Yes	Yes	Yes
Coal Clough	420	0	0	0	n/a	n/a	n/a	n/a
Llangwyryfon								
Haverigg	600, 1000	0	0	0	n/a	n/a	n/a	n/a
Royd Moor								

Effects of topography

Following experience from mainland Europe, initial expectations had been that the noise from wind turbines would be most intrusive at wind speeds at and just above cut-in. It had been expected that as the wind speed increased, the background noise generated by the passage of wind through trees and around buildings would increase at a faster rate than the noise generated by the turbines. The margin of the turbine noise above background noise would then have been greatest at relatively low wind speeds with the turbine noise progressively drowned out as the wind speed increased. This has not always been the case, however, particularly at many of the sites at which complaints over wind farm noise have arisen. At Cold Northcott, Penrhyddlan and Llidiartywaun, Rhyd-y-Groes and Delabole the noise was felt to be more intrusive at hub height wind speeds of 8m/s and above. In some cases this is influenced by the switching to a higher turbine rotational speed in higher winds but is primarily because properties are frequently sited in sheltered areas. It is not unusual for turbines to be operating in relatively strong winds on an exposed hill top location while some of the nearest properties in relatively sheltered valleys remain out of the wind and hence background noise levels can remain low in the absence of significant wind-generated background noise.

Change in attitude with time

There was no firm evidence of complainants becoming accustomed to the noise and their level of concern diminishing as a result. Decreasing annoyance was seen at some wind farm sites but this was usually due to remedial action being taken to reduce the noise from the wind turbines. An example of this occurred at Delabole where the turbines on commissioning could under certain conditions produce a noise described as a "squawk". This was also observed at Carland Cross using the same model of turbines and was believed to be caused by an instability in the flow over the turbine rotor blades. The effect was remedied by making adjustments to the pitch control settings and application of tapes, or boundary layer trips, to the trailing edges of the blades. These boundary layer trips disturbed the boundary layer or air flow close to the surface of the blade, causing it to become turbulent rather than laminar. As a laminar boundary layer is a prerequisite for the excitation process to occur this eliminated the noise source.

At sites which have not been able to reduce noise levels to the satisfaction of residents, complainants have become impatient and shown increasing annoyance.

Characteristics of the noise

At all sites at which complaints have been made reference has also been made to particular characteristics of the noise. Mechanical noise of a tonal nature, usually from the gearbox, has been frequently cited as being an aspect of the noise leading to complaints. In cases where mechanical noise is present it is not surprising that this should lead to increased annoyance, as is reflected in the penalties for tonal content added to rating levels of noise in standards such as BS 4142.

Blade swish is a phenomenon more peculiar to wind turbines which has emerged as another characteristic which can under certain circumstances add to the likelihood of complaints. Swish was identified as being one aspect of the noise leading to complaints at Penrhyddlan and Llidiartywaun, Cold Northcott and Carland Cross. Recorded time trace data from a property near to Carland Cross showed peak to trough differences of the A-weighted noise up to 3dB in an open situation and up to 6dB in a location where multiple reflections from nearby buildings affected noise levels. A noticeable level of swish was also observed by the Environmental Health Officer at Coal Clough although no complaint has been made at this site.

Intermittent blade thump was cited as being a contributing factor leading to complaints at Carland Cross.

Noise levels

As illustrated later in Chapter 6 background noise and turbine noise levels can be quite variable and show a fair degree of scatter even when plotted against wind speed. From the often limited data available it has therefore not been possible to reach any firm conclusions on noise levels which are likely to lead to complaints, particularly as in many cases the character of the noise has been as influential as the actual noise level in leading to complaints.

Time of day

Indications of periods during which the noise was found to be most audible or most intrusive were generally the same irrespective of whether weekdays or the weekend were being considered. At Cold Northcott, Rhyd-y-Groes and Delabole night-time (22.00-06.00) was reported to be the period at which nearby residents found the noise most intrusive, along with the evening (18.00-22.00) at Cold Northcott and Delabole and early morning (06.00-09.00) at Rhyd-y-Groes.

Relative impact, indoors compared to outdoors

The level of intrusion was in general a degree less indoors than out of doors. If the level of intrusion was considered high outdoors it was low indoors; if the noise could only be heard faintly outdoors it was inaudible indoors. On some sites (Blood Hill and Chelker) the turbines were considered largely inaudible both indoors and outdoors. The finding that outdoor levels were found to be more intrusive than indoor levels is somewhat at odds with the previous finding that the intrusion was in some cases greater at night when you would expect people to be indoors.

Reasons for absence of complaints

Although this section has concentrated on the factors affecting the likelihood of complaints it should be noted that at eight of the thirteen wind farms for which we have data no complaints have been received. The most frequently given reason is (not surprisingly) the low noise levels or inaudibility of the wind farm. Perceived low noise levels are usually the result of one or more factors including:

- background noise levels being sufficiently high at all wind speeds to substantially mask the turbine noise
- relatively quiet turbines with little or no tonal content in the noise emissions
- relatively large separation distances between turbines and nearest residences
- public acceptability of the wind farm in general.

Conclusions from the survey

- The framework for assessing wind turbines needs to relate noise at residences to turbine noise, taking into account the possibility of nearest residences remaining sheltered from the wind when turbines are operating in moderate-to-high wind speeds.
- Once nearby residents are sensitised to noise they are unlikely to get used to it over a relatively short period of time (approximately 12-18 months at the time of writing).
- The assessment method should impose penalties for distinctive characteristics of the noise.
- The assessment method should take account of the lower background noise levels at night.
- By using best practice it is possible to develop wind farms which are unlikely to lead to complaints over noise levels from the nearby residents.

6. NOISE LIMITS

Introduction

The background against which members of the Noise Working Group have set out to define a procedure for the measurement and rating of noise from wind turbines has been explored in Chapter 2. This chapter describes a framework for measurements with indicative noise levels thought to offer a reasonable degree of protection to wind farm neighbours without placing unreasonable restrictions on wind farm development or adding unduly to the costs and administrative burdens on wind farm developers or local authorities. The suggested noise limits and their reasonableness have been evaluated with regard to regulating the development of wind energy in the public interest. They have been presented in a manner that makes them a suitable basis for noise-related planning conditions or covenants within an agreement between a developer of a wind farm and the local authority.

The noise limits suggested have been derived with reference to:

- existing standards and guidance relating to noise emissions
- the need of society for renewable energy sources to reduce the emission of pollutants in pursuance of Government energy policy
- the ability of manufacturers and developers to meet these noise limits
- the researches of the Noise Working Group in the UK, Denmark, Holland and Germany
- the professional experience of members of the Working Group in regulating noise emissions from wind turbines and other noise sources
- the discussion of the issues at meetings of the Noise Working Group and with others with appropriate experience.

The Noise Working Group has sought to protect both the internal and external amenity of the wind farm neighbour. Wind farms are usually sited in the more rural areas of the UK where enjoyment of the external environment can be as important as the environment within the home.

The noise limits have been devised with regard for the human environment without specific consideration of the effect of noise on farm livestock. Members of the Noise Working Group are however unaware of any problems in this area to date. Indeed, at many windswept locations the turbine towers and transformers appear to offer a welcome degree of protection from the elements.

The guidance contained in this chapter refers to the operation of the wind farm, and is not appropriate to the construction phase which should be considered separately according to existing guidance such as BS 5228: 1984, Noise Control on Construction and Open Sites.

Locations for setting noise limits

At the wind farm, at the site boundary or at noise-sensitive properties?

There are broadly four options to consider when deciding upon the most appropriate location(s) to set noise limits:

1) In the wind farm.

2) At the boundary of the site occupied by the wind farm.

3) At the surrounding noise-sensitive properties.

4) At any position over a given distance from the nearest turbine.

The advantages of options (1) and (2) are that at these positions the noise will be easier to monitor as access to the site is controlled by the operator and the noise levels will be higher and therefore probably more easy to distinguish from the background noise. The disadvantage with this approach is that in its simplest form it does not take account of the proximity of the noise-sensitive properties, and even if noise levels at nearest properties are theoretically derived from limits and measurements close to the wind farm, this type of limit offers little protection to residents if the inferred levels prove inaccurate.

Option (3) has been the preferred method on all planning conditions on wind farms in the UK to date and is described as the normal approach in Annex 5 of PPG 24. This approach has the advantage that the limits can directly reflect the existing environment at the nearest properties and the impact that the wind farm may have on this environment. In some circumstances access to nearest properties may prove problematical but it is the Noise Working Group's experience that in general residents are happy to allow access to monitor noise levels, particularly if monitoring is required in response to complaints.

The fourth option, setting limits at a standard distance from the development in addition to those limits set at nearest properties, was one of the recommendations of the Welsh Affairs Committee's Report on Wind Energy [23]. This approach has some merits in that it avoids large areas of land becoming unsuitable for future development because of noise and conversely provides the wind farm operator with some protection from claims of nuisance from future development. In practice, because of the population distribution in the UK, limits on wind farm noise will be dictated by consideration of nearest properties. This has been the case with wind farm developments built to date in England and Wales. If limits were related to background noise levels then a knowledge of the variation in background noise levels with wind speed at all positions around a wind farm would be required. Determining these levels would be prohibitively expensive unless some crude assumptions were made.

For the reasons given above the Noise Working Group recommends that the current practice on controlling wind farm noise by the application of noise limits at the nearest noise-sensitive properties is the most appropriate approach. This approach has the advantage that the limits can directly reflect the existing environment at the nearest properties and the impact that the wind farm may have on this environment, for the reasons given above.

Internal or external noise limits?

Given that one of the aims of imposing noise limits is to protect the internal environment one might consider it appropriate to set these limits and hence monitoring locations at positions within the building. There are, however, some practicalities to take into consideration which lead us to believe that the current practice of setting external limits on noise is the more sensible approach:

- Monitoring of noise to demonstrate compliance with planning conditions may require data to be logged over a period of days in order to capture enough data at the required conditions. It may not always be feasible or reasonable to expect to leave equipment set up in someone's bedroom or living room for this period of time.

- Noise levels inside a dwelling would be extremely difficult to predict as they would depend upon the noise insulation properties of the windows, doors, roof and walls and the acoustic properties of the rooms. Each room in each property would have to be considered separately. It is simpler and as safe to predict free-field noise levels outside of the property and then make a conservative assumption on the attenuation properties of the building envelope.

- Noise limits, and therefore measurements, are in any event required outside the property to protect the external amenity. If internal noise levels can be inferred from these external limits then a requirement for internal measurements would place an unreasonable burden on the operator.

The noise limits applied to protect the external amenity should only apply to those areas of the property which are frequently used for relaxation or activities for which a quiet environment is highly desirable. For example, if a farm house is one of the noise-sensitive properties it would probably not be appropriate to apply limits to all the land belonging to the farm.

Types of noise limit

Options available

There are three types of constraints that can be placed on noise-producing developments. Ranked in order of complexity these are:

1) A minimum separation distance between the development and the nearest properties.

2) An absolute limit based on the average level of noise which should not be exceeded in a specified time period.

3) A relative limit based upon the permitted increase in noise level with respect to the background noise level. This is the approach used in BS 4142: 1990.

The descriptions of (2) and (3) are taken from PPG 24 which indicates either may be appropriate depending upon circumstances. The merits of each approach are considered in turn below.

Minimum separation distance

Paragraph 47 of the annex to PPG 22 refers to experience from mainland Europe which has shown that there is unlikely to be a significant noise problem for a residential property situated further than distances of 350-400 metres from a wind turbine. The PPG also suggests that:

> *"Lesser separation distances may be acceptable depending on the turbines used and the specific conditions at a site."*

This was true for the flat, open sites typical of Northern Europe and for the size and number of turbines used in wind farms at the time of writing PPG 22. We believe the guidance in PPG 22 was intended to give the reader an appreciation of the magnitude of the separation distances that would be required to protect local amenity. Indeed, wind farms have been constructed with this order of separation distance which have not resulted in complaints over noise. There are however a number of further considerations relevant today.

The emitted sound power level (SWL) from different wind turbines may vary by several dB for the same wind speed condition at hub height depending upon the size and design features of the turbine. Assuming hemi-spherical propagation with atmospheric absorption of 0.005dB/m this means that a quiet wind turbine with a SWL = 95dB(A) positioned at 245m from a dwelling would have the same acoustic impact as a turbine with a SWL = 101dB(A) positioned at 437m from a dwelling. (Note: this would result in an incident noise level at a dwelling of ≈ 38dB(A) from a single wind turbine.)

For small and medium-sized wind farms, say less than 10 to 20 turbines, incident noise levels at a residence are usually only influenced by those turbines closest to the residence. However, the advent of the larger wind farms being proposed and built today means that the cumulative effect of many turbines at some distance from the residence may also increase the noise levels around a property. Greater separation distances will therefore be required to achieve the same noise levels as a smaller wind farm using the same type of turbines.

The difference in noise emissions between different types of machine, the increase in scale of turbines and wind farms seen today and topographical effects described below all dictate that separation distances of 350-400 metres cannot be relied upon to give adequate protection to neighbours of wind farms.

Absolute limits

There are a number of ways in which absolute noise limits for wind farms can and have been set:

- A maximum level not to be exceeded at any wind speed at any property.

- A maximum level not to be exceeded at a specific wind speed or over a range of wind speeds set irrespective of the prevailing background noise level.

- A maximum level not to be exceeded at a specific wind speed or over range of wind speeds based on measurements of the prevailing background noise level taken prior to the construction of the wind farm.

The second option is of the type used in Denmark where noise from wind turbines is commonly limited to 40dB(A) in residential areas when measured at a wind speed of 8m/s at 10m height. This approach has its attractions in that it is relatively simple to use. Manufacturers need only state sound power levels for their machines at one wind speed, developers do not have to concern themselves with background noise surveys and actual levels need only be monitored at one, frequently occurring wind speed. The flat open countryside of Denmark enables one to be reasonably confident that if the noise limits at 8m/s are attained then the noise from the wind farm at other wind speeds is unlikely to be unduly disturbing. As demonstrated in Chapter 4, at cut-in the noise level will be less than 36-37dB(A) whereas at higher wind speeds the background will increase at a faster rate with wind speed than the turbine noise, such that the background noise soon approaches that of the turbine.

PPG 22 also advises at paragraph 42 that wind-generated background noise increases with wind speed and at a rate greater than that of wind turbines. It is also stated that the greatest level difference between turbine noise and background noise is liable to occur when wind speeds are low. PPG 22 does however note that for some sheltered locations the background noise levels may remain low even when wind speeds are well above the cut-in wind speed for the wind turbines.

In general, the assumption that the greatest difference in level might be at low wind speeds is true for flat sites which do not offer any shelter from the wind. These types of sites may be found in the Netherlands and Denmark where the topography of the landscape is such that little shelter exists. However, within the UK landscape, the positioning of a majority of wind farms to the West of the country has resulted in sites being developed within landscapes that are not flat. The effect of deep valleys (like those found in Wales, the Pennines and Scotland) and sheltered positions (like those that are found in Cornwall), is to protect dwellings from the effects of the wind and thereby from an increase in the background noise level due to the wind. Figs 2, 3 and 4 show the differences that can be experienced by dwellings when positioned in exposed or sheltered positions.

Fig 2 details measurements made within a deep valley positioned 150 metres below a mountain top plateau. Fig 3 details measurements made in a location which was partially protected from the prevailing wind by existing buildings and a tree wind break whereas Fig 4 details measurements performed at an exposed position on the top of a mountain. Wind speed measurements were performed on the top of a mountain at positions where wind turbines would be expected to be erected. It should be noted that the anemometer measurement height is different in Fig 3. The actual wind speed at the hub height of a wind turbine might be expected to be higher than that shown in Figs 2 & 4 by as much as a factor of 1.21, ie a wind speed of 10m/s measured at a height of 10 metres may be expected to be a wind speed of 12.1m/s measured at a hub height of 30 metres.

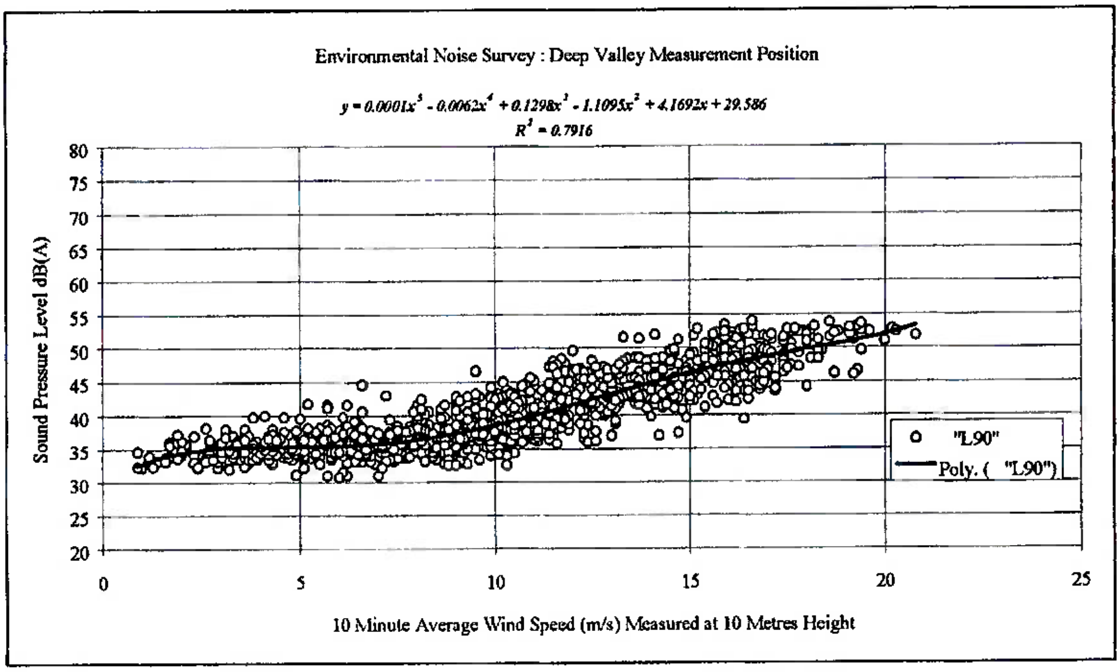


Figure 2 Background noise measurements in a deep valley position

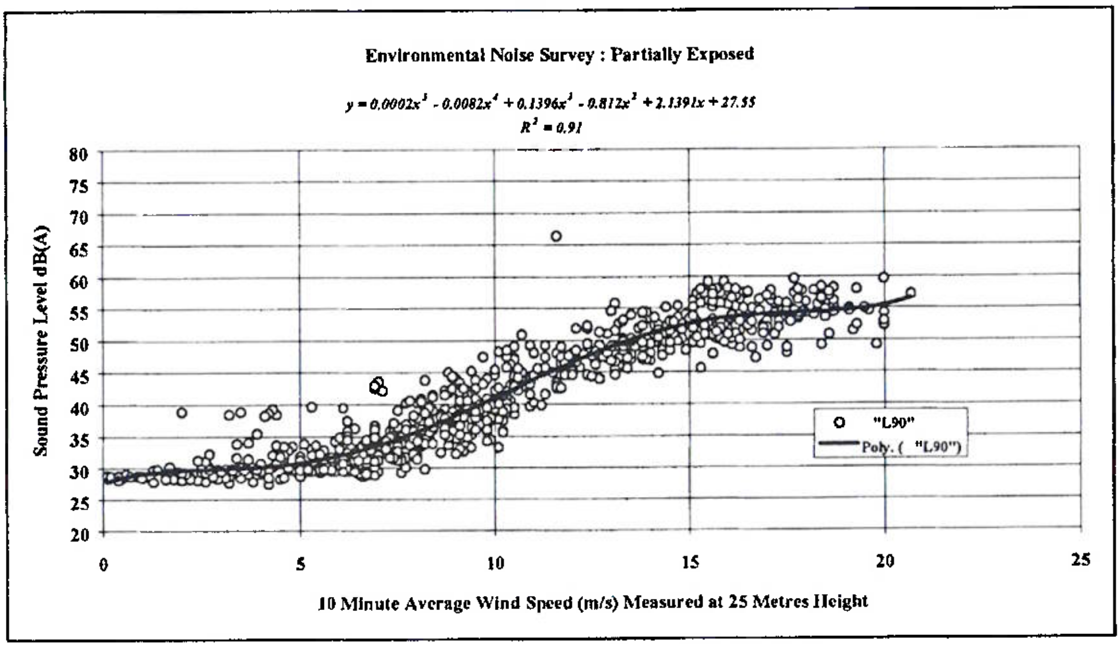


Figure 3 Background noise measurements in a partially exposed position

The variation of the rate of increase of the background noise level with wind speed has resulted in some sites experiencing complaints at high wind speeds but no complaints at low wind speeds. This is because, although turbine noise continues to rise with an increase in wind speed, the background noise levels have remained unchanged. Therefore, the level difference between the incident noise from a wind farm and the prevailing background noise level when the wind farm is not operating has been greatest at these higher wind speeds.

It may be seen that this sheltering effect results in each site having its own background noise environment with respect to wind-generated noise. Therefore, each position adjacent to a site should be considered for sheltering effects from the wind. The assumption that background noise levels will increase at a greater rate than the emitted turbine noise does not always hold true for the hillier sites which are found within the UK.

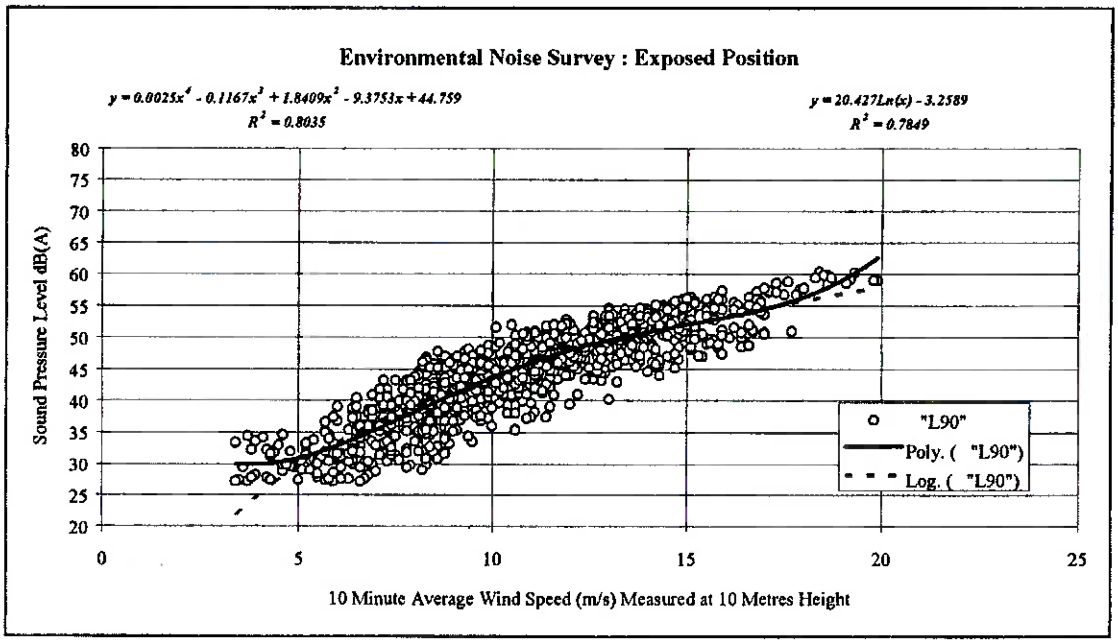


Figure 4 Background noise measurements in an exposed position

Even in Denmark the assumption that background noise increases with wind speed at a faster rate than the turbine noise may not be true for variable speed machines which, although usually quieter than fixed speed machines at low wind speeds, are characterised by a steeper rate of increase in noise emission with wind speed.

For the reasons given above the Noise Working Group considers that absolute noise limits applied at all wind speeds are not suited to wind farms in typical UK locations and that limits set relative to the background noise are more appropriate in the majority of cases. Later in this chapter consideration is given to the use of absolute levels in circumstances when background noise levels are low and in cases where low turbine noise levels can be achieved over a range of wind speeds.

Relative limits

PPG 24 introduces the concept of using BS 4142, a standard designed to predict the likelihood of complaints, as a tool for setting noise limits on industrial development. Paragraph 19 within Annex 3 of PPG 24 considers noise from industrial and commercial developments. It is stated that:

> *"The likelihood of complaints about noise from industrial development can be assessed, where the Standard is appropriate, using guidance in BS 4142: 1990. Tonal*

or impulsive characteristics of the noise are likely to increase the scope for complaints and this is taken into account by the "rating level" defined within BS 4142. This "rating level" should be used when stipulating the level of noise that can be permitted."

It should be noted that the guidance proposes the use of BS 4142 where the standard is appropriate. For the reasons described in the next section a literal interpretation of BS 4142 is difficult to apply to an assessment of wind farm noise and it may therefore not be appropriate. The Noise Working Group does however consider the principle of setting noise limits relative to the existing background noise level is appropriate, subject to the discussion on low noise levels later in this chapter.

Problems with interpretation and the literal application of BS 4142.

Paragraphs 43-44 of PPG 22 consider the use of BS 4142: 1990 and reports that this standard has been advocated as the standard which comes nearest to dealing with the issues encountered in wind farm developments.

Paragraph 44 states three reasons why using BS 4142: 1990 may be inappropriate for assessing wind turbine noise. These are:

"a) Wind farms are likely to be developed in largely rural areas and not in the areas to which the standard is principally addressed, namely mixed residential and industrial areas;

b) the scope of BS 4142 specifically precludes situations where background noise levels are below 30dB(A);

c) BS 4142 recommends that noise measurements should not be taken in extreme weather conditions such as high wind speeds greater than 5 metres per second average".

Paragraph 45 of the annex to PPG 22 states that:

"Where any of these factors gives rise to concern about whether BS 4142 is appropriate as a means of determining potential or actual perceived noise nuisance, the combined effect of the wind turbines should be determined by reference to the particular character and sensitivity of the area."

It is therefore worth exploring the reasons behind these qualifications on the use of BS 4142 and what measures are necessary to overcome these limitations.

Although the standard is intended for use in mixed residential and industrial areas as suggested by its title, there are no obvious reasons which prevent its application in more rural areas and indeed Members of the Noise Working Group have used it in such areas. There is no evidence to suggest that the average rural dweller is more or less sensitive to noise than their suburban or urban counterparts. On the one hand some people may be attracted to the countryside for its peace and quiet whereas for others the countryside is their workplace and noisy activities are a part of working life.

The scope of BS 4142 precludes its use where background noise levels are below 30dB(A). Background noise levels in rural areas, particularly during the quiet periods of the day and night, may frequently fall below this level. Two reasons have been suggested for this limitation in scope [24]:

- Measurements of background noise giving results below 30dB(A) may not be reliable due to the limitations of the instrumentation (although one could be fairly certain that the actual levels were no more than those measured!).

- The standard is designed to assess the likelihood of complaints from people residing <u>inside</u> a building based on measurements outside of the building. It is considered that when noise levels are less than 30dB(A) when measured externally the masking level inside the property will be dominated by internal noise sources.

This exclusion of the rating method contained within BS 4142 for these situations might be considered to leave rural environments, which can be very quiet, open to developments which could result in a significant change in the noise environment.

The current standard might be precluded if a background noise level was measured of 29dB(A) and the rated incident noise level were 40dB(A). Using the assessment method proposed within BS 4142, a level difference of 11dB(A) would otherwise be considered likely to give rise to complaints. However, if the background noise level were 31dB(A) and the rated noise level again 40dB(A), BS 4142 would no longer be precluded from use and a level difference of 9dB(A) would still be considered likely to give rise to complaints. The only difference is an increase in the measured background noise level of 2dB(A).

This apparent inconsistency has been considered by the committee for BS 4142 and has led to a proposed change within the scope of BS 4142, in the form of a revision. It is proposed that it will now read:

"The method is not applicable for assessing the noise inside buildings or when the background and specific noise levels are low.

Note: For the purposes of this Standard, background noise levels below 30dB and rating levels below 35dB are considered to be very low."

The question that arises is: if one intends to apply the principles of BS 4142 to the protection of external amenity, and the instrumentation is available to accurately measure noise levels below 30dB(A), should a margin above background approach be pursued in low noise environments or can an absolute level be justified in such circumstances? This question is addressed in the following section.

BS 4142 also suggests that:

"Noise level measurements should not generally be made under extreme weather conditions such as high winds (greater than 5m/s average)...."

The reason given for this limitation is:

"Weather conditions may affect measurements either by generating extraneous noise or by influencing sound propagation."

PPG 22 warns that:

"Wind farms are likely to be sited in windy conditions where the BS 4142 conditions may not be satisfied."

At the nearest residences to wind farms, even though the wind speed will usually be less than at the wind farm site, the local wind speed may still rise above 5m/s during periods when measurements are required. One should therefore exercise caution to ensure that measurements are not contaminated by wind noise on the microphone and consider the use of secondary windshields.

Propagation effects in high winds could result in unrepresentative results being obtained, particularly for ground-based sources located some distance upwind or downwind of the receiver. The warning contained in BS 4142 about taking measurements in winds greater than 5m/s guards against these effects on sound propagation. In the case of wind farms the turbines will often be in winds greater than 5m/s when at the same time the nearest residences are in relatively calm conditions. As wind speeds at both locations and all points in between will affect propagation and because most, if not all, turbine operation will occur at hub-height wind speeds greater than 5m/s one could argue that measurements taken in such conditions would strictly be outside the scope of BS 4142. It should be noted however that the effect of wind strength and direction on propagation may be less for elevated sources such as wind turbines. It is of course essential to be able to take measurements during windy conditions when assessing wind turbine noise and so it is suggested here that measurements are taken over a variety of wind directions to ensure that typical results are obtained.

Setting noise limits relative to the background noise level is relatively straightforward when the prevailing background noise level and source level are constant. However, wind turbines emit noise that is related to wind speed, and the environment within which they are heard will probably also be dependent upon the strength of the wind and the noise associated with its effects. It is therefore necessary to derive a background noise level that is indicative of the noise environment at the receiving property for different wind speeds so that the turbine noise level at any particular wind speed can be compared with the background noise level in the same wind conditions. This is consistent with the approach of BS 4142: 1990 which offers the following guidance on the measurement of background noise levels:

"Make measurements during periods when the background noise is typical of the background noise when the specific noise source is or will be operating."

"Measure the background noise during periods when weather conditions are similar to

those which prevail when the specific noise level is measured or are likely to be typical during the operation of a new or modified specific noise source."

In the case of wind turbines the specific noise level varies with wind speed, as does the background noise level. Measurements of the turbine noise level at a given wind speed should therefore only be compared to background noise measurements taken when weather conditions are similar ie the same wind speed. Only by measuring the background noise over a range of wind speeds will it be possible to evaluate the impact of the turbine noise, which also varies with wind speed, on the local environment.

Structure of limits

When assessing the overall noise levels emitted by a wind farm it is necessary to consider the full range of operating wind speeds of the wind turbines. This covers the wind speed range from around 3-5m/s (the cut-in wind speed) up to a wind speed range of 25-35m/s measured at the hub height of a wind turbine. The Noise Working Group is, however, of the opinion that one should only seek to place limits on noise over a range of wind speeds up to 12m/s at 10m height on the site of the wind farm. There are four reasons for restricting the noise limits to this range of wind speed:

1) Wind speeds are not often measured at wind speeds greater than 12m/s at 10m height. For example, measurements over a one year period from May 1993 to April 1994 at the Delabole Wind Farm indicated that the wind speed measured over a 10-minute period exceeded 12m/s at 10m height (which was shown by measurement to be equivalent to 15m/s at the hub-height of 32m) for only 5% of the time. The annual mean wind speed for this year was 8.0m/s.

2) Reliable measurements of background noise levels and turbine noise will be difficult to make in high winds due to the effects of wind noise on the microphone and the fact that one could have to wait several months before such winds were experienced.

3) Turbine manufacturers are unlikely to be able to provide information on sound power levels at such high wind speeds for similar reasons. 12m/s wind speeds are even rarer in other parts of Europe.

4) If a wind farm meets noise limits at wind speeds lower than 12m/s it is most unlikely to cause any greater loss of amenity at higher wind speeds. Whilst turbine noise levels will still be reasonably constant, even in sheltered areas the background is likely to contain much banging and rattling due to the force of the wind.

At the low wind speed range of turbine operation it is expected that some quiet rural locations will experience background noise levels that are very low. At medium wind speeds, it would be expected that background noise levels would increase with increasing wind speed and noise levels above 30dB(A) would be experienced, although possibly at levels still less than the predicted or actual levels from the wind farm. At high wind speeds it may be expected that, unless tones are present, the wind noise will mask turbine noise levels unless significant shelter is afforded to a dwelling. These different environmental factors require the development of an assessment procedure that will take into account individual dwellings, the noise environment and shelter from the wind that each dwelling experiences.

The recommendation of the Noise Working Group is that generally the noise limits should be set relative to the existing background noise at nearest noise-sensitive properties and that the limits should reflect the variation in both turbine source noise and background noise with wind speed. The Noise Working Group has also considered whether the low noise limits which this could imply in particularly quiet areas are appropriate and has concluded that it is not necessary to use a margin above background approach in such low noise environments. This would be unduly restrictive on developments which are recognised as having wider national and global benefits. Such low limits are, in any event, not necessary in order to offer a reasonable degree of protection to the wind farm neighbour. It is instead proposed to control noise through absolute limits up until wind speeds where the background noise has increased to a level such that relative limits are again appropriate. The proposed values for an absolute limit and their justification are discussed in the next section.

Separate noise limits should apply for day-time and for night-time. The reason for this is that during the night the protection of external amenity becomes less important and the emphasis should be on preventing sleep disturbance. Day-time noise limits will be derived from background noise data taken during quiet periods of the day and similarly the night-time limits will be derived from background noise data collected during the night. Background noise data collected during the night may be lower than those collected during the quiet periods of the day and would lead to unnecessarily tight restrictions on wind farm noise. The absolute limit for night-time operation can be higher than that in place during the day because of the extra attenuation afforded by the propagation of sound through even an open window.

Quiet daytime periods are defined as:
All evenings from 6pm to 11pm,
plus Saturday afternoon from 1pm to 6pm,
plus all day Sunday, 7am to 6pm.

Night time is defined as 11pm to 7am.

Consideration has also be given to circumstances where a more simplified approach, based on a fixed limit, may be appropriate.

Setting values for noise limits

Selection of units

The 1990 revision of BS 4142 was to bring the British Standard into line with ISO 1996 which has subsequently been adopted as British Standard BS 7445. The change that occurred was the proposal that the rating level of a new noise source be based upon a measured L_{Aeq} rather than a visual averaging of the meter. Also, sound power level data for wind turbines are based upon the measured L_{Aeq} at a predetermined distance from a wind turbine. Therefore, it might be expected to be appropriate to use the L_{Aeq} index to perform an assessment of wind turbine noise at dwellings.

However, experience in the field when performing such measurements indicates that short, transitory noise events can significantly change the L_{Aeq}. These events are not related to the noise emitted by the wind farm. These transitory noise events can be sources such as low flying aircraft, bird song, animal noises, cars, wind effects on the microphone, etc. The rating and assessment method contained within BS 4142 compares the existing L_{A90} background noise level with the L_{Aeq} of the rated noise level from the new source. A level difference of 10dB(A) between these two levels indicates that complaints are likely from neighbouring residents to the new noise source.

Measurements performed in rural areas indicate that the ambient L_{Aeq} noise levels may be 5-25dB(A) above the L_{90} background noise level due to these transitory events. Therefore, when performing noise measurements for the assessment of compliance with planning conditions or obligations, confusion can occur due to the L_{Aeq} being significantly higher than the L_{90} background noise level due to noise sources not associated with the wind farm. This might unfairly indicate that the condition is being failed if the condition is related to an L_{Aeq} exceedence above the background L_{A90}.

Fig 5 details environmental noise measurements that indicate the high background L_{Aeq} levels when compared with the background L_{A90} noise levels. These measurements were performed in the absence of any other noise source except those found in a typical rural environment. The figure plots the noise measurements performed over a 24-hour period. It may be seen that there are many occasions when the L_{Aeq} exceeds the L_{A90} by over 10dB(A) and at times by over 20dB(A).

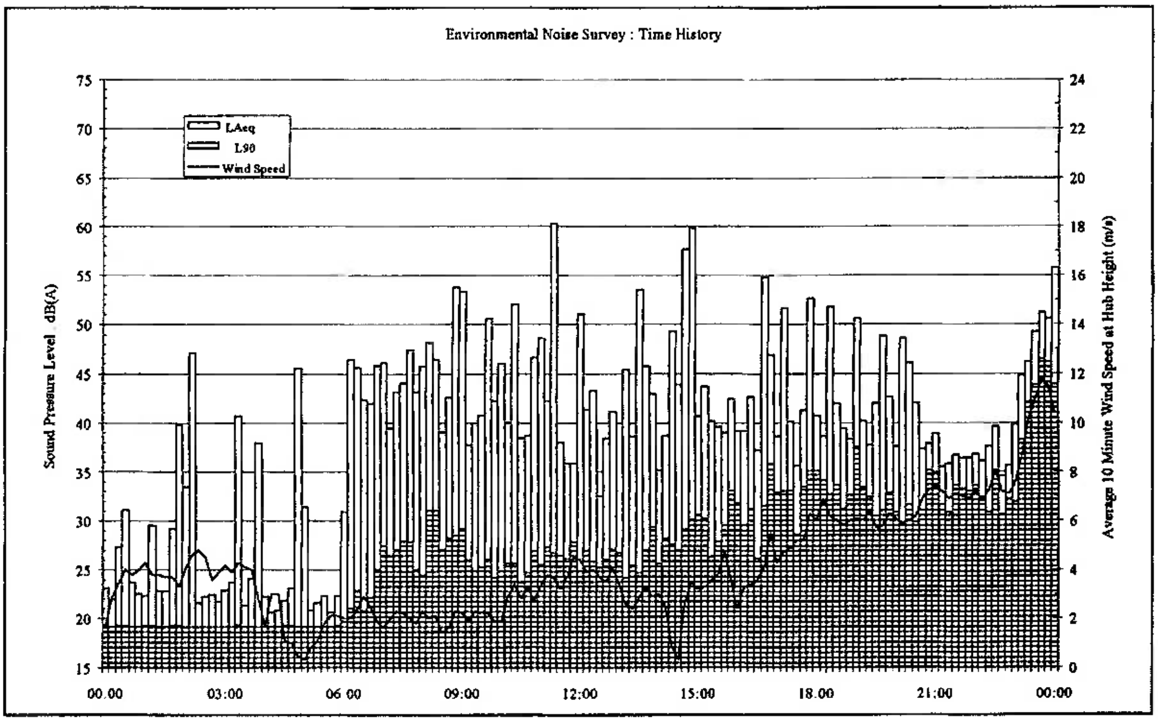


Figure 5 Comparison of L_{Aeq} and L_{A90} background noise levels

Note: The electrical noise floor of the sound level meter used to obtain this data was 18dB(A).

This problem has been encountered when using the L_{Aeq} index and has led to the use of other noise descriptors. Measurements of the L_{A90} and the L_{A50} have been proposed for the testing and application of noise conditions for wind farms. In South West England, conditions have been agreed with local authorities that relate the L_{A90} noise levels of the wind farm to either the existing background noise level during the test or to an agreed level at a specified wind speed, as measured on the wind farm site. The selection of an L_{A90} level does not follow the guidance contained within BS 4142 or BS 7445 but it does attempt to address the problems that may be experienced in the field. Early work performed at the Carmarthen Bay demonstration site used the L_{A50} index to assess turbine noise. Again, this was to minimise the errors that may occur due to transient noise events.

Another related drawback of using two noise indices as suggested by BS 4142 (although outside of its scope in rural locations) becomes apparent when one considers the effect of correcting the noise source measurements for background noise. BS 4142 proposes that a correction should be applied when the new noise source does not exceed the background noise level by more than 10dB (see section 5.4.4 of BS 4142). It advises that to obtain the correct level for the specific noise source, the L_{A90} background noise level when the source is not operating should be subtracted from the measured L_{Aeq} when the source is on. However, as has been identified above, in quiet noise environments the L_{Aeq} level may be 10-20dB(A) above the background noise level even when the source is not operating. Therefore, measurements performed and corrected using the method described within BS 4142 will underestimate the contribution of the existing noise sources to the measured L_{Aeq} noise level when a wind farm is operating. This effect may result in a wind farm being deemed to fail any noise conditions that have been imposed. It is considered very important that, when applying corrections to the measured incident noise source, like indices are used to obtain the necessary corrections, ie L_{A90} levels obtained when the wind farm is not operating are compared with L_{A90} noise levels when the wind farm is operating.

The steady nature of the emitted noise from wind turbines is such that the level difference between the L_{Aeq} and L_{A90} noise levels close to the turbines, and in the absence of other noise sources, is typically less than 2dB(A) as shown in Fig 6. It should be noted that these data are taken using a 1-minute measurement period.

The data in Fig 7 are taken at a residential location a few hundred metres from the nearest turbine. The difference between L_{Aeq} and L_{A90} ranges from 2-4dB(A) although some measurements will be influenced by background noise at these low levels. Data from other operational wind farms indicate that the difference between L_{Aeq} and L_{A90} measurements of wind turbine noise taken at residence-type locations is of the order of 2dB(A).

The use of a 10-minute measurement period has evolved as common practice for wind farm noise assessments. This is because wind speed measurements performed on-site in order to estimate the annual mean wind speed and subsequent energy production are normally performed over 10-minute intervals. As the noise data are usually plotted against wind speed it makes sense to use the same measurement period for the noise measurements.

Experience indicates that a measurement period of 10 minutes is more likely to provide a good correlation of background noise level with site wind speed than a 5-minute period. In simplistic terms, a gust of wind progressing across the ground at 5m/s will cover a distance of

300 metres in a minute. Therefore, separation distances between a wind farm and a dwelling of 1200 metres, a not uncommon distance for large-scale developments, will create a time lag of 4 minutes.

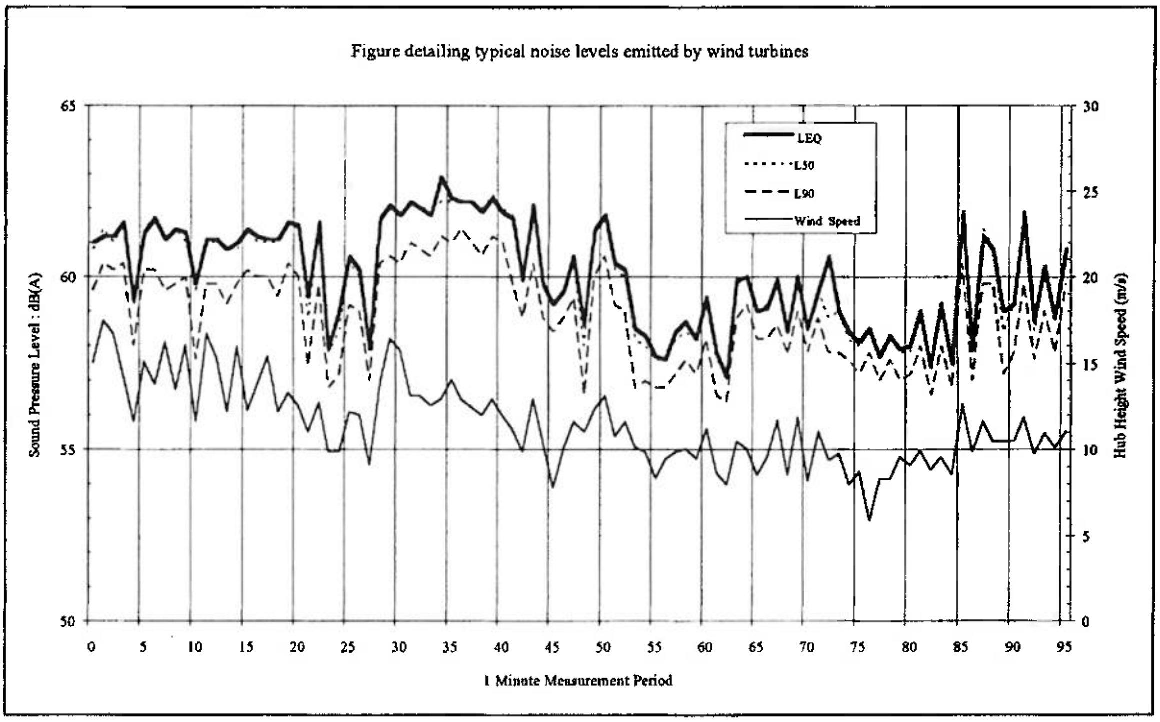


Figure 6 Comparison of measurements with different noise indices

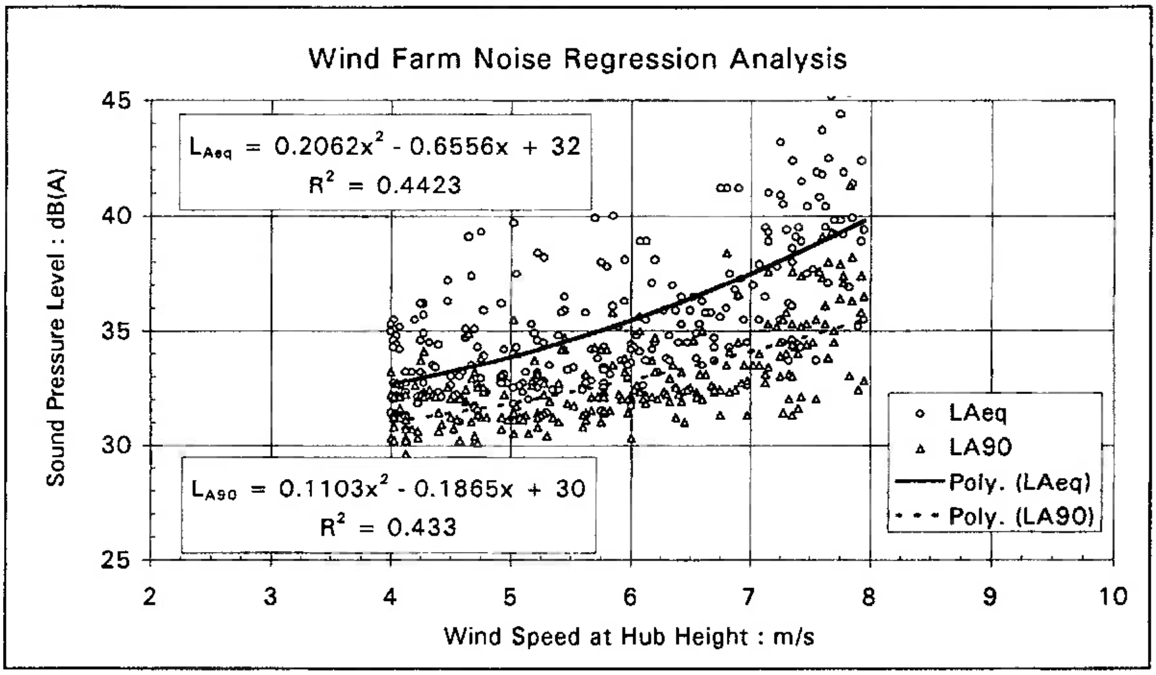


Figure 7 Comparison of L_{Aeq} and L_{A90} turbine measurements at a nearby residence

The effect of extending the measurement period to more than 10 minutes would be to lose some resolution in the variation of noise level with time. As the measurement period is increased the results tend towards those of the most typical conditions and it becomes more difficult to establish the variation of either turbine noise or background noise with wind speed.

In summary, the Noise Working Group is agreed that the $L_{A90,10min}$ descriptor should be used for both the background noise and the wind farm noise and that when setting limits it should be borne in mind that the $L_{A90,10min}$ of the wind farm is likely to be about 1.5-2.5dB(A) less than the L_{Aeq} measured over the same period.

Free-field measurements

The limits to be proposed relate to free field (except for ground reflections) measurements in the vicinity of noise-sensitive properties. Measurements performed near or at a building facade will exhibit higher noise levels due to the reflection of the sound from the facade. As this effect is dependent upon the measurement position, it is difficult to allow for in noise predictions and therefore free-field noise levels which are unaffected by the facade of a building are preferred. The potential for "hot-spots" due to particular building configurations should be discussed with the EHO during the initial site assessment. For example, courtyards with an open side facing the site of the proposed wind farm will require special consideration. Further advice on the positioning of microphones is to be found in Chapter 7.

Cumulative impact

The Noise Working Group is of the opinion that absolute noise limits and margins above background should relate to the cumulative effect of all wind turbines in the area which contribute to the noise received at the properties in question. It is clearly unreasonable to suggest that, because a wind farm was constructed in the vicinity in the past which resulted in increased noise levels at some properties, the residents of those properties are now able to tolerate still higher noise levels. The existing wind farm should not be considered as part of the prevailing background noise.

The assessment of typical background noise levels

Wind turbines operate day and night dependent upon wind speeds. It will be necessary to acquire background noise data for both day- and night-time periods because:

- the absolute lower limit is likely to be different for day- and night-time operation
- the noise limits are to be related to the background noise levels
- background noise levels may be different in the day than during the night

The impact from the wind turbines during waking hours will be greatest during otherwise quiet periods, usually Saturday afternoon, all day Sunday and weekday evenings. It is therefore proposed that the background noise measurements upon which the day-time noise limits are based are taken during these quiet periods. This is consistent with the approach of PPG 24 which advises in Annex 3, paragraph 19, that:

> *"Since background noise levels vary throughout a 24-hour period it will usually be necessary to assess for separate periods (eg day and night) chosen to suit the hours of operation of the proposed development. Similar considerations apply to developments that will emit significant noise at the weekend as well as during the week."*

In principle this implies, and quite rightly, that one could justify the setting of higher limits during the working day when background noise levels will be higher due to increased human activity. The developers represented in the Noise Working Group thought that this approach would however be unworkable since the wind farm would have to be designed to meet the stricter conditions applicable during quiet periods and the economics of wind farms would not allow one to consider switching off certain turbines at given times of day at the most critical wind speeds. We therefore propose that the day-time limits should be set in relation to the background noise measured during the quiet period of the day and that these should apply over all waking hours.

Should developers wish to investigate the cost effectiveness of switching off turbines at certain times of day over a given range of wind speeds in order to allow more turbines to be placed on a site, then an additional set of background noise data should be obtained for periods when all turbines would be operating.

Data acquired during all hours of the night are considered relevant to setting of night-time noise levels.

It is proposed that the background noise levels upon which limits are based, and the noise limits themselves, are based upon typical rather than extreme values at any given wind speed. An approach based upon extreme values would be difficult to implement as the difference in measurements between turbine noise and background would depend upon the length of time one is prepared to take data. A more sensible approach is to base limits upon typical or average levels, but to appreciate that both turbine and background noise levels can vary over several dB for the same nominal conditions.

The variation in background noise level with wind speed will be determined by correlating $L_{A90,10min}$ noise measurements taken over a period of time with the average wind speeds measured over the same 10-minute periods and then fitting a curve to these data. The mechanics of undertaking the background noise survey and the significance of seasonal effects on background noise are discussed in Chapter 7.

The aim of the background noise survey is to provide an indication of the noise environment existing at each noise-sensitive property in the vicinity of the wind farm. If there are several properties within ear-shot of the proposed wind farm then to conduct noise surveys at each and every property would be time consuming, costly, unnecessary and would therefore impose an unreasonable burden on developers. In such situations it is suggested that the developer and the local authority identify groups of properties that through their exposure and proximity to other noise sources would be expected to have similar background noise levels. In this manner it is expected that the number of noise surveys could be limited to a reasonable amount.

Rating method

The wind farm noise limits proposed below refer to rating levels in a similar manner to that proposed in BS 4142. That is, additions are made to the measured noise to reflect the character of the noise. The procedure for applying penalties for the character of the noise is presented later in this chapter.

Margin above background

It is proposed to limit the noise from a wind farm relative to the existing background noise but with special consideration given to the very low noise limits this would imply in particularly quiet areas. Noise from the wind farm will be limited to 5dB(A) above background for both day- and night-time (with the exception of the lower limits and simplified method described below), remembering that the background level of each period may be different. It should be noted that this limit applies to the noise from the wind farm only and not to the total ambient noise with the wind farm operating. Noise limits would apply up to 12m/s (10m height) on the assumption that, even in the most sheltered areas, if the wind farm can meet the conditions at lower wind speeds, it is unlikely to be a problem in higher winds. In high winds bangs and clatters from existing sources and gusts of wind are likely to be more disturbing than the wind farm noise.

When comparing the proposed margin with the complaints criteria suggested by BS 4142 it is important to bear in mind that the L_{A90} descriptor is also being proposed for the turbine noise. The L_{Aeq} levels can be expected to be about 1.5-2.5dB greater. An addition of 1.5-2.5dB places the margin at the upper end of the range which can be considered to be of marginal significance ie around 5dB.

On balance it is considered that a margin of 5dB(A) will offer a reasonable degree of protection to both the internal and external environment without unduly restricting the development of wind energy which itself has other environmental benefits.

Although not a factor to influence the specification of the allowable margin above background, it is worth noting that limits less than 5dB(A) would be difficult to monitor. One would have to resort to approximate methods such as extrapolating noise levels measured nearer to the turbines than the neighbouring properties, back to the locations of the properties, using an agreed propagation model.

Lower limit

Applying the margin above background approach to some of the very quiet areas in the UK would imply setting noise limits down to say 25-30dB(A) based upon background levels perhaps as low as 20-25dB(A). Limits of this level would prove very restrictive on the development of wind energy. As demonstrated below, it is not necessary to restrict wind turbine noise below certain lower fixed limits in order to provide a reasonable degree of protection to the amenity.

Recommendation of night-time lower limit

During the night one can reasonably expect most people to be indoors and it will not be necessary to control noise to levels below those required to ensure that the restorative process of sleep is not disturbed. A night-time absolute lower limit is therefore appropriate based upon sleep disturbance criteria.

The existing guidance relating to sleep disturbance criteria was reviewed in Chapter 4. The results were summarised, as in Table 7.

Table 7 Summary of sleep disturbance criteria and internal noise levels

Source of Proposed Criteria	Falling Asleep	Light Sleep	Deep Sleep	Max. Level
CEC Report EUR 5398 e: 1975 Environment and Quality of Life: Damage and Annoyance Caused by Noise		L_{Aeq} = 30-35		L_{Aeq} + 10
OECD Report: Reducing Noise in OECD Countries: 1978	L_{Aeq} = 35	L_{Aeq} = 45	L_{Aeq} = 50	L_{Aeq}+10 to 15
WHO Environmental Health Criteria 12 - Noise: 1980	L_{Aeq} = 35	L_{Aeq} = 35	L_{Aeq} = 35	
WHO Criteria Document: Community Noise: Environmental Health Criteria: External Review Draft 1993	L_{Aeq} = 30	L_{Aeq} = 30	L_{Aeq} = 30	L_{AMAX}< 45dB
PPG 24 Planning and Noise, 1994	L_{Aeq} = 35 (Based on WHO Environmental Health Criteria 12)			
Planning and Noise Circular W.O. 16/73	Good Standard Internal Noise Level CNL (Corrected Noise Level) Day = 45dB(A) Night = 35dB(A)			

The Noise Working Group recommends that an appropriate fixed limit for the night-time is 43dB(A). This limit is derived from the 35dB(A) sleep disturbance criteria referred to in PPG 24. An allowance of 10dB(A) has been made for attenuation through an open window (free-field to internal) and 2dB subtracted to account for the use of L_{A90}s rather than L_{Aeq}s (assuming the L_{A90} of turbine noise is 1.5-2.5dB below the L_{Aeq}).

Recommendation of day-time lower limit

Guidance relating to the control of external noise levels was also summarised in table form in Chapter 4 and this too is reproduced below.

Table 8 Summary of external noise criteria

Source of Criterion	External Noise Limit dB
CEC Report EUR 5398 e: 1975 Environment and Quality of Life: Damage and Annoyance Caused by Noise.	L_{Aeq} = 50-55
British Standard BS 5228: Part 1: 1984 Noise Control on Construction and Open Sites. Part 1. Code of practice for basic information and procedures for noise control	$L_{Aeq,1\ Hour}$ at facade = 40-45
PPG 24 Planning and Noise	BS 4142 where appropriate
MPG 11 Control of Noise at Surface Mineral Workings	Day $L_{Aeq,1h}$= 55 (No less than 45 in quiet area) Night $L_{Aeq,1h}$ = 42 Gardens/open spaces $L_{Aeq,1h}$= 55-65
WHO Criteria Document: Community Noise: Environmental Health Criteria: External Review Draft 1993	Daytime L_{Aeq}= 50 Moderate Annoyance Night-time L_{Aeq}= 45

The Noise Working Group believes that the external levels around 50dB(A) suggested by some of these documents for the protection of external amenity would be entirely inappropriate in the quiet rural locations of the UK. Furthermore, even the 43dB(A) limit ($L_{A90,10min}$) derived above to protect sleep disturbance inside the property does not offer sufficient protection to the external amenity in quiet areas of the UK during the day.

It is also the opinion of the Noise Working Group that there is no need to restrict noise levels below a lower absolute limit of $L_{A90,10min}$ = 33dB(A); if an environment is quiet enough so as not to disturb the process of falling asleep or sleep itself then it ought to be quiet enough for the peaceful enjoyment of one's patio or garden. This level would however be a damaging constraint on the development of wind power in the UK as the large separation distances required to achieve such low noise levels would rule out most potential wind farm sites. There are however the following justifications for relaxing this limit:

- Wind farms have global environmental benefits which have to be weighed carefully against the local environmental impact.

- Wind farms do not operate on still days when the more inactive pastimes (eg sunbathing) are likely to take place. For example, wind speed measurements at Delabole Wind Farm over the period May 1993 to April 1994 show that over the Summer months (June, July, August) the wind speed was below the 5m/s cut-in wind speed of the turbines for 34% of the time [25]. If the cut-in wind speed had been reduced to 4m/s the proportion of time would have been reduced to 20%. The figures for the whole year are 22% and 13% of the time for wind speeds below 5m/s and 4m/s respectively. So that residents benefit from periods of low wind speeds it is important to ensure that the turbine controllers do not allow for excessive idling. When a turbine is idling it is rotating, probably at a speed less than its normal operating speed, but without producing any power. The turbines can however generate a degree of noise in this condition, although usually at lower levels than when the turbines synchronise with the grid and start producing power.

- The absolute lower limits will only come into force when the turbine noise is more than 5dB above the background noise level and when this level of 5dB above background is below a figure in the range discussed below. The period of greater exposure to noise will therefore be limited and on some sites will not occur at all.

- There is no evidence for or against the assertion that wind farm noise with no audible tones is acceptable up to and including $L_{A90,10min}$ levels of 40dB(A) even when background noise levels are 30dB or less.

- Noise levels inside the property will be approximately 10dB less than those outside assuming an open window. Noise levels could therefore be increased before sleep and relaxation inside the property begin to be affected.

For periods during the day the Noise Working Group has adopted the approach that external noise limits should lie somewhere between that required to avoid sleep disturbance even if the occupant is outside of the property and the higher level that would still prevent sleep disturbance inside the property.

The Noise Working Group has therefore concluded that in low noise environments the day-time level of the $L_{A90,10min}$ of the wind farm noise should be limited to an absolute level within the range of 35-40dB(A). We believe that limits within this range offer a reasonable degree of protection to wind farm neighbours without placing unreasonable restriction on wind farm development. The levels are low compared to some of the advisory documents reviewed and this is because of our concern to properly protect the external environment.

As the night-time lower fixed limit is greater than the day-time limit, the night-time limit could become superfluous unless background noise levels are less during the night than during the quiet day-time periods. Where the local authority and the developer are in agreement that the background noise levels do not vary significantly between the quiet day-time periods and the night-time, then a single lower fixed limit of 35-40dB(A) can be imposed based upon background noise levels taken during quiet day-time periods and the night analysed together.

There are two aspects to consider when assessing the impact of the absolute lower limit:

- Although the range of limit proposed is 5dB, the actual difference in wind farm noise levels between the two cases, at any given wind speed, is usually less than 5dB.

- Imposing an absolute lower limit of 40dB(A) on a property with background noise levels at turbine cut-in of, say, 30dB(A) will not result in the turbine noise being 10dB greater than the background.

These two initially somewhat surprising results arise because of the variation in turbine noise with wind speed and can be illustrated by reference to Fig 8. Noise limits with an absolute lower limit of 35dB(A) and 40dB(A), both giving way to a 5dB margin above background criterion at higher wind speeds, have been constructed for a typical background noise curve in a quiet and reasonably sheltered rural location. Two lines were then drawn to represent the maximum level of turbine noise which could be experienced for each of the two cases. The slope of the increase in turbine noise with wind speed has been chosen to be 1.0dB(A) per m/s, a typical rate of increase for modern turbines.

It can be seen that the gap between the two lines representing the turbine noise is somewhat less than 5dB (3.5dB for the example given) and that the turbine noise limited to an absolute lower limit of 40dB(A) is only 37dB(A) at a typical cut-in wind speed of 4m/s. The extent to which these two effects are seen increases with the rate of increase in turbine noise with wind speed and the degree of shelter of the property from the wind.

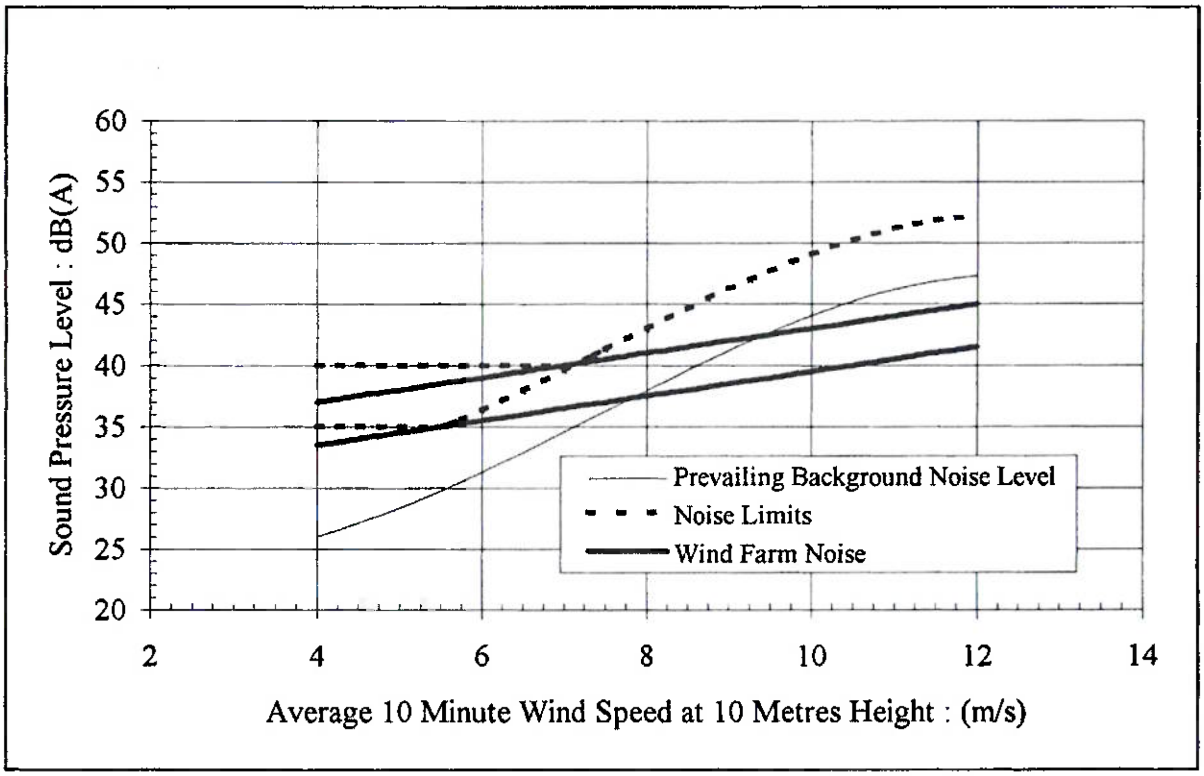


Figure 8 Comparison of day-time noise criteria

It is of interest to note that the Danish Statutory Order for Noise from Wind Mills [12] proposes noise limits of 45 and 40dB L_{Aeq} at dwellings and noise-sensitive locations when measured at external positions. These noise levels must be shown by calculation to be achievable before construction of the wind farm. However, the source sound power level used to perform this calculation is set at a wind speed of 8m/s at a height of 10 metres above ground level. This is equivalent to a wind speed of about 9.5m/s at the hub height of the wind turbine (see "wind shear" in Glossary). Table 4 in Chapter 4 indicates the predicted noise levels that may be experienced at the cut-in wind speed for wind turbines of 30m hub height, based upon the Danish Statutory Order criteria levels. It may be seen that at the cut-in wind speed, it would be expected that these levels would be 35-42dB L_{Aeq}. Thus, the levels proposed here for absolute lower limits are similar to those in use in Denmark at cut-in. The difference is that the lower absolute limits proposed for use in the UK will extend to higher wind speeds until the background noise increases sufficiently to be within 5dB of the turbine noise.

The actual value chosen for the day-time lower limit, within the range of 35-40dB(A), should depend upon a number of factors:

- Number of dwellings in the neighbourhood of the wind farm.

  The planning process is trying to balance the benefits arising out of the development of renewable energy sources against the local environmental impact. The more dwellings that are in the vicinity of a wind farm the tighter the limits should be as the total environmental impact will be greater. Conversely if only a few dwellings are affected, then the environmental impact is less and noise limits towards the upper end of the range may be appropriate. Developers still have to consider the interests of individuals as protected under the Environmental Protection Act 1990. It is our belief however, in accordance with the report of the Welsh Affairs Committee [23], that there have been no cases of complaints of noise at levels similar to those caused by wind farms leading to a successful prosecution as a statutory nuisance. It should be noted however that the Welsh Affairs Committee also reports that although the noise may not be a statutory nuisance it can clearly be a cause for distress and disturbance, particularly if residents have been promised inaudibility and the noise has a particular quality leading to complaints.

- The effect of noise limits on the number of kWh generated.

  Similar arguments can be made when considering the effect of noise limits on uptake of wind energy. A single wind turbine causing noise levels of 40dB(A) at several nearby residences would have less planning merit (noise considerations only) than 30 wind turbines also causing the same amount of noise at several nearby residences.

- Duration and level of exposure.

  The proportion of the time at which background noise levels are low and how low the background noise level gets are both recognised as factors which could affect the setting of an appropriate lower limit. For example, a property which experienced background noise levels below 30dB(A) for a substantial proportion of the time in which the turbines would be operating could be expected to receive tighter noise limits than a property at which the background noise levels soon increased to levels above 35dB(A). This approach is difficult to formulate precisely and a degree of judgement should be exercised.

Increased lower fixed limit with financial involvement

It is widely accepted that the level of disturbance or annoyance caused by a noise source is not only dependent upon the level and character of the noise but also on the receiver's attitude towards the noise source in general. If the residents at the noise-sensitive properties were financially involved in the project then higher noise limits will be appropriate, particularly if a tie could be made between the wind farm and the property, such as giving the developer first option to buy the property if it came up for sale. We recommend that both day- and night-time lower fixed limits can be increased to 45dB(A) and that consideration should be given to increasing the permissible margin above background where the occupier of the property has some financial involvement in the wind farm.

Simplified assessment method

Much of the complexity of the proposed method is necessary because of the variety of background noise environments present in the UK. However, if the developer can demonstrate that noise conditions would be met even if there was no increase in background noise with wind speed until quite high wind speeds, then a simplified approach can be adopted. We are of the opinion that if the noise is limited to an $L_{A90,10min}$ of 35dB(A) up to wind speeds of 10m/s at 10m height then this condition alone would offer sufficient protection of amenity, and background noise surveys would be unnecessary. We feel that, even in sheltered areas when the wind speed exceeds 10m/s on the wind farm site, some additional background noise will be generated which will increase background levels at the property. This type of condition may be suitable for single turbines or wind farms with very large separation distances between the turbines and the nearest properties.

Summary of noise limits

A graphical representation of the recommended limits appears in Figs 9 and 10 based upon a fairly typical background noise curve for a quiet rural area. Both background levels and turbine noise are determined by best fit curves through representative data. Further guidance appears in Chapter 7.

At low wind speeds noise is controlled through the application of the lower absolute limit in the range of $L_{A90,10min}$ = 35-40dB (day-time) and 43dB (night-time). In the example shown, during the day, between wind speeds of 5.5m/s and 7.0m/s depending on the lower limit agreed, a limit of 5dB above the existing background noise limit then comes into force.

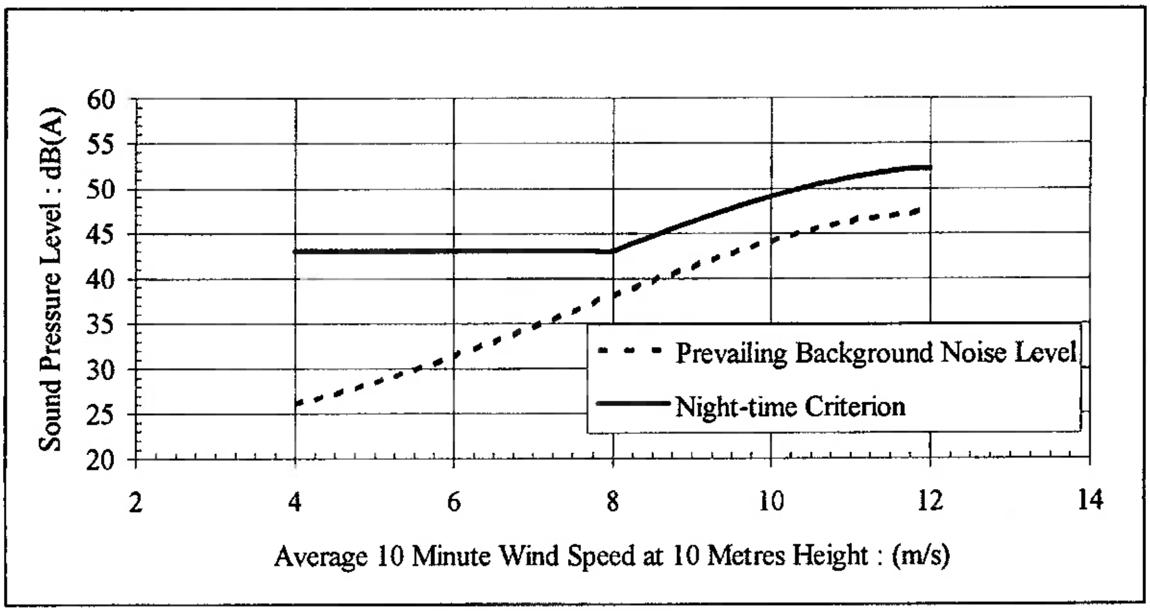


Figure 9 Example of night-time noise criterion

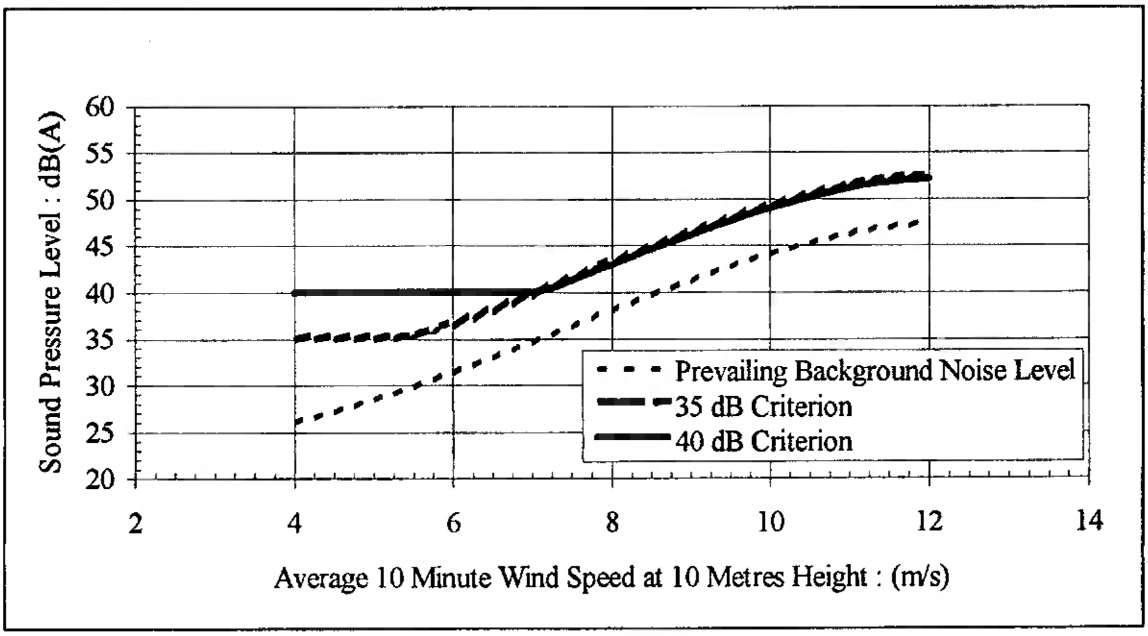


Figure 10 Examples of day-time noise criteria

Penalties for the character of the noise

We have decided that, as far as possible, the limits suggested here for wind turbine noise should account for the particular character of the noise received. This is the approach adopted by BS 4142 in which the rating level of the noise source includes the addition of any adjustment necessary for the character of the noise [2]. We have considered the two main elements that can add to the character of wind turbine noise: blade swish and tones.

Blade swish

Blade swish, the amplitude modulation at blade passing frequency of the aerodynamic noise caused by the passage of the blades through the air, has been fully described in Chapter 3.

The modulation or rhythmic swish emitted by wind turbines has been considered by some to have a characteristic that is irregular enough to attract attention. The level and depth of modulation of the blade noise is, to a degree, turbine-dependent and is dependent upon the position of the observer. Some wind turbines emit a greater level of modulation of the blade noise than others. Therefore, although some wind turbines might be considered to have a character that may attract one's attention, others have noise characteristics which are considerably less intrusive and unlikely to attract one's attention and be subject to any penalty.

This modulation of blade noise may result in a variation of the overall A-weighted noise level by as much as 3dB(A) (peak to trough) when measured close to a wind turbine. As distance from the wind turbine/wind farm increases, this depth of modulation would be expected to decrease as atmospheric absorption attenuates the high frequency energy radiated by the blade. However, it has been found that positions close to reflective surfaces may result in an increase in the modulation depth perceived at a receiver position remote from a site. If there are more than two hard, reflective surfaces, then the increase in modulation depth may be as much as ± 6dB(A) (peak to trough).

The selection of the measurement position can also result in particular frequencies exhibiting a greater depth of modulation due to standing wave effects from reflected waves off the surrounding structures. These effects are very specific to the positions at which measurements are undertaken and are more the result of building layouts at the receiver position than a change in the character of the emitted wind turbine noise.

It is the opinion of the Noise Working Group that there is insufficient data available at this time to formulate an accurate measurement methodology for blade swish where it occurs. It is envisaged that further research will be required to enable proper measurement and assessment to be devised, if in the future this is felt to be necessary. Work is already under way aimed at establishing the causes of blade swish, the frequency and magnitude of its occurrence and developing an appropriate metric for its measurement.

The noise levels recommended in this report take into account the character of noise described in Chapter 3 as blade swish. Given that all wind turbines exhibit blade swish to a certain extent we feel this is a more common-sense approach given the current level of knowledge. Debates at public inquiries on whether a literal interpretation of clause 7.2 of BS 4142:1990 would include blade swish have in general been unhelpful.

Method of tonal assessment

Introduction

It has been our experience, confirmed by the survey reported in Chapter 5, that where complaints have been made over noise from existing wind farms the tonal character of the noise has been the feature that has caused greatest annoyance. This finding corresponds with the results of a survey of EHOs and noise consultants undertaken by NPL on complaints about industrial noise sources [26] which indicated that a significant number of noise complaints are caused by the tonal character of the noise. In order to reflect the increased potential for annoyance caused by noise containing a tonal component we therefore feel it appropriate that tonal noise should be penalised. This penalty should be imposed in a similar manner to that described in BS 4142 ie the noise level of the source is described as a rated level, that is the sum of the overall level and any penalty due to a tonal content.

Review of options

Broadly speaking, there are three methods by which a noise can be assessed as to whether a tonal penalty is appropriate: subjective methods, 1/3 octave methods and narrow band methods. The relative merits of each are reviewed below.

Subjective methods

The method for rating a noise source that is contained within BS 4142 requires that the noise is assessed by the subjective judgement of a listener. The perceived level of the tonal noise will however be dependent upon the attitude of the listener towards the noise source and the sensitivity of the individual to tonal noise. What may therefore be acceptable to one person may not be acceptable to another. Another drawback with this method is that in order to obtain a warranty for a wind turbine from a manufacturer that includes a criterion for tonal emission, an objective measurement procedure must be agreed. This warranty will provide little comfort unless tonal emissions from the wind farm are assessed in a similar manner. The absence of any standard method within the UK has caused problems when agreeing noise conditions. To reduce these potential areas of conflict it is proposed that an objective test be undertaken of the incident noise that assesses the audibility of any tonal noise emissions and provides a rating for the noise.

Methods based on 1/3 octave bands

BS 7445 [16] (ISO 1996, DIN 45 465) indicates that a prominent tone may be identified when the level difference between contiguous third octaves is greater than 5dB. This definition of prominent tone is satisfactory when the frequency of interest is above 500Hz. However, at frequencies below 500Hz the criterion is too severe. It is possible that at low frequencies, this assessment method may result in a tone being measured objectively when none is audible. This effect has been allowed for within the third octave criteria that have been developed by Kern County in the USA, see Appendix B. Furthermore the method is unsuited to the detection of tones that are only just detectable by the observer and would prove difficult to implement for the sometimes complex spectrum shapes associated with wind turbine noise.

Narrow band analysis

The principles of three, narrow band, tonal assessment methods, BS 7135 [17], the Joint Nordic Method [21]and the draft DIN 45 681 [22], have been described in Chapter 4. This Section reviews the strengths and weaknesses of the methods available so that recommendations leading to a reliable method of assessment can be made.

All three methods are based upon the concept of Zwicker critical bands. The methods compare the sound pressure level of the tone to the sound pressure level of the broadband masking noise with a range of frequency either side of the tone, the critical band width. The audibility of a tone is determined according to the difference between the tone level and the masking level, often referred to as the tone level difference. The main differences between the methods are in the precise specification of the critical band width, audibility criteria and the measures taken, if any, for non-stationary tones (tones whose amplitude varies with time).

The Joint Nordic Method simplifies the derivation of the critical band bandwidths, ie the critical bandwidth for a tone below 500Hz is 100Hz and above 500Hz is 0.2 × the tone frequency. BS 7135 and DIN 45 681 use the mathematical formula obtained by Zwicker. The width of the critical band, Δf_c, centred at any frequency, f, is given by the following equation:

$$\Delta f_c = 25 + 75 \times [\, 1 + 1.4 \times (f / 1000)^2 \,]^{0.69}$$

(eg Δf_c = 162.2Hz at f = 1000Hz)

This results in a small, frequency-dependent difference between the Joint Nordic Method and the other two methods in the calculated critical band masking level. Fig 11 details the level difference between each critical band assuming a flat spectrum. It may be seen that predicted difference will be less than 1dB until a frequency of over 1.0kHz is reached, although a peak of 0.69dB occurs at a frequency of 500Hz. The graph shows that the Joint Nordic Method would underestimate the masking level around a tone of 500Hz by 0.69dB.

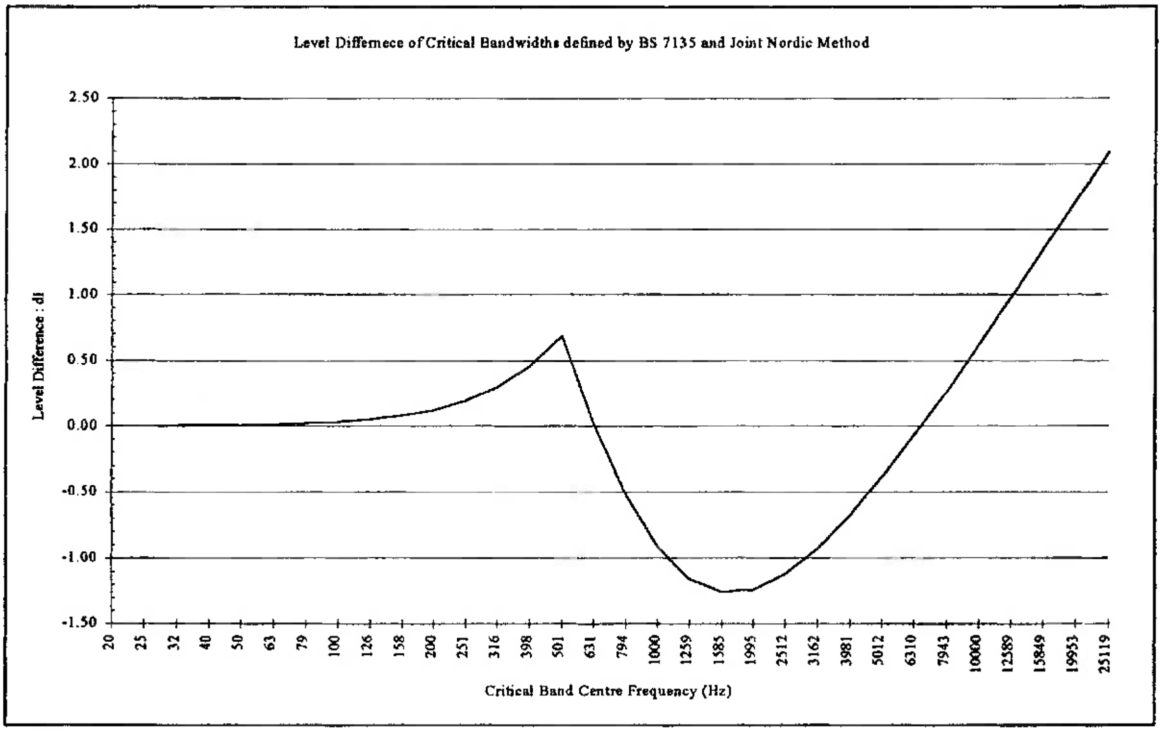


Figure 11 Level difference of critical bandwidths defined by BS 7135 and the Joint Nordic Method

Differences also exist in audibility criteria. Fig 12 details the difference between the audibility criteria defined within the Joint Nordic Method, BS 7135 and DIN 45 681. It can be seen that at relatively low frequencies, commonly of interest when assessing tonal noise from wind turbines, the audibility threshold for DIN 45 681 is up to 4dB lower than the Joint Nordic Method. The Joint Nordic Method uses the frequency-dependent audibility curve suggested by Zwicker whereas the other two methods adopt a simplified approach, assuming the tone level difference necessary for audibility is constant across the frequency range. The following extract from the draft DIN 45 681 illustrates the thinking behind this approach.

"At low frequencies the level difference $L_G - L_T$ (L_G = masking level, L_T = tone level) *at the audibility threshold is 2dB. This rises continuously to 6dB at high frequencies. On average then, a sinusoidal tone in a masking noise is just perceptible (midrange audibility threshold) when $L_G - L_T$ = 4dB. This is the value set by the tone content criterion ISO 7779: 1988, section D.4.1* (and BS 7135).

The mid-range hearing threshold is defined such that in repeated hearing tests a group of people with normal hearing will perceive the tone in 50% of cases. The tone content criterion introduced by this standard (a noise has tone content when $L_G - L_T$ = 6dB, see section 2.) is more stringent at midrange and low frequencies in that about 20 to 30% of people will hear the tone."

At low frequencies the differences between the two approaches to audibility is reduced because the Joint Nordic Method applies a "Hanning correction" to the measured level of the masking noise. This is designed to correct for the effective analysis bandwidth of the frequency analyser being wider than the frequency resolution. With the commonly applied

Hanning window, the analysis bandwidth is 1.5 times the resolution resulting in a correction or reduction in the measured level of 10log1.5dB or 1.8dB. This means that a tone of given magnitude would appear to have a level difference 1.8dB greater when analysed using the Joint Nordic Method than it would have if assessed using BS 7135 or DIN 45 681.

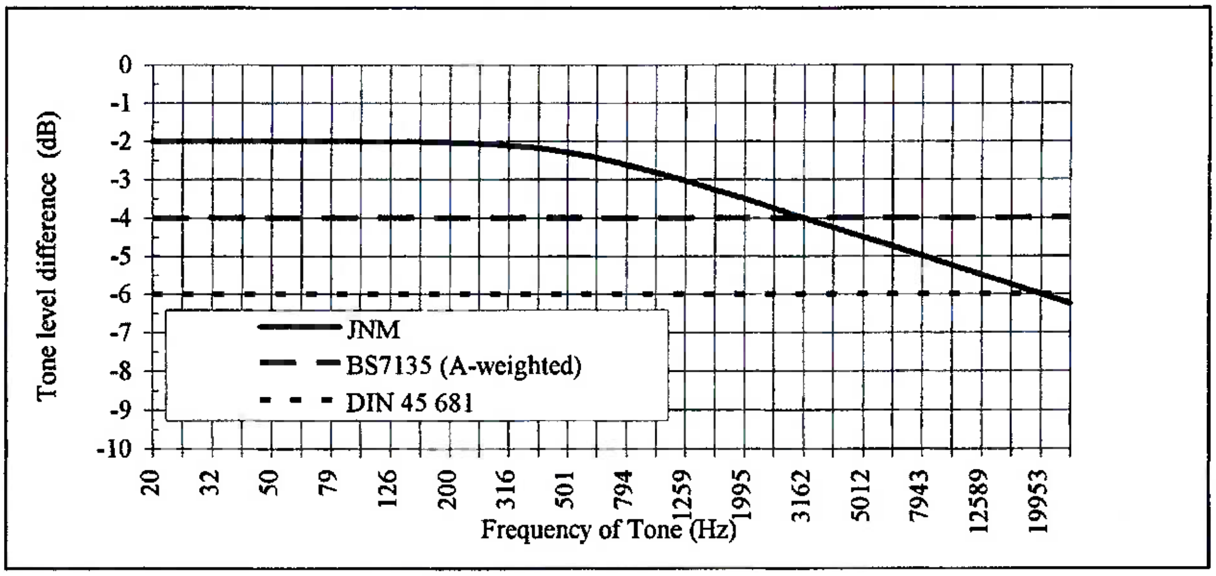


Figure 12 Difference in audibility criteria as defined by the Joint Nordic Method, BS 7135 and DIN 45 681.

The situation is further complicated by the recommendation within BS 7135 that if the measurements are performed using a linear weighting instead of an A-weighting the threshold of audibility should be reduced so that a tone is deemed audible when it is 6dB below the masking level in the critical band, the same level as in the DIN standard. This suggestion for change in audibility criteria with frequency weighting is difficult to understand as the tone is compared to masking noise of similar frequency to itself and differences will be second order, resulting from the slope in the A-weighting curve. It has been demonstrated [27] that, for wind turbine noise, choice of frequency weighting has no systematic effect on the magnitude of the tone level difference.

Tones from wind turbines can be classed as non-stationary; that is, the level of a tone, and hence its audibility, can fluctuate by several dB over the course of a few seconds [28]. These fluctuations arise from variations in source level and short-term propagation effects over distances of a few hundred metres. The Joint Nordic Method is the only one of the three which attempts to deal with non-stationary tones by suggesting that the highest level of the tone is found by averaging the five highest tone levels from a number of individual spectra. It has been shown [28] that, for wind turbine noise measured at near-residence type locations, averaging the 10% highest tone levels will result in the measured tone level being typically 3-4dB higher than if it had been derived from the rms level of the tone in accordance with DIN 45 681 or BS 7135.

It can be seen from the above discussion that even the use of objective, narrow band methods of tonal analysis can lead to widely differing assessments of audibility because of differences in the specification of critical band widths and audibility curves and in the treatment of Hanning correction, frequency weighting and non-stationary tones. The Noise Working Group has decided that the method proposed here will be based upon the Joint Nordic Method because of the more accurate, frequency-dependent audibility curve and in the interests of maintaining consistency, where possible, with other recommended practices.

The Joint Nordic Method is the tonal assessment method that is proposed for the assessment of the character of the noise within Nordic countries and has been adopted by the IEA as the basis for tonal assessment in their series of Recommended Practices [11]. It has also been adopted by Danish wind turbine manufacturers as a standard against which they will test and warrant their wind turbines. The tonal assessment method within the current draft of IEC/TC 88 Part 10 [29], dealing with acoustic measurement techniques of wind turbines, is also based upon the Joint Nordic Method. This method, therefore, currently seems to be the method by which most wind turbine manufacturers within the world market will be assessing the tonality of their wind turbines.

Description of Recommended Method

The recommended method is based upon the Joint Nordic Method for non-stationary tones with some embellishments in areas where it is not entirely prescriptive such as tone identification and averaging periods. The method aims to assess the audibility of a tone as perceived by the average listener. There are three main steps in the procedure:

A) Frequency analysis of the noise at receiver locations.

B) Determination of the sound pressure level of the tone(s) and the sound pressure level of the masking noise within the critical band.

C) Evaluation of the difference between the tone and the masking noise sound pressure levels (ΔL_{tm}) by comparison with a criterion curve to determine the audibility of a tone.

A. Frequency analysis

The analysis of non-stationary tones is quite intensive; it will therefore be convenient to record the signal to be analysed on to tape. For each tonal assessment 2-minutes of uninterrupted clean A-weighted recording is required.

A 2-minute, rms-averaged FFT is performed on the sampled data using a Hanning window, a frequency resolution of 3.0 ± 0.5Hz and an analysis bandwidth of 2kHz. It may be necessary to inspect a similar spectrum with greater bandwidth to ensure that there are no tones present at higher frequencies.

The short term, individual rms-averaged FFTs within the sampled data are also calculated using the same parameters as described above. This results in an averaging time of 0.29 to 0.4 seconds.

B. Determination of sound pressure levels

The bandwidth of a critical bands is:

Centre Frequency f_c, Hz	20-500	Above 500
Bandwidth	100Hz	20% of f_c

If a single tone is present the critical band is centred upon the tone. If two or more, closely spaced tones are present, the critical band is placed so that it contains the maximum possible amount of tonal energy. In order to do this it is first necessary to identify the tones within the spectrum. To do this each line in the 2-minute spectrum must be classified according to the following criteria based upon the draft DIN 45 681. A peak is classed as a tone if its level is more than 6dB above the logarithmic average of the sound pressure levels of the rest of the lines in the critical band centred on the peak, but excluding the one line each side of the peak. If the peak qualifies as tone the adjacent lines are also classified as a tone if their level is within 10dB of the peak and greater than 6dB above the average level previously calculated. If a spectral line is more than 6dB above the average masking level and more than 10dB below the peak level it is classified as neither tone nor masking. Having identified the tones the critical band can be placed to maximise the sound pressure level of the tones within the critical band.

Because classifying a line as a tone means it can no longer be counted as masking, an iterative procedure is required for the proper identification of tones and masking. This is described by reference to the worked example below.

Fig 13 shows the stages in the tone identification and classification process. These are:

- Find peaks in the spectrum, in this case line 23.
- Calculate the average energy in the critical band centred on each peak, not including the two lines adjacent to the peak (9.10dB).
- If the peak is more than 6dB above the average masking level then it is a tone, therefore line 23 is a tone.
- Classify adjacent spectral lines:

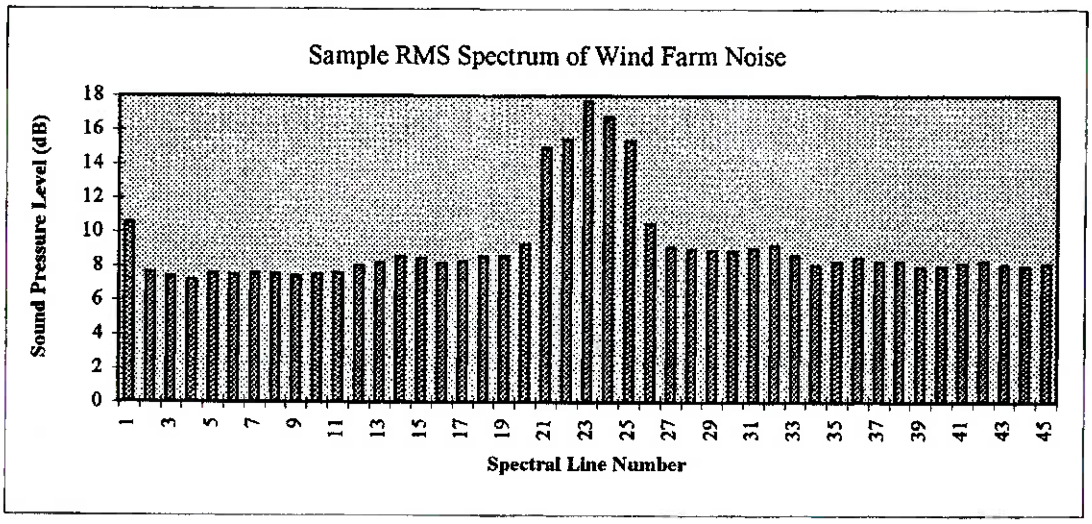
    Pass 1
    - Compare spectral lines above and below the peak to the average level.
    - If a line is more than 6dB above the average and less than 10dB below the peak then it is a tone, therefore lines 22, 24 and 25 are tones.

    Pass 2
    - Calculate new average masking level centred around the peak, discounting adjacent spectral lines and all other lines classed as tones (8.75dB).
    - Compare spectral lines above and below the peak to the average level.

- If a line is more than 6dB above the average and less than 10dB below the peak then it is a tone, therefore lines 21, 22, 24 and 25 are tones.

Pass 3

- Calculate new average masking level centred around the peak, discounting adjacent spectral lines and all other lines classed as tones (8.39dB).
- Compare spectral lines above and below the peak to the average level.
- If a line is more than 6dB above the average and less than 10dB below the peak then it is a tone. Therefore lines 21, 22, 24 and 25 are tones, but no spectral lines have been reclassified in this pass so the iterative process is complete.



Tone Identification and Classification						
Peak line = 23	**Peak Level = 17.71dB**					
	Pass 1		**Pass 2**		**Pass 3**	
Average about peak	9.10		8.75		8.39	
Adjacent line assessment	**Level above average**	**Classif-ication**	**Level above average**	**Classif-ication**	**Level above average**	**Classif-ication**
Line number						
19	-0.49	masking	-0.14	masking	0.22	masking
20	0.20	masking	0.55	masking	0.91	masking
21	5.83	masking	6.18	tone	6.54	tone
22	6.34	tone	6.69	tone	7.05	tone
24	7.64	tone	7.99	tone	8.35	tone
25	6.26	tone	6.61	tone	6.97	tone
26	1.40	masking	1.75	masking	2.11	masking
27	-0.01	masking	0.34	masking	0.70	masking

Figure 13 Tone identification and classification process

If a spectral line is more than 6dB above the average masking level and more than 10dB below the peak level then it is classified as neither tone nor masking, and not included in the calculation for either level.

The process described above is repeated for every critical band centred around tonal peaks in the spectrum. The result is that within each critical band every spectral line is classified as tone energy, masking energy or neither.

Having identified the lines in each spectrum contributing to tonal levels, masking levels or neither, the tonal analysis can continue as follows:

- The masking energy within the critical band is calculated from the 2-minute rms spectrum. Calculate the masking level in the critical band, L_{pm}, correcting for a reduction in the number of lines due to the exclusion of tones and for the Hanning window.

  $$L_{pm} = 10\log\sum 10^{L_m/10} + 10\log\frac{(\text{critical band width})}{(N_m \times \Delta f)} + 10\log(1/1.5)$$

  where L_m = sound pressure level of each line containing masking noise
  N_m = number of lines within the critical band containing masking noise.
  $\sum$ = sum of

- For each of the short term spectra of 0.29 to 0.4 seconds duration, calculate the tone energy within each critical band, L_{pt}', using the lines identified as tones from the 2-minute spectrum.

  $$L_{pt}' = 10\log\sum 10^{L_t/10}$$

  where L_t is the sound pressure level of each line containing tonal noise.

  The Joint Nordic Method for non-stationary tones calculates tone level as the mean of the top 5 levels from a "number of analysis" (at least 50 short term spectra as interpreted by the IEA Recommended Practice). As the result obtained using 5 out of 50 would obviously be different to that using 5 out of 500, the method proposed here is more specific. The tone level used in the assessment, L_{pt}, is the arithmetic mean of the top 10% of tone levels, L_{pt}', from all the short-term spectra constituting the 2 minutes of data.

C. Evaluation of the audibility of the tone(s)

The audibility of a tone is dependent upon the tone level difference, ΔL_{tm}, and the frequency of the tone:

$$\Delta L_{tm} = L_{pt} - L_{pm}$$

The audibility criterion is defined as follows:

$$\Delta L_{tm,crit} = -2 - \text{Log}\,(1 + (f / 502)^{2.5})$$

where f = frequency at the centre of the critical band.

This is the level at which the average listener will be just able to hear the tone. Fig 14 details the audibility criterion based upon the above equation. It can be seen from the figure that the audibility criterion is related to the frequency of the tone.

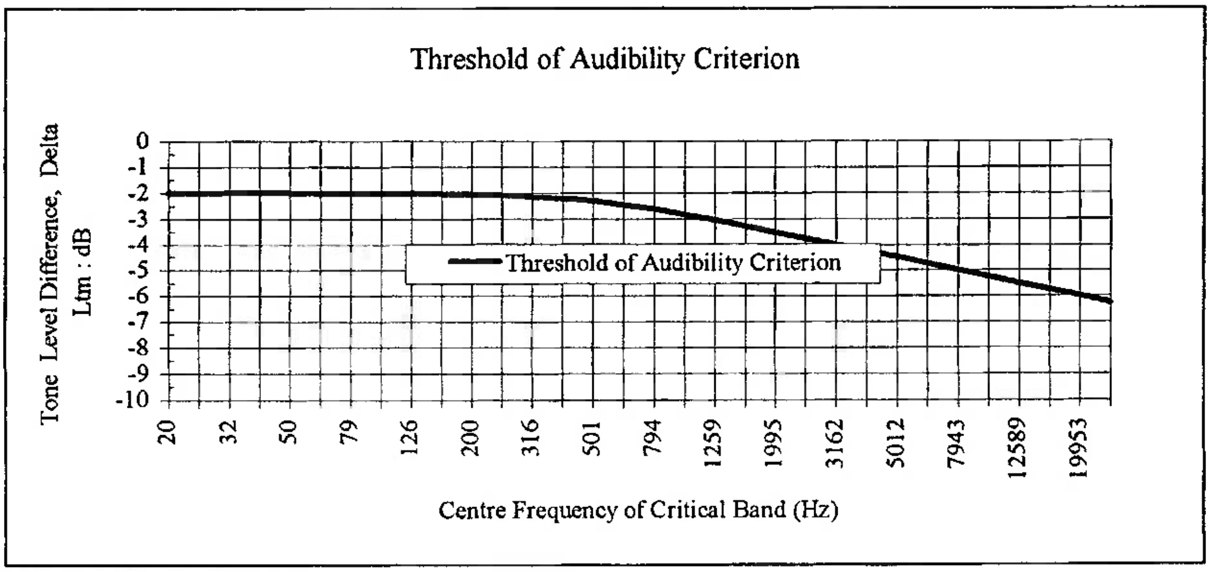


Figure 14 The audibility criterion for tonal noise assessment

It is recognised that this method for assessing the audibility of a tone is somewhat complex and may prove difficult for some to perform. It is nevertheless a rigorous implementation of the widely accepted Joint Nordic Method. It would be helpful to be able to simplify the method without undue loss of reliability so it can be more easily applied. One possibility is to replace the assessment of the tonal pressure from the top 10% of the short term spectra with a level derived from the 2-minute rms spectra. This would however require the adjustment of the audibility criterion to account for the reduced tonal levels which would result from such a change. Further work would be required to calibrate a new audibility criterion with the average listener's response.

Penalties for tonal noise

No standard, objective method is currently available within the UK for the assignment of penalties to noise containing tonal components. BS 4142 allows for a subjective assessment to determine whether a 5dB penalty should be added (see Chapter 4). The DOE has initiated studies on tonal penalties and rating systems but this work is not expected to be included within any revised version of BS 4142 for a number of years. Therefore, the penalty system proposed derives from existing standards and guidance, recent research on the subjective response to tones from wind farms and the experiences of members of the Noise Working Group.

Comparison of existing standards

The tonal penalties imposed by the Joint Nordic Method (JNM), draft Din 45 681 and BS 7445 are considered below.

The Joint Nordic Method proposes that a 5dB penalty be applied when the tone is considered prominent; prominence is defined as being 6.5dB above audibility. The method proposed by the Noise Working Group is based upon the Joint Nordic Method for variable tones.

Draft DIN 45 681 proposes that a sliding scale of penalties ranging from 0-6dB be used which is related to the level of a tone above the audibility criterion. When applying these penalties to the method proposed by the Noise Working Group three differences between the Noise Working Group method and the DIN standard have to be borne in mind:

1. The audibility criterion is different for the two methods (see Fig 12). For tones of less than 800Hz, ie those most commonly identified in wind turbine spectra, the tone level difference required for audibility is 3-4dB lower for the DIN standard than for the JNM. This implies that tones will be identified as audible at lower levels using the DIN standard.

2. Conversely, the method proposed here is based upon an average of the highest 10% of short-term spectra rather than on rms spectra which results in higher tone levels being identified using this method. Studies have shown this difference to be on average 3.6dB, with a range of 2.2-4.4dB [28].

3. The method proposed here, being based upon the JNM, applies a Hanning correction (reduction) of 1.8dB to the broadband masking noise thus increasing the tone level difference by 1.8dB when compared to the DIN standard.

The net result of these differences is that a tone measured using this method and equal in level difference to the audibility criterion of the JNM would be ranked between zero and 3.2dB below audibility using the draft DIN standard, typically -2dB below audibility. Or put the other way round, a tone identified as being on the threshold of audibility using the DIN standard would be ranked as 2dB above audibility using this method. The penalties specified in the draft DIN 45 681 and how they transpose to the audibility criterion of the Noise Working Group's implementation of the JNM are shown in Table 9.

BS 7445 also describes a progressive approach to tonal penalties differentiating between tones that are "just detectable" and "clearly audible".

> *"In some practical cases, a prominent tonal component may be detected in 1/3 octave spectra if the level of a 1/3 octave band exceeds the level of adjacent bands by 5dB or more, but a narrow band frequency analysis may be required in order to detect precisely the occurrence of one or more tonal components in a noise signal. If tonal components are clearly audible and their presence can be detected by a 1/3 octave analysis, the adjustment may be 5 or 6dB. If the components are only just detectable by the observer and demonstrated by narrow band analysis, an adjustment of 2 to 3dB may be appropriate."*

Table 9 Comparison of DIN 45 681 with the Joint Nordic Method

Tone Level above Audibility, ΔL (dB), using DIN 45681	Equivalent Tone Level above Audibility, ΔL (dB), using this Implementation of the JNM for Variable Tones	Tone Penalty, dB, from DIN 45681
$0 \geq \Delta L$	$2 \geq \Delta L$	0
$0 < \Delta L \leq 2$	$2 < \Delta L \leq 4$	1
$2 < \Delta L \leq 4$	$4 < \Delta L \leq 6$	2
$4 < \Delta L \leq 6$	$6 < \Delta L \leq 8$	3
$6 < \Delta L \leq 8$	$8 < \Delta L \leq 10$	4
$8 < \Delta L \leq 10$	$10 < \Delta L \leq 12$	5
$L > 10$	$L > 12$	6

Pedersen [30] has computed the equivalent narrow band tone level difference for a tone responsible for a 5dB increase in a 1/3 octave band level. The tone level differences are calculated using the critical band widths of the JNM but do not include any correction for use of the Hanning window. In order to enable a comparison with the JNM for variable tones to be made, a further adjustment of 3.6dB is required because of the difference in peak and rms levels as for the DIN standard above. The results are frequency-dependent and summarised in Table 10.

Table 10 Comparison of a 1/3 octave based criterion to the JNM audibility criterion

Tone Frequency Hz	Equivalent Tone Level Difference of 5dB 1/3 Octave Tone	Tone Level Difference after Correction (+ 1.8 + 3.6)	JNM Audibility Criterion	Equivalent Margin above Audibility for 5dB Penalty.
50	-6	-0.6	-2.0	1.4
100	-3	2.4	-2.0	4.4
200	0	5.4	-2.0	7.4
400	3	8.4	-2.2	10.6
500	4	9.4	-2.3	11.7
800	4	9.4	-2.6	12.0
1000	4	9.4	-2.8	12.2
2000	4	9.4	-3.5	12.9

It can be seen that the results are strongly frequency-dependent, but for the frequency range of interest (100-800Hz) the application of the 5-6dB penalty for a clearly audible tone would be incurred at levels above audibility of 4.4-12dB when using the JNM for variable tones. Given the above it is unclear at what levels the 2-3dB penalty would be incurred but one could interpret "just detectable by the observer" as any audible tone.

A graphical comparison of the three penalty systems is shown in Fig 15. The BS7445 penalties for "just detectable" and "clearly audible" have been set in the middle of the range suggested, ie 2.5dB and 5.5dB respectively, and have been plotted for 100Hz and 800Hz tones to represent the frequency range most commonly encountered.

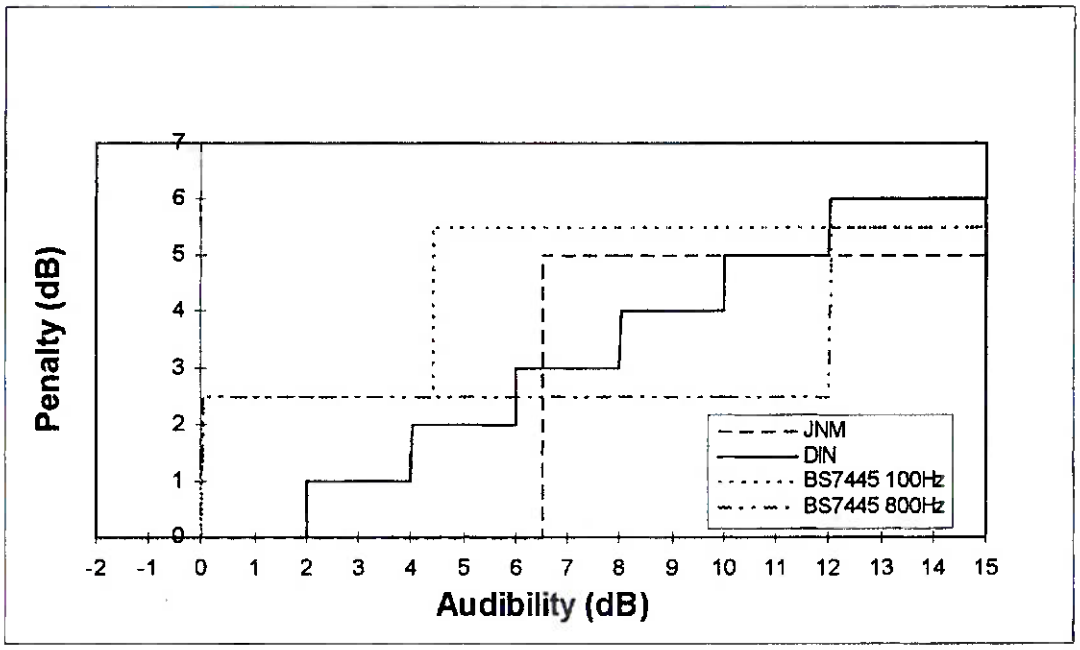


Figure 15 Comparison of tonal penalties from various standards

Recommended levels of tonal penalties

The members of the Noise Working Group agreed on the penalty system depicted in Fig 16 based upon their review of existing standards and guidance, recent research on the subjective response to tones from wind farms from listening tests [27] and their experiences in the field.

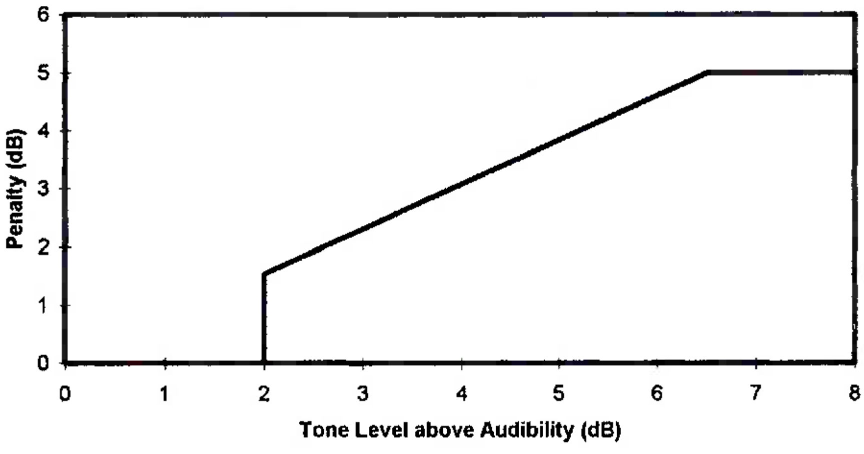


Figure 16 Penalties for tonal noise

At levels of audibility above 6.5dB a 5dB penalty is incurred. Between audibility levels of 2dB and 6.5dB a sliding scale of penalties is introduced varying linearly from 1.54dB to 5dB. Extrapolation of this linear relationship passes through the origin. No penalties are incurred at audibility levels below 2dB.

A penalty of 5dB at 6.5dB above audibility is suggested because:

- it is consistent with the Joint Nordic Method upon which the Noise Working Group method is based and is broadly in line with the advice for prominent tones in BS 7445

- the results from the listening tests demonstrated that at audibility levels at and above 6dB more than 95% of listeners describe the tone as audible and around 50% find the tone to be prominent

A sliding scale of penalties is preferred for audibilities between 2dB and 6.5dB because:

- intuition suggests that annoyance gradually increases with margin above audibility

- it prevents large differences in tonal penalty being affected by small differences in the measured level of audibility

- it enables local authorities to exert downward pressure on tonal levels from turbines which do not represent best practice

- it penalises tones which the subjective tests indicate a large proportion of the population will be able to hear

- below levels of audibility of 2-4dB the results from the listening tests indicate that the measured level of audibility does not correlate well with the subjective response, be it percentage of subjects describing the tone as audible or equal annoyance level; the Noise Working Group was agreed that a significant penalty should be introduced at 2dB above audibility; a convenient method for constructing such a penalty system which increases progressively up to 5dB at 6.5dB above audibility was a straight line passing through the origin but with no penalties incurred below 2dB of audibility.

- it is the view of the Noise Working Group, based upon a comparison of their experiences of tonal levels from a variety of wind farms against measured levels for those wind farms, that tonal penalties are not appropriate at levels measured below 2dB.

It is important to note that although this assessment procedure and associated penalties have been derived and tested [27, 28] using the best information currently available they have not yet been proven in the field. For example, little is known about the medium to long term variation in tonal levels from wind turbines and, if such variations do occur, which levels are most appropriate for assessment purposes. It is the belief of the Noise Working Group that the best of the turbines currently available are without tonal noise problems and would not warrant any penalty; it is intended that this assessment procedure reflects that evaluation.

Complex tones containing harmonic components

A wind turbine may emit a complex tone comprising a series of harmonics (partials) at integral multiples of some fundamental frequency. Although several peaks may occur in a narrow band spectrum of such noise, the tone complex is usually perceived as having a single pitch. For the purposes of this specification, when an audible discrete tone comprises two or more harmonic components, only that component with the greatest audibility need be evaluated unless two or more harmonics lie within the same critical band.

Variable speed machines

If a variable speed wind turbine were to be assessed using this technique and the wind turbine were to emit tonal noise, the variation in rotation speed would result in a variation of the tone frequency. Over a two-minute period it would be expected that the tone would affect the masking band level centred around the tone such that the masking band level would be considered higher than the actual level when measured instantaneously.

Additional problems will also occur with variable frequency tones, as the tone frequency during the analysis will not be the same throughout the assessment period. Therefore, the average maximum level for an individual tone will not necessarily be easily determined.

It is possible these difficulties could be overcome if tonal measurements were performed close to one machine and the measurements were of short duration. Further experience in this area is needed before more precise advice can be given.

7. NOISE MONITORING

Introduction

During the planning stage of a wind farm, discussions are likely to have been held with the local Environmental Health Officer with respect to agreeing acceptable levels of noise from the proposed site. The performance of a background noise survey around the site will help identify the dwellings that are the most sensitive with respect to noise and the wind speeds at which the greatest noise impact from the development will occur.

The prevailing background noise level at sensitive dwellings will need to be agreed with the local EHO so that noise limits at different turbine operating wind speeds can be set. Predictions are then undertaken and changes made to the proposed wind turbine layout, where necessary, to ensure that the noise limits that have been set can be achieved.

These noise limits may then form the basis of any conditions that are imposed by the local district council and agreed by the developer. Testing of these conditions is required to ensure compliance in the event of any complaints arising over noise from the wind turbines. Therefore, a method for undertaking this compliance test is required that eliminates errors due to noise not associated with the wind farm and which relates the operating condition of the wind farm to the noise levels incident at a dwelling.

Monitoring will be complaint-driven as developer access to properties cannot be guaranteed. A condition requiring periodic monitoring at residences in the absence of complaints would be unenforceable and therefore fail the test of a planning condition.

Monitoring locations

Nearest properties

Monitoring should be undertaken at the locations to which the noise limits apply, ie the noise-sensitive properties around the wind farm from which complaints have been received.

Microphone height and position

The microphone should be tripod mounted at a height of 1.2-1.5m above ground level in accordance with the requirements of BS 4142. A height of 1.2m is most commonly used as the microphone is then that little more out of the wind, less likely to be shaken or blown over and 1.2m is generally a more convenient working height.

The measurement position should be selected to minimise the effects of reflections from buildings because the noise limits recommended refer to free-field measurements for the reasons given in Chapter 6. Measurements performed in the field around existing wind farms indicate that reflection effects from buildings are minimised when measurement positions are at least 10 metres from a building facade. This compares with the guidance given in the USA where measurements are performed at a distance of 50' (15.24m) from the sensitive property. However, it should be borne in mind that areas within gardens such as patios may be used by an occupier more often that other areas of their garden. Such seating areas may be positioned close to buildings for protection from the wind. Dwellings may also have small gardens. In this event, it may not be possible to undertake measurements that are free of reflections from buildings. This should be considered during any initial assessment of the wind farm site by the developer.

In order to ensure that measurements of wind turbine noise are not influenced by reflections off buildings the microphone should be positioned at least 10m away from the facade. It may be appropriate to undertake background noise measurements closer than this if sheltered locations close to the property are most often used for rest and relaxation. Background noise measurements should not be taken closer than 3.5m from the facade. In circumstances where these conditions cannot be fulfilled an alternative location should be identified at which the measurements of free-field turbine noise can be expected to be the same as at the property in question, or can be readily corrected by an agreed method, and with some confidence, to levels at the property.

Equipment

Wind shields

Even using the $L_{A90,10min}$ noise descriptor there is a risk that measured noise levels can become contaminated by the effect of wind noise on the microphone when using the wind shields available commercially. Studies are currently being undertaken to evaluate the constraints on existing measurement systems with a view to offering suggestions for improved windshield design [31].

Certification and calibration

As specified in Sections 3 and 4 of BS 4142: 1990.

Background noise survey

The limits proposed are set in relation to the existing background noise level at wind speeds up to 12m/s measured on the wind farm site at 10m elevation. It is therefore necessary that background noise measurements should be correlated with wind speed measurements performed at the proposed site, such that the actual operating noise levels from the turbines may be compared with the noise levels that would otherwise be experienced at a dwelling.

Survey Period

Background noise measurements should be undertaken over a sufficient period of time to allow a reliable assessment of the prevailing background noise levels to be performed. Variations in the background noise levels due to wind effects may result in changes of ± 5dB(A) during a period of 1 minute, a medium term variation in level. Long-term variation of the background level may be caused by a change in wind direction. Background noise levels will also change according to the amount of rain that may have fallen during the preceding days; levels in deep valleys in Mid-Wales have been found to vary by as much as 25dB L_{A90}. The time of year that measurements are performed may also have an effect. Summer months may be expected to give higher ambient noise levels due to leaves on trees but lower levels due to reduced rainfall. Winter months may result in lower ambient noise levels due to no leaves on trees but higher level due to more rain. Conversely, the increased wind resistance of trees and shrubs in Summer can increase the level of shelter at the property such that lower wind speeds and hence noise levels are experienced for a given wind speed at the wind farm. Periods of external amenity vary in time of year from site to site and this should be considered when planning background noise surveys.

It is expected that to avoid the results being weighted by unrepresentative conditions at least 1 week's worth of measurements will be required. The actual duration will depend upon the weather conditions, in particular the strength and direction of the wind that has blown during the survey period and the amount of rain.

Measurements should not be used from periods of heavy rainfall when noise levels will be high due to the noise of the rain itself, and more important, due to the increased water flow in nearby streams and rivers.

When sheltered dwellings are positioned close to a site within a deep valley, it is recommended that special consideration is given to noise data that are collected for the wind condition that affords maximum shelter to the property.

Measurement of wind speed

Wind speed measurements are likely to be performed on-site as part of the wind resource study prior to development and if they are to be used for the noise assessment, measurements of the 10-minute average should be recorded. Measurements are performed using anemometers placed at known heights above ground level. Wind speed varies with height above ground level, increasing with increased height (see "wind shear" in Glossary). Therefore, the height at which wind speed measurements are performed and the height of the proposed wind turbines will affect the derived prevailing background noise level. We propose that measurements should be corrected to a standard height of 10m using the procedure described under "wind shear" in the Glossary. The recommendations for noise limits have been made assuming wind speed measurements corrected to 10m. Measurements at 10m will be easier to perform due to the availability of portable masts of this height.

Wind speed measurements performed at two different heights on the same mast will allow an assessment of the wind shear that exists at the wind measurement position. Derivation of the wind shear allows an assessment of the wind speed at 10m height to be performed if the anemometers are not positioned at 10m.

Analysis and derivation of background noise levels

The derivation of the prevailing background noise level at a dwelling is performed using the noise data that have been collected at the dwelling and the measured on-site wind speed at the anemometer height.

When deriving the prevailing background noise level, the height at which the wind speed is measured should be clearly stated and converted to 10m height.

It should be expected that measurements performed over an extended survey period will be affected by weather conditions that are not associated with wind speed. Rainfall will lead to increased noise levels at a measurement position due to a number of factors. These may include the increased flow of water within streams and brooks, the sound of rain drops falling on the wind shield and any associated equipment that may contain the sound level meter. Other noise sources may also increase measured noise levels. Work in fields, milking equipment and milk chillers, traffic and aircraft noise all increase the measured noise levels especially during the day-time periods.

The increased levels due to sources not associated with the wind will reduce the correlation between the wind speed and the measured background noise level. However, measurements undertaken during evening and night-time periods are less affected by these extraneous sources as human and animal activity is reduced, thereby minimising any effects. Rainfall, however, is harder to detect. Rain gauges provide an indication when rain fell during survey periods. Increased noise levels during night-time periods that are not associated with respective increases in wind speed are also an indication that rain may have fallen.

It is considered appropriate to remove the noise data that may be affected by rainfall during a survey. Measurements that are affected by human or animal activity during the night, ie traffic passing along nearby roads or owls in nearby trees, should be considered as the noise environment at the dwelling.

Background noise curves are required for both the day-time quiet periods and for the night-time. The periods are defined in Chapter 6.

Appendix C provides a fuller discussion on the measurement of background noise levels.

Measurement of wind farm noise

Wind speed measurement

To assess wind farm noise levels, measurements are correlated with the operating condition of the wind turbines. This is because the emitted noise from a wind turbine is related to the wind speed that a turbine experiences.

A possible method for determining the wind speed during a compliance test is to use an anemometer mast that has a height that is below the lowest point described by the wind turbine rotor, the suggested height being 10 metres. At this height it has been suggested that the true wind speed will be measured, ie which has not been affected by the rotor wakes of wind turbines upwind of the anemometer mast. This mast could then be placed at the original mast position used to determine the prevailing background noise level.

It should be noted that data collection of the wind speed resource at a proposed wind farm site may also have measured the wind shear at the mast position. If measurements have been gathered of the wind speed at 10 metres height, the background noise level measurements may be correlated with this measurement height data and any noise conditions set based upon this wind speed measurement height. A potential additional benefit of using a wind speed measurement height of 10 metres is that the IEA Recommended Practice for the measurement of noise emissions from wind turbines [11] proposes that the standardised sound pressure level and sound power level of a wind turbine be quoted for a wind speed reference condition of 8m/s at a height of 10 metres above ground level. Therefore, the use of a 10m-high anemometer mast may provide additional consistency through the measurement and assessment procedure.

Identification of critical periods for monitoring

It will not normally be necessary to demonstrate compliance with planning conditions at all wind speeds. If monitoring is required in response to complaints then a log of times at which the turbine noise is most intrusive, taken by the complainant, will enable the developer to establish the conditions which require further investigation.

Having established the critical wind speed conditions over which measurements are to be carried out one needs to consider the amount of data that will be required to give a reliable estimate of the typical turbine noise levels in these conditions. It is the opinion of the Noise Working Group that at least 20 to 30 measurements of the $L_{A90,10min}$ should be taken within $\pm$ 2m/s of the critical wind speed. At least ten measurements should lie either side of the critical wind speed. Measurements should be taken in representative conditions and not for example when the wind is in a direction rarely encountered.

To minimise the effects of extraneous noise sources it may be necessary to perform these measurements during night-time periods when other human and animal activity noise sources are likely to be at a minimum.

Analyses

Filtering of data

As with the background noise data it will again be necessary to filter data for effects such as periods of rainfall to ensure reliable results are obtained. Also, if the measurement of wind speed is from an anemometer which may be in the wake of a turbine in certain wind directions these data should also be removed.

Calculation of wind farm noise level

A best fit curve can be fitted to the data obtained for a particular critical wind speed. A straight line will usually be sufficient given the small range in wind speed. The noise level at the critical wind speed can be read from this curve. If this level is below that set in the noise limits and the EHO considers that there are no audible tones then no further action is necessary. If, however, either the noise is above the limit or the application of a tonal penalty may take the noise over the limit then a correction for the influence of the existing background noise should be performed or the measurements repeated at times of lower background noise.

The background noise at the critical wind speed should be assessed using the procedure described for turbine noise above. A correction shall then be made as follows:

$$L_{pw} = 10 \log (10^{L_{pc}/10} - 10^{L_{pb}/10})$$

where L_{pw} = wind farm noise, dB(A)
L_{pc} = combined wind farm and background noise as measured, dB(A)
L_{pb} = background noise only, dB(A).

It is recognised that the correction method above only strictly applies to the correction of one L_{eq} by another. Readers are referred to the paper by Nelson [32] for more discussion on correcting percentile measurements.

Measuring tonal levels

A review of options and a description of a recommended method for tonal assessment were given in Chapter 6. This Section describes the application of that method in the field so that reliable results can be obtained.

Instruments

The information contained in this assessment method is sufficiently complete to allow the identification of audible discrete tones to be made using a variety of measuring instruments; therefore no specific type of instrument is specified. The procedure requires, however, the measurements of the sound pressure level of the tone, L_{pt}, and the sound pressure level of the noise in the critical band centred at the frequency of the tone, L_{pm}. The instruments used should be capable of determining the difference between these levels to within ± 1dB.

Commercially available or specially designed analogue or digital instruments may be used to measure the levels directly or, more conveniently, raw data may be acquired and then processed by a digital computer. An A-weighted network shall be used when performing this assessment as this may be more convenient given a requirement to simultaneously measure the overall A-weighted sound pressure level.

Measurements

Tonal assessment should be carried out at times of typical background noise levels so that the effect of the existing background noise on the masking of tones is not over- or under-emphasised. It has been shown [27] that the audibility of a tone from wind turbines evaluated by the method described in Chapter 6 fluctuates by several dB without any appreciable change in wind speed. It is therefore necessary to introduce some averaging into the assessment procedure to increase the repeatability and reliability of the derived results. As for overall levels, 20 to 30 measurements should be taken within $\pm$ 2m/s of the critical wind speed. These measurements should be taken during the same periods as the measurements of overall noise level. At least ten measurements should lie either side of the critical wind speed. The measurements should be taken over a period of 2 minutes and regularly spaced at 10-minute intervals so that each measurement corresponds to a measurement of the $L_{A90,10min}$ used in the assessment of the overall noise level. As with overall levels, measurements should be taken in representative conditions and not for example when the wind is in a direction rarely encountered.

Analysis

Tonal analysis of each 2-minute sample is performed according to the recommended procedure described in Chapter 6:

- For each of the 2-minute samples calculate the margin above or below the audibility criterion of the tone level difference, ΔL_{tm}, by comparison with the audibility criterion given in Chapter 6.

- Plot the margin above audibility against wind speed for each of the 2-minute samples. For samples for which the tones are inaudible or no tone is identified substitute a value of zero audibility.

- Perform a linear regression to establish the margin above audibility at the critical wind speed. If there is no apparent trend with wind speed then a simple arithmetic average will suffice.

- The tonal penalty, K_T, is derived from the margin above audibility of the tone according to Fig 16 in Chapter 6.

The rating level

The rating level is the arithmetic sum of the wind farm noise level, L_{pw}, and the tonal penalty, K_T. It is this level which determines whether the wind farm has complied with the limits set in the planning condition.

8. THE PLANNING OBLIGATION

The Noise Working Group thought that it would be beneficial to present its recommendations in a form which might be useful to developers and planners. We therefore considered drafting planning conditions, but came to the conclusion that the necessary definitions of terms which would be required would make planning conditions too complicated. Therefore it was decided to produce covenants for inclusion within an Agreement between a developer and a local authority. Alternatively, the developer may be required, through a planning condition, to agree a noise rating and monitoring scheme with the local planning authority prior to operation of the development. The scheme may then incorporate the definitions and provisions which we have included within the Planning Obligation. This may be particularly helpful where a developer does not own the proposed wind farm site.

It is appreciated that on first reading the Planning Obligation can appear somewhat complicated. It is anticipated that when there has been more experience of drafting such obligations it may be possible for some simplifications to be made.

The Planning Obligation is supplemented by some Guidance Notes to which it refers. These Guidance Notes also serve as a useful summary of the proposed measurement procedure.

DATED 1996

THE WIND FARM LIMITED (1)

and

THE COUNCIL (2)

PLANNING OBLIGATION BY AGREEMENT

Relating to Land at

Assumptions within this document:

1. The Developer owns the freehold of the Site
2. There are no other interests in the Site and in particular there is no charge over the Site

---

Bond Pearce
Plymouth

THIS PLANNING OBLIGATION BY AGREEMENT is made the day of 199 BETWEEN:

(1) **THE WIND FARM LIMITED** a company registered in with number and whose registered office is at

(2) **THE COUNCIL** of the Council Offices at

WHEREAS:

(1) The Council is the local planning authority for the purposes of the 1990 Act for the area which includes the Site

(2) The Developer owns the legal estate in the Site

(3) The Developer intends to construct and operate the Development

(4) The Developer has by the Application applied to the Council for planning permission for the Development

(5) The Council in exercise of its powers under the 1990 Act has decided to grant planning permission for the Development

(6) The Developer has agreed to enter into this Obligation

NOW THIS OBLIGATION WITNESSES as follows:

1. In this Obligation unless the context otherwise requires:-

1.1 "**the Developer**" means The Wind Farm Limited and its successors in title

1.2 "**the Council**" means The [ ] Council and any successor authority

1.3 "**the Site**" means the land edged red on the plan numbered x attached to this Obligation being land at .....

1.4 "**the Application**" means an application for the Permission for the Development submitted to the Council under the 1990 Act on registered under number ....

1.5 "**the Development**" means the erection on the Site of x wind turbine generators, a grid connection building and ancillary development as specified in the Application

1.6 "**the Permission**" means any planning permission issued pursuant to the Application (together with any modifications thereto made with the consent of the Developer) by the Council on the determination of the Application

1.7 **"the 1990 Act"** means the Town and Country Planning Act 1990 (as amended by the Planning and Compensation Act 1991 and any subsequent legislation)

1.8 **"the Wind Turbines"** means the wind turbine generators proposed to be erected as part of the Development.

2. It is the intention of the parties that:

2.1 This Obligation is made pursuant to the provisions of Section 106 of the 1990 Act

2.2 This Obligation shall be enforceable by the Council

2.3 This Obligation shall not take effect until the Permission has been granted and implemented by the carrying out of a specified operation as defined in Section 56 (4) of the 1990 Act

2.4 No person or company shall be liable for any breach of this Obligation unless he or it holds an interest in the part of the Site in respect of which such breach occurs or held such an interest at the date of the breach

2.5 Nothing in this Obligation shall be construed as prohibiting or limiting the development of the whole or any part of the Site in accordance with any planning permission granted by the Council after the date of this Obligation (save and except the Permission)

2.6 Where the context so requires the singular includes the plural and terms using the masculine gender include the feminine

2.7 References to Schedules and Appendices mean Schedules and Appendices to this Obligation

3. The Developer hereby covenants with the Council to observe and perform the obligations contained in the Schedule all of which relate to the Development

4. Any dispute arising from the terms of this Obligation will be referred to the decision of a single arbitrator (acting as an expert and not an arbitrator) under the terms of the Arbitration Act 1979, such arbitrator to be appointed by agreement between the parties or in default of agreement by the President for the time being of the Institute of Acoustics (or provision for determination of disputes by the County Court)

IN WITNESS whereof the parties hereto have executed these presents the day and year first before written

THE SCHEDULE

1. In this Schedule unless the context otherwise requires:

1.1 "**Audibility**" means the audibility of Tonal Noise as defined in (and to be measured in accordance with) the recommended method in Section 2.1 of the Guidance Note

1.2 "**Background Noise Level**" means the ambient noise level already present within the environment (in the absence of noise generated by the Development) as measured prior to the date of this Obligation and correlated with Wind Speeds

1.3 "**Best Fit Curve**" means a best fit linear regression curve expressing noise levels as a function of wind speed derived from measured noise levels for data points extracted in accordance with the recommendations in Section 1.2 of the Guidance Note

1.4 "**Critical Band Width**" means a band with a prescribed frequency range determined in accordance with the recommendations in Section 2.1 of the Guidance Note Appendix 3

1.5 "**$dB(A)_{L90,10min}$**" means the dB(A) level exceeded 90% of the time and measured over a period of 10 minutes

1.6 "**Free-field Conditions**" means an environment in which there are no reflective surfaces (except the ground) affecting measurements within the frequency range being measured

1.7 "**Guidance Note**" means the 'Supplementary Guidance Notes to the Planning Obligation" presented in Chapter 8 of the report 'The Assessment and Rating of Noise from Wind Farms", September 1996, report number ETSU-R-97.

1.8 "**Night Hours**" means 2300-0700 hours on all days

1.9 "**Quiet Waking Hours**" means 1800-2300 hours on all days plus 0700-1800 hours on Sundays and 1300-1800 hours on Saturdays

1.10 "**Tonal Noise**" means noise containing a discrete frequency component

1.11 "**Wind Speeds**" means (unless the context otherwise demands) wind speeds measured at a height of 10 metres above ground level on the Site at Ordnance Survey grid reference aaaaaa.

1.12 "**Wind Turbine Noise Level**" means the rated noise level due to the combined effect of all the Wind Turbines including any penalty incurred under clause 7 or 8 of this Schedule but excluding the existing background noise level

2. At the reasonable request of the Council following a complaint to the Council relating to noise emissions from Wind Turbines the Developer shall measure at its expense the level of noise emissions from the Wind Turbines (inclusive of existing background noise) using an L_{A90} index over a minimum of 20 periods each of 10 minutes duration. At least 10 of the periods of measurement shall be made at Wind Speeds between a wind speed specified by the Council and a wind speed of not more than 2 metres per second above that specified by the Council. At least 10 measurements shall be made at Wind Speeds between the wind speed specified by the Council and a wind speed not less than 2 metres per second below that specified by the Council. Measurements of noise emissions shall be made in consecutive 10-minute periods provided that they fall within the wind speed range defined in this clause

3. The measurements under clause 2 shall be made using a sound level meter of at least type 1 quality (as defined in International Electrotechnical Commission standard 651 (1979)) incorporating a windshield with a ½ inch diameter microphone in free-field conditions between 1.2 and 1.5 metres above ground level and at least 10 metres from any wall, hedge or reflective surface (using a fast time weighted response)

4.

Alternative 1

(a) In this clause the values of X Y and Z are specified in the Tables within Appendix A of this Agreement in relation to the dwellings referred to or named as described in Section 1.3 of the Guidance Note.

(b) The Wind Turbine Noise Level as measured in accordance with clauses 2, 3 and 5 shall not exceed:

(i) During Night Hours the greater of the Night Hours L_{A90} Background Noise Level plus XdB or YdB$(A)_{L90,10min}$ at Wind Speeds not exceeding 12 metres per second;

and at all other times

(ii) The greater of the Quiet Waking Hours L_{A90} Background Noise Level plus XdB or ZdB$(A)_{L90,10min}$ at Wind Speeds not exceeding 12 metres per second

Provided that this covenant shall only apply to dwellings existing at the date of this Obligation.

Alternative 2

The Wind Turbine Noise Levels as measured in accordance with clause 2, 3 and 5 shall not exceed 35dB$(A)_{L90,10min}$ at Wind Speeds not exceeding 10 metres per second provided that this can only apply to dwellings existing at the date of this Obligation.

5. (a) Measurements made in accordance with the provisions of this Schedule in order to demonstrate compliance with the requirements of clause 4 shall be correlated with Wind Speeds

(b) The $L_{A90,10min}$ noise level from the combined effect of the Wind Turbines (inclusive of existing background noise) shall be derived using a Best Fit Curve.

6. Tonal Noise shall be measured for Audibility in accordance with the recommended method described in Section 2.1 of the Guidance Note.

7. If Tonal Noise from the combined effect of the Wind Turbines (when measured in accordance with clause 6) exceeds the threshold of Audibility by more than 6.5dB a penalty of 5dB shall be added to the noise level derived in accordance with clause 5(b)

8. If Tonal Noise from the combined effect of the Wind Turbines (when measured in accordance with clause 6) exceeds the threshold of Audibility by more than 2.0dB but less than 6.5dB a penalty of ((5/6.5)xAudibility)dB shall be added to the noise level derived in accordance with clause 5(b)

9. If measurements made in accordance with clauses 2, 3 and 5 exceed the levels of noise emissions provided in clause 4 then in order to investigate compliance with such levels by an assessment of the contribution of background noise to the measured levels the measurements shall be repeated by the Developer at a time when the contribution of the Background Noise Level to measured noise levels can be expected to be less than at the time of the first set of measurements.

10. If measurements made in accordance with clause 9 exceed the levels of noise emissions provided in clause 4, or noise levels measured in accordance with clauses 2, 3, 5, 6, 7 and 8 exceed the levels provided in clause 4, then in order to investigate compliance with such levels by an assessment of the contribution of background noise to the measured levels, measurement shall be made in accordance with the requirements of clause 2, 3 and 5(b) (with the Wind Turbines stationary). A correction shall be applied in accordance with the recommended method in Section 2.0 of the Guidance Note to the measured noise levels in order to determine the contribution of background noise to the overall levels of noise measured when the Wind Turbines are in operation.

11. The Developer shall supply Wind Speeds and wind direction data to the Council at its request to enable the Council to check compliance by the Developer with the provisions of this Schedule.

EXECUTED AS A DEED AND DELIVERED)
BY authorised to)
sign for and on behalf of)
)
in the presence of:)

THE COMMON SEAL OF THE)
COUNCIL)
was hereunto affixed)
in the presence of:)

Authorised Person

Authorised Person

Bond Pearce
1996 (ref GMT)

SUPPLEMENTARY GUIDANCE NOTES TO THE PLANNING OBLIGATION

1.0 Prior to construction of the wind farm

1.1 Identification of properties where background noise surveys are required

Before the wind farm is constructed, the developer/operator should identify the nearest noise-sensitive properties to the wind turbines.

If there is a small number of such properties, a background noise survey will be required at each one.

If there are rather more properties, it may be appropriate to identify a smaller number of properties, in agreement with the local authority/EHO, that have similar background noise levels to a group of properties in their immediate vicinity. A background noise survey will be required at each one of these indicative properties as the noise limits relate to the existing background noise levels.

The precise locations at which the background noise surveys should be made at each property should be agreed in consultation with the local authority/EHO.

In addition, the developer/operator of the wind farm should agree, in consultation with the local authority/EHO, the lower limit on wind farm noise that will apply at each property, or group of properties under consideration. This limit should normally lie in the range 35-40dB(A), except where the occupants of a property receive a financial benefit from the wind farm, where a higher limit of 45dB(A) may be appropriate. It may be desirable to agree these lower limits after the background noise surveys have been completed, rather than beforehand.

Note that where it can be demonstrated that the expected levels of wind farm noise would not exceed 35dB(A) at a property for wind speeds of up to 10m/s at 10m height, then no background noise survey is required for that property.

Note also that where a new wind farm is planned for an area where another wind farm is already operating, the contribution to noise levels from the existing wind farm should not be included in any assessment of prevailing background noise levels.

1.2 The background noise survey

The background noise survey should be taken over a sufficient period of time to enable a reliable assessment of the prevailing background noise levels at each property to be made. As a guideline, an appropriate survey period might be 1 week, although the actual duration will depend upon the weather conditions, in particular the wind speed and direction during the survey period. It must be ensured that, during the survey period, wind speeds over the range zero to at least 12m/s (10min average at 10m height), and a range of wind directions that are typical of the site, are experienced.

The aim of the survey, at each location, is to characterise the variation in prevailing background noise level with wind speed. This is achieved by correlating background noise measurements with wind speed measurements made over identical time periods. The following sections identify the measurements required to enable this.

1.2.1 Acoustic measurements

Background noise levels should be measured using the A-weighted L_{90} statistic over consecutive 10-minute intervals, ie $L_{A90,10min}$. A sound level meter of at least IEC 651 type 1 quality should be used, and this should be fitted with a ½" diameter microphone and calibrated in accordance with the procedure specified in BS 4142: 1990.

The microphone should be mounted on a tripod at 1.2-1.5 m above ground level, fitted with a wind shield, and placed in the vicinity of, and external to, the property, at least 3.5m away from any reflecting surfaces. The intention is that the acoustic measurements should be made in "free-field" conditions.

1.2.2 Wind speed and direction measurements

Wind speed and direction data should be recorded as average values over 10-minute intervals, v_{10min} & Θ_{10min}, these intervals to be synchronised with the measurement period for the $L_{A90,10min}$ acoustic data.

The measurements should preferably be made using instruments mounted at 10m height. Where this is not possible, wind speeds measured at one height can be "corrected" to the value that would have been measured at another height using the expression:-

$$V_1/V_2 = \ln(h_1/z_0) / \ln(h_2/z_0)$$

where V_1 = wind speed (m/s) at a height of h_1 metres above ground level.
V_2 = wind speed (m/s) at a height of h_2 metres above ground level.
z_0 = ground roughness length (m).

The ground roughness length can be calculated from wind speed measurements at two or more heights. Alternatively it can be estimated from Table 11.

The instruments should be mounted on a mast positioned on the site so that they give a reasonable description of meteorological conditions at the noise-sensitive properties. Where there are several masts on a site, data from the instruments mounted on the mast closest to each property should be used.

Table 11 Roughness lengths for various types of terrain

Type of Terrain	Roughness Length z_0
Water areas, snow or sand surfaces	0.001m
Open, flat land, mown grass, bare soil	0.01m
Farmland with some vegetation	0.05m
Suburbs, towns, forests, many trees and bushes	0.30m

1.2.3 Data reduction

At the end of the survey period, data recorded during periods of rainfall, or afterwards, where rainfall may have affected flow in nearby rivers or streams, should be discarded.

Two sub-sets of the data should be created, for the following periods:

- quiet waking hours (18:00-23:00 every day, 13:00-18:00 on Saturday, 07:00-18:00 on Sunday)

- night hours (23:00-07:00, every day).

These two sub-sets are identified as the "day-time" data, and the "night-time" data.

For each sub-set, a "best fit" curve should be fitted to the data using a least squares approach, usually a polynomial model (of no more than 4th order).

Where there is considerable scatter in the data, it may be appropriate to bin the acoustic data into 1m/s bins, before identifying a best fit model.

These two curves, referred to as the "day-time curve" and the "night-time curve", provide a characterisation of the prevailing background noise levels, for the day-and night-time respectively, as functions of wind speed from zero to 12m/s at 10m height.

Note that whatever model is used to describe the measured data, this should not be extrapolated outside of the range of measured wind speed data.

1.3 Identification of noise criteria

1.3.1 Day-time noise criterion

The criterion curve for acceptable levels of wind farm noise during day-time, ie 07:00-23:00 each day, is usually equal to the day-time curve plus 5dB(A) at every wind speed.

Where this criterion curve falls below the lower limit (35-40dB(A), or 45dB(A) - see Section 1.1), the criterion curve should be amended so that it equals the lower limit. This results in a piece-wise, continuous curve, equal to the lower limit from zero to the wind speed at which the day-time curve plus 5dB(A) equals the lower limit, and the day-time curve plus 5dB(A) thereafter, to an upper wind speed of 12m/s at 10m height.

1.3.2 Night-time noise criterion

The criterion curve for acceptable levels of wind farm noise during night-time, ie 23:00-07:00 each day, is equal to the night-time curve plus 5dB(A) at every wind speed.

Where this criterion curve falls below 43dB(A), the criterion curve is amended so that it equals 43dB(A). As before, this results in a piece-wise, continuous curve, equal to 43dB(A) from 0m/s up to the wind speed at which the night-time curve plus 5dB(A) equals 43dB(A), and the night-time curve plus 5dB(A) thereafter, to an upper wind speed of 12m/s at 10m height.

Note that where the occupants of a noise-sensitive property are financial beneficiaries of the wind farm, the 43dB(A) figure may be replaced with 45dB(A) - see section 1.1.

1.3.3 Table of noise limits

The limits agreed for each property or group of properties can be summarised in tabular form in an Appendix to the Planning Obligation, see Section 4 of the Schedule. Properties not mentioned specifically by name or address should be included by applying limits to "any other property". In Section 4 X refers to the margin above background (usually 5dB), Y refers to the night-time lower fixed limit (usually 43dB) and Z refers to the day-time lower fixed limit (usually in the range 35-40dB).

2.0 Procedure to be followed in the event of a complaint

Where the local authority/EHO receive a complaint about noise levels following the construction of the wind farm, the following steps should be taken:

1 The complainant should log the times when the noise is most intrusive. This will enable the meteorological conditions in which the complaint occurs to be determined and, in particular, the critical wind speed.

2 At least 20 values of the $L_{A90,10min}$ noise statistic should be measured at the affected property using a sound level meter of at least IEC 651 Type 1 quality. This should be fitted with a ½" diameter microphone and calibrated in accordance with the procedure specified in BS 4142: 1990. The microphone should be mounted on a tripod at 1.2-1.5 m above ground level, fitted with a wind shield, and placed in the vicinity of, and external to, the property. The

intention is that, as far as possible, the measurements should be made in "free-field" conditions. To achieve this, the microphone should be placed at least 10m away from the building facade or any reflecting surface, where possible, and no less than 3.5m away where this is not possible with appropriate adjustment made to measured levels to account for facade effects.

The 20 $L_{A90,10min}$ measurements should be synchronised with measurements of the 10-minute average wind speed, and be made in wind speeds within ± 2m/s of the critical wind speed. Further, at least 10 of these should lie either side of it. The measurements should be made during conditions that are generally typical for the site and not, for example, during periods with a rarely encountered wind direction.

To minimise the effects of extraneous noise sources, it may be necessary to perform these measurements during night-time periods.

Any data recorded during periods of rainfall, or immediately afterwards, where rainfall may have affected flow in nearby rivers or streams, should be discarded. Where this is necessary it shall be ensured that the conditions relating to the number of data points, and their distribution, are still adhered to.

3 A least squares, "best fit" curve should be fitted to the data points - generally a straight line fit will be sufficient.

4 The noise level at the critical wind speed, L_c, shall be determined from this best fit curve. If this level lies below the value indicated from the two noise criteria curves at the critical wind speed, and the local authority/EHO consider there to be no audible tones, then no further action is necessary.

5 If the noise level is above the limit, or if the application of a tonal penalty - see later - takes it above the limit, a correction for the influence of background noise should be made. This may be achieved by repeating steps 2-4, with the wind farm switched off, and determining the background noise at the critical wind speed, L_b. The wind farm noise at this speed, L_w, is then calculated as follows:

$$L_w = 10\log\left(10^{\frac{L_c}{10}} - 10^{\frac{L_b}{10}}\right)$$

If the wind farm noise level lies below the value indicated from the two noise criteria curves at the critical wind speed, and the local authority/EHO consider there to be no audible tones, then no further action is necessary.

6 Where, in the opinion of the local authority/EHO, the noise immission contains a tonal component, the following rating procedure should be used. This is based on the repeated application of a tonal assessment methodology - see below.

For each 10-minute interval for which $L_{A90,10min}$ data have been obtained, a tonal assessment - see Section 2.1 - is performed on noise immission during 2-minutes of the 10-minute period. The 2-minute periods should be regularly spaced at 10-minute intervals provided that uninterrupted clean data are obtained.

For each of the 2-minute samples the margin above or below the audibility criterion of the tone level difference, ΔL_{tm}, is calculated by comparison with the audibility criterion given in Section 2.1 below.

The margin above audibility is plotted against wind speed for each of the 2-minute samples. For samples for which the tones were inaudible or no tone was identified, substitute a value of zero audibility.

A linear regression is then performed to establish the margin above audibility at the critical wind speed. If there is no apparent trend with wind speed then a simple arithmetic average will suffice.

The tonal penalty, K_T, is derived from the margin above audibility of the tone according to Fig 17.

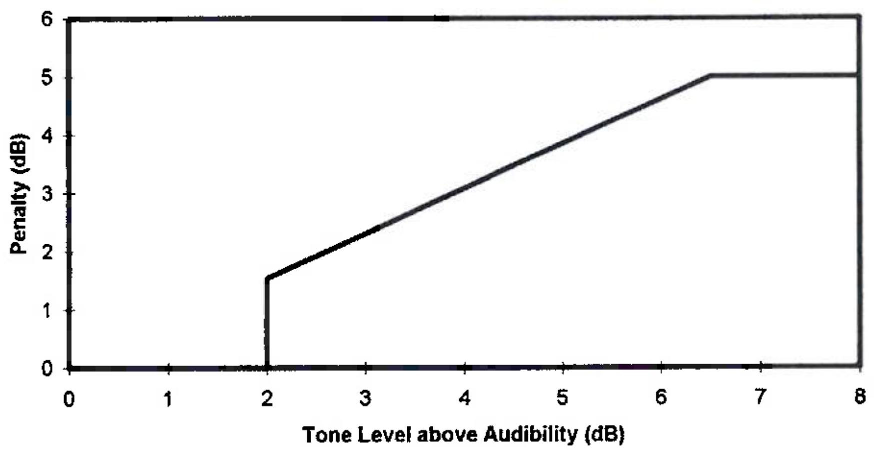


Figure 17 Penalties for tonal noise

The rating level is the arithmetic sum of the wind farm noise level, L_{pw} and the tonal penalty, K_T. It is this level which determines whether the wind farm has complied with the limits set in the planning condition.

2.1 *Tonal assessment methodology*

The recommended method is based upon the Joint Nordic Method for non-stationary tones with some embellishments in areas where it is not entirely prescriptive such as tone identification and averaging periods. The method aims to assess the audibility of a tone as perceived by the average listener. There are three main steps in the procedure:

A) Frequency analysis of the noise at receiver locations.

B) Determination of the sound pressure level of the tone(s) and the sound pressure level of the masking noise within the critical band.

C) Evaluation of the difference between the tone and the masking noise sound pressure levels (ΔL_{tm}) by comparison with a criterion curve to determine the audibility of a tone.

A. Frequency analysis

The analysis of non-stationary tones is quite intensive; it will therefore be convenient to record the signal to be analysed onto tape. For each tonal assessment 2-minutes of uninterrupted clean A-weighted recording is required.

A 2-minute, rms-averaged FFT is performed on the sampled data using a Hanning window, a frequency resolution of 3.0 ± 0.5Hz and an analysis bandwidth of 2kHz. It may be necessary to inspect a similar spectrum with greater bandwidth to ensure that there are no tones present at higher frequencies.

The short term, individual rms-averaged FFTs within the sampled data are also calculated using the same parameters as described above. This results in an averaging time of 0.29 to 0.4 seconds.

B. Determination of sound pressure levels

The bandwidth of a critical band is:

Centre Frequency f_C, Hz	20-500	Above 500
Bandwidth	100Hz	20% of f_C

If a single tone is present the critical band is centred upon the tone. If two or more, closely spaced tones are present, the critical band is placed so that it contains the maximum possible amount of tonal energy. In order to do this it is first necessary to identify the tones within the spectrum. To do this each line in the 2-minute spectrum must be classified according to the following criteria based upon the draft DIN 45 681. A peak is classed as a tone if its level is more than 6dB above the logarithmic average of the sound pressure levels of the rest of the lines in the critical band centred on the peak, but excluding the one line each side of the peak. If the peak qualifies as tone the adjacent lines are also classified as a tone if their level is within 10dB of the peak and greater than 6dB above the average level previously calculated. If a spectral line is more than 6dB above the average masking level and more than 10dB below the peak level it is classified as neither tone nor masking. Having identified the tones the critical band can be placed to maximise the sound pressure level of the tones within the critical band.

Because classifying a line as a tone means it can no longer be counted as masking, an iterative procedure is required for the proper identification of tones and masking. This is described by reference to the worked example below.

Fig 18 shows the stages in the tone identification and classification process. These are:

- Find peaks in the spectrum, in this case line 23.

- Calculate the average energy in the critical band centred on each peak, not including the two lines adjacent to the peak (9.10dB).

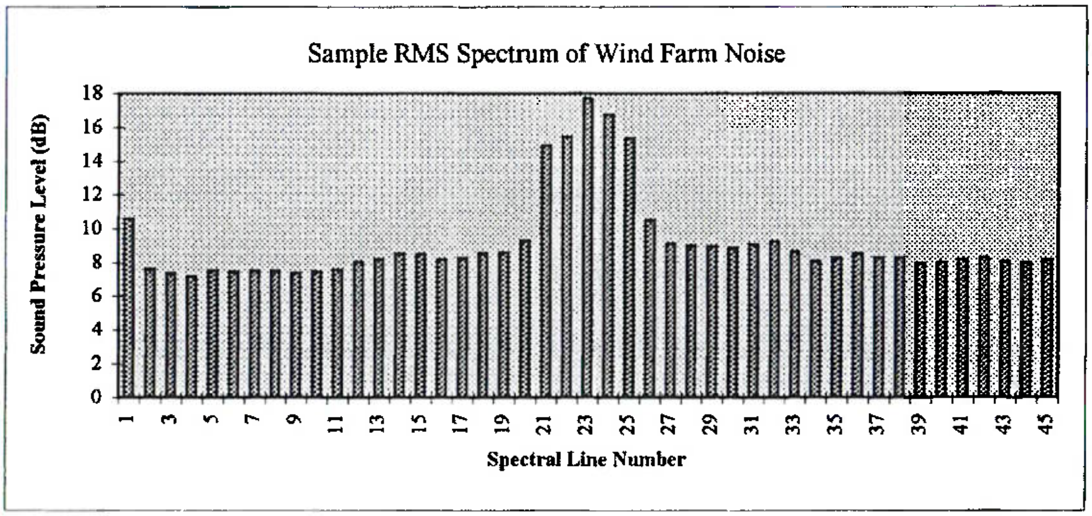
- If the peak is more than 6dB above the average masking level then it is a tone, therefore line 23 is a tone.

- Classify adjacent spectral lines :

    Pass 1
    - Compare spectral lines above and below the peak to the average level.
    - If a line is more than 6dB above the average and less than 10dB below the peak then it is a tone, therefore lines 22, 24 and 25 are tones.

    Pass 2
    - Calculate new average masking level centred around the peak, discounting adjacent spectral lines and all other lines classed as tones (8.75dB).
    - Compare spectral lines above and below the peak to the average level.
    - If a line is more than 6dB above the average and less than 10dB below the peak then it is a tone, therefore lines 21, 22, 24 and 25 are tones.

    Pass 3
    - Calculate new average masking level centred around the peak, discounting adjacent spectral lines and all other lines classed as tones (8.39dB).
    - Compare spectral lines above and below the peak to the average level.
    - If a line is more than 6dB above the average and less than 10dB below the peak then it is a tone. Therefore lines 21, 22, 24 and 25 are tones, but no spectral lines have been reclassified in this pass so the iterative process is complete.



Tone Identification and Classification						
Peak line = 23	**Peak Level = 17.71dB**					
	Pass 1		**Pass 2**		**Pass 3**	
Average about peak	9.10		8.75		8.39	
Adjacent line assessment	**Level above average**	**Classif-ication**	**Level above average**	**Classif-ication**	**Level above average**	**Classif-ication**
Line number						
19	-0.49	masking	-0.14	masking	0.22	masking
20	0.20	masking	0.55	masking	0.91	masking
21	5.83	masking	6.18	tone	6.54	tone
22	6.34	tone	6.69	tone	7.05	tone
24	7.64	tone	7.99	tone	8.35	tone
25	6.26	tone	6.61	tone	6.97	tone
26	1.40	masking	1.75	masking	2.11	masking
27	-0.01	masking	0.34	masking	0.70	masking

Figure 18 Tone identification and classification process

If a spectral line is more than 6dB above the average masking level and more than 10dB below the peak level then it is classified as neither tone nor masking, and not included in the calculation for either level.

The process described above is repeated for every critical band centred around tonal peaks in the spectrum. The result is that within each critical band every spectral line is classified as tone energy, masking energy or neither.

Having identified the lines in each spectrum contributing to tonal levels, masking levels or neither, the tonal analysis can continue as follows:

- The masking energy within the critical band is calculated from the 2-minute rms spectrum. Calculate the masking level in the critical band, L_{pm}, correcting for a reduction in the number of lines due to the exclusion of tones and for the Hanning window:

$$L_{pm} = 10\log\sum 10^{L_m/10} + 10\log\frac{(\text{critical band width})}{(N_m \times \Delta f)} + 10\log(1/1.5)$$

where L_m = sound pressure level of each line containing masking noise
N_m = number of lines within the critical band containing masking noise.

- For each of the short term spectra of 0.29 to 0.4 seconds duration, calculate the tone energy within each critical band, L_{pt}', using the lines identified as tones from the 2-minute spectrum.

  $$L_{pt}' = 10\log\sum 10^{L_t/10}$$

  where L_t is the sound pressure level of each line containing tonal noise.

  The tone level used in the assessment, L_{pt}, is the arithmetic mean of the top 10% of tone levels, L_{pt}', from all the short-term spectra constituting the 2-minutes of data.

C. Evaluation of the audibility of the tone(s).

The audibility of a tone is dependent upon the tone level difference, ΔL_{tm}, and the frequency of the tone:

$\Delta L_{tm} = L_{pt} - L_{pm}$.

The audibility criterion is defined as follows:

$\Delta L_{tm,crit} = -2 - \text{Log}(1 + (f/502)^{2.5})$

where f = frequency at the centre of the critical band.

This is the level at which the average listener will be just able to hear the tone. Fig 19 details the audibility criterion based upon the above equation. It can be seen from the figure that the audibility criterion is related to the frequency of the tone.

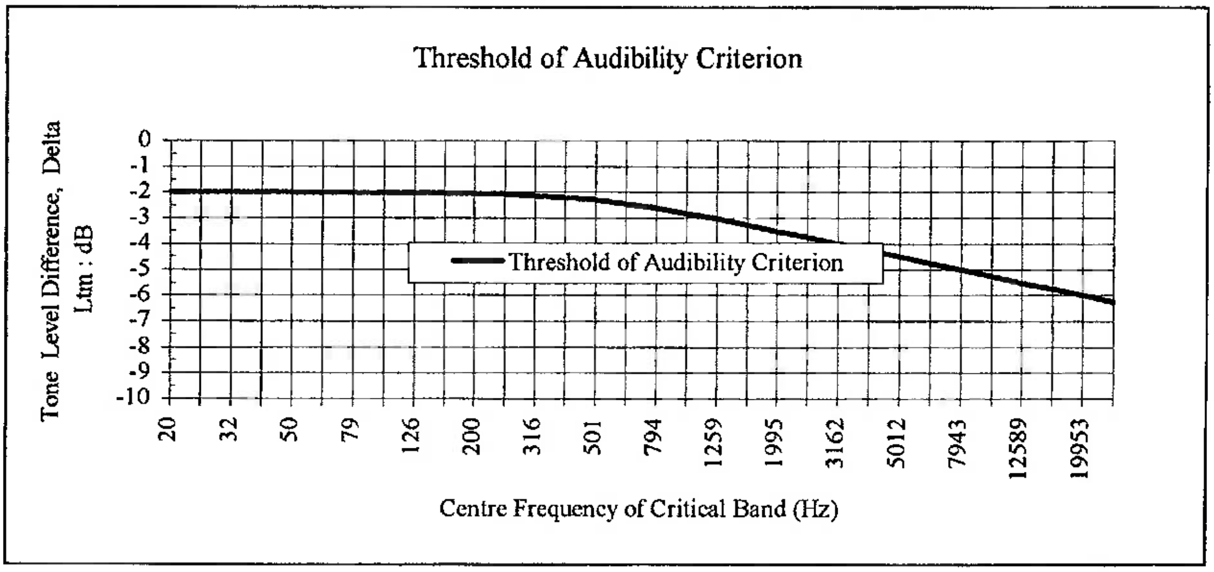


Figure 19 The audibility criterion for tonal noise assessment

Tonal assessment should be carried out at times of typical background noise levels so that the effect of the existing background noise on the masking of tones is not over- or under-emphasised.

It has been shown [27] that the audibility of a tone from wind turbines evaluated by the method described in these guidance notes fluctuates by several dB without any appreciable change in wind speed. It is therefore necessary to introduce some averaging into the assessment procedure to increase the repeatability and reliability of the derived results. As for overall levels, 20 to 30 measurements should be taken within $\pm$ 2m/s of the critical wind speed. These measurements should be taken during the same periods as the measurements of overall noise level. At least 10 measurements should lie either side of the critical wind speed. The measurements should be taken over a period of 2 minutes and regularly spaced at 10-minute intervals so that each measurement corresponds to a measurement of the $L_{A90,10min}$ used in the assessment of the overall noise level. As with overall levels, measurements should be taken in representative conditions and not for example when the wind is in a direction rarely encountered.

9. FURTHER WORK

This chapter makes some observations that may form the basis of a review of the contents of this report. It also outlines current research within the DTI New and Renewable Energy Programme of relevance to those working in the environmental assessment of noise from wind turbines.

Review of the report and its recommendations

This report was drafted in the light of the best information available at the time and in the circumstances prevailing at the time. However it is acknowledged that as more experience and information become available and as circumstances develop it may become necessary to revise and improve the contents of this report

The Noise Working Group therefore suggests this report and its recommendations are reviewed in 2 years time. We anticipate that the wind industry will itself take the initiative for such a review and that this review will be undertaken by a cross-section of users of the report. This review should establish:

- To what extent have the recommendations been followed?
- Have the recommendations been interpreted as originally intended?
- Do the suggested noise limits provide the right balance between protecting the local amenity and providing for the development of renewable energy sources?
- Do the measurement procedures strike the right balance between repeatability and reliability on the one hand and ease of use on the other?
- Are there any circumstances which the recommendations do not properly address but which could be covered by general advice?

More specific issues which could warrant further attention are:

- The simplification of the tonal assessment method.
  An IEA Recommended Practice on "The Measurement of Noise Immission Levels from Wind Turbines at Noise Receptor Locations" is currently under preparation. This may contain a simpler method for the measurement of the difference between the tone level and the masking noise based upon rms-averaged spectra. It is unlikely however that this tone level difference will be able to be transformed into a measure of the audibility of a tone without validation by further work.
- Tonal assessment of variable speed machines.
  In 2 years time there is likely to be more information and experience available on the tonal emissions from variable speed machines which could then be incorporated in to the tonal

assessment method.

- The correction of turbine noise for the influence of background noise.
  The report acknowledges that the expression used for correction of turbine noise for background noise is only strictly applicable to L_{eq} measurements and may slightly underestimate the correction required. If user experience shows that greater accuracy is required then further investigation of how to correct one average L_{90} measurement by another will be necessary.

Current research projects

This section briefly reviews current research projects being undertaken as part of the DTI's New and Renewable Energy Programme which may be of interest to readers. The reports from these projects will be available on loan from the Enquiries Bureau at ETSU following publication.

Low Frequency Wind Turbine Noise and Vibration

Contractor: Powergen.

Objectives: 1. To measure the low frequency noise and vibration levels in the frequency range 0.1Hz to 60Hz in the immediate vicinity of a modern wind farm and at distances up to 1km.
2. To assess the measured noise and vibration levels in relation to existing noise and vibration criteria and in relation to existing published data on low frequency noise and vibration.

Publication: November 1996.

Report No: ETSU W/13/00392/REP.

Wind Turbine Measurements for Noise Source Identification

Contractor: Hoare Lea and Partners.

Objectives: 1. To acquire high quality data on noise and vibration from two types of wind turbine.
2. To relate the noise to vibration and turbulence measurement.
3. To provide full information on the trends of principal noise features with wind speed, wind turbine power, direction of observation, and other relevant parameters.
4. To compare the data with recently developed theory for aerodynamic noise.
5. To establish the mechanisms that result in blade "swish", to determine its temporal and spectral character, to devise an objective metric for blade swish prominence and to identify conditions under which blade swish is likely to occur.

Publication: December 1996.

Report No: ETSU W/13/00391/REP.

Wind Farm Noise Control Strategy

Contractor:	Wind Prospect Ltd.
Objectives:	1. To develop and implement a tuned dynamic wind farm noise control strategy based upon varying cut-in wind speeds with wind direction to achieve specified noise constraints at specified locations close to a wind farm. 2. To evaluate the effectiveness and financial implications of such a method.
Publication:	June 1997.
Report No:	ETSU W/13/00499/REP.

Propagation of Noise from Wind Turbines over Variable Terrain

Contractor:	The Hayes McKenzie Partnership.
Objectives:	1. To use an impulsive noise source to establish the influence of secondary propagation paths and other terrain effects on received noise levels in complex terrain. 2. To establish improved (empirical) modelling techniques for noise propagation over various types of terrain under different wind conditions.
Publication:	March 1997.
Report No:	ETSU W/13/00354/045/REP.

A Critical Appraisal of Wind Farm Noise Propagation

Contractor:	Renewable Energy Systems Ltd
Objectives:	1. To obtain high quality noise immission ("far" field) data at locations surrounding a controlled loudspeaker noise source. 2. To obtain high quality noise emission ("near" field) and noise immission ("far" field) data from a number of UK wind farms. 3. To review existing long-term noise immission data previously collected by the participants from UK wind farms. 4. To use these data to critically appraise the performance of a wide range of popular sound propagation models and, based on this, to estimate the prediction uncertainties associated with the different propagation models. 5. To recommend either the "best" sound propagation model to use, or the "best" given certain circumstances, eg flat, open terrain. 6. To develop a new, empirical noise propagation model for predicting wind farm noise immission levels under practically encountered conditions, and to place confidence limits on these predictions by defining an envelope in which sound pressure levels are likely to lie.
Publication:	May 1998.
Report No:	ETSU W/13/00385/REP.

Noise Immission from Wind Turbines

Contractor:	National Engineering Laboratory.
Objectives:	1. To reduce the effects of wind-induced self noise on noise measurements made with outdoor microphones. 2. To measure noise levels around a number of wind farms for comparison with noise propagation models. 3. To develop, validate and generate a PC version of a noise propagation model developed under a previous JOULE II contract. 4. To quantify the uncertainty of reported sound power measurements due to different measurement practices and differing interpretation of existing standards. 5. To quantify the uncertainty of reported tone levels from wind turbines. 6. To quantify the "nuisance value" of noise from wind turbines in comparison with a common reference.
Publication:	May 1998.
Report No:	ETSU W/13/00503/REP.

10. REFERENCES

1. Department of the Environment, Planning Policy Guidance Note PPG 22: Renewable Energy. 1993, HMSO.

2. British Standards Institution 1990. Method for Rating Industrial Noise Affecting Mixed Residential and Industrial Areas. BS 4142.

3. Noise: Report of the Committee on the Problem of Noise. AWilson (Chairman) HMSO 1963/4.

4. DOE Circular 10/73 (WO 16/73), Planning and Noise, HMSO.

5. Department of the Environment, Planning Policy Guidance, PPG 24: Planning and Noise. 1994, HMSO.

6. Department of the Environment. Mineral Planning Guidance Note, MPG 11: The Control of Noise at Surface Mineral Workings. 1993, HMSO.

7. Department of Trade and Industry Energy Paper 62. New and Renewable Energy: Future Prospects in the UK. March 1994, HMSO.

8. DOE Circular 11/95, The Use of Conditions in Planning Permissions, HMSO.

9. Lowson, M.V., Assessment and Prediction of Wind Turbine Noise, 1993, ETSU W/13/00284/REP.

10. Lowson, M.V. and Fiddes, S.P., Design Prediction Model for Wind Turbine Noise, 1994, ETSU W/13/00317/REP.

11. IEA Expert Group Study on Recommended Practices for Wind Turbine Testing and Evaluation. 4. Acoustics Measurement of Noise Emission from Wind Turbines. 3rd Edition 1994.

12. Statutory Order from the Ministry of the Environment No:304 of May 14, 1991 on Noise from Windmills, Ministry of the Environment, Denmark, National Agency of Environmental Protection.

13. Antoniou, I., Madsen, H.A., Paulsen, U.S. A Theoretical and Experimental Investigation of New Tip Shapes, European Community Wind Energy Conference, 8-12 March, 1993.

14. The World Health Organisation Environmental Health Criteria 12 - Noise: 1980

15. British Standards Institution 1984. Noise Control on Construction and Open Sites. Part 1 : Code of Practice for Basic Information and Procedures for Noise Control. BS 5228: Part 1.

16. British Standards Institution 1991. Description and Measurement of Environmental Noise. BS 7445: Parts 1-3.

17. British Standards Institution 1989. Noise Emitted by Computer and Business Equipment Part 1. Method of Measurement of Airborne Noise, BS 7135: Part 1.

18. The Commission of the European Communities Report EUR 5398 e: Environment and Quality of Life: Damage and Annoyance caused by Noise, 1975.

19. OECD Report : Reducing Noise in OECD Countries: 1978.

20. WHO Environmental Health Criteria Document on Community Noise, External Review Draft, 1993.

21. Danish National Agency of Environmental Protection, Guideline No 6, Measurement of Environmental Noise from Industry, The Joint Nordic Method for the Evaluation of Tones in Broadband Noise. 1984.

22. DIN 45 681. Detection of Tonal Components and Determination of Tone Adjustment for the Noise Assessment. Draft 1995.

23. The Welsh Affairs Committee, Second Report, Wind Energy. 1994, HMSO.

24. Porter, N.D., Acoustics Bulletin, Jan/Feb 1992, pp.11.

25. CSM Assiciates Ltd, Delabole Wind Farm Technical Performance Analysis, May 1993 - April 1994, ETSU W/32/00302/REP, 1995.

26. Porter, N.D., Final Results of the NPL Data Sheet Study on BS 4142: 1990, Proc. I.O.A. Vol 15, Part 8, pp.149-158, 1993.

27. Hoare Lea and Partners, Objective and Subjective Rating of Tonal Noise Radiated from UK Wind Farms (Part II), ETSU W/32/00228/55/REP, 1996 (in preparation).

28. Hoare Lea and Partners, Objective and Subjective Rating of Tonal Noise Radiated from UK Wind Farms (Part I), ETSU W/13/00354/44/REP, 1996 (in preparation).

29. IEC. Wind Turbine Generator Systems - Part 10: Acoustic Noise Measurement Techniques. Committee Draft, 1995.

30. Pedersen, T.H., Methods for Evaluating the Prominence of Audible Tones in Noise. Lydteknisk Institut, 1988.

31. ISVR Consultancy Services, Noise Measurements in Windy Conditions, ETSU W/13/00386/REP 1996.

32. Nelson. P.M., The Combination of Noise from Separate Time Varying Sources, Applied Acoustics (6), pp.1-21, 1973.

11. GLOSSARY

Aerodynamic Noise
Noise emitted by a wind turbine due to the passage of air over the blades.

Background Noise
The ambient noise level already present within the environment in the absence of wind farm operation.

Blade Passing Frequency
The frequency at which the blades pass the tower ie three times rotational speed for three-bladed machine.

Blade Swish
The modulation of broadband noise at blade passing frequency.

CNEL (Community Noise Equivalent Level)
An Leq noise level with the 5dB penalty added to noise emitted between 1900 and 2200 hours and 10dB added to noise emitted at night between 2200 and 0700 hours.

Critical Bandwidth
A band with a prescribed frequency range centred around a tone.

Cut-in Wind Speed
The wind speed at which a turbine produces a net power output. This is usually at hub height wind speeds of 4-5 metres per second.

Downwind Rotor
Rotor which is positioned downwind of the turbine tower.

Free Field
An environment in which there are no reflective surfaces affecting measurements within the frequency region of interest.

Hertz (Hz)
The unit of frequency measurement representing cycles per second.

Hub
The centre of the rotor.

Hub Height Wind Speed
The wind speed at the hub height of the turbine or the centre of the rotor. Measurements made during turbine operation are corrected for the slowing down effect that an operational wind turbine has on the air.

Infrasound
Sound frequencies below the audible range ie below about 20 Hertz.

L_{AN}
The dB(A) level exceeded N% of the time, eg L_{A90}, the dB(A) level exceeded 90% of the time, is commonly used to estimate background noise level.

Masking
The process by which threshold of audibility of one sound is raised by the presence of another (masking) sound.

Masking Level
A measure of the sound energy contained within a critical band.

Mechanical Noise
Noise emitted by a wind turbine from machinery usually within the nacelle.

Modulation
Periodic variation in phase, frequency or amplitude but most commonly in amplitude when associated with wind turbine noise.

Nacelle
Enclosure at the top of the tower usually housing gearbox and generator.

Pitch Regulation
The control of turbine output power by altering the angle of the turbine blades to the oncoming wind.

Rated Output
The maximum steady output power of the wind turbine.

Rating Level
The noise level, as measured by a defined method, after corrections have been made for any tonal content.

Rotor
Wind turbine blade assembly.

Sound
Energy that is transmitted by pressure waves in air or other materials and is the objective cause of the sensation of hearing. Commonly called noise if it is unwanted.

Sound Intensity
The rate of sound energy transmission per unit area in a specified direction.

Sound Level Meter
An electronic instrument for measuring the rms level of sound in accordance with an accepted national or international standard.

Sound Power
The total sound energy radiated by a source per unit time.

Sound Power Level
The fundamental measure of sound power. Defined as:

$$L_W = 10 \log \frac{P}{P_o} dB$$

where P is the rms value of sound power in watts, and P_0 is 1pW. (1 x 10^{-12}W).

Sound Pressure
A dynamic variation in atmospheric pressure. The pressure at a point in space minus the static pressure at that point.

Sound Pressure Level
The fundamental measure of sound pressure. Defined as:

$$L_p = 20 \log \frac{P}{P_o} dB$$

where p is the rms value (unless otherwise stated) of sound pressure in pascals and P_O is $2 \times 10^{-5} N/m^2$ (20μPa) for measurements in air. When A-weighting is used, the sound level is given in dB(A).

Stall Regulation
The control of turbine output power by stalling the air flow over the turbine blade.

Standard Deviation
A quantitative measure of the spread of readings.

Tones/Tonal Noise
Noise containing a discrete frequency component most often of mechanical origin.

Audible Tone
A tone whose level is sufficiently above the broad band masking level such that it can just be heard by 50% of the population.

Upwind Rotor
Rotor which is positioned upwind of the turbine tower.

Wavelength
The distance measured perpendicular to the wave front in the direction of propagation between two successive points in the wave, which are separated by one period. Equals the ratio of the speed of sound in the medium to the fundamental frequency.

Wind Shear
A description of the increase in wind speed with height above ground level. Wind speeds measured at one height can be "corrected" to the value that would have been measured at another height using the expression:

$$V_1/V_2 = \ln(h_1/z_0) / \ln(h_2/z_0)$$

where V_1 = wind speed (m/s) at a height of h_1 metres above ground level.
V_2 = wind speed (m/s) at a height of h_2 metres above ground level.
z_0 = ground roughness length (m).

The ground roughness length can be calculated from wind speed measurements at two or more heights. Alternatively it can be estimated from Table 12.

Table 12 Roughness length for various types of terrain

Type of Terrain	Roughness length z_0
Water areas, snow or sand surfaces	0.001m
Open, flat land, mown grass, bare soil	0.01m
Farmland with some vegetation	0.05m
Suburbs, towns, forests, many trees and bushes	0.30m

Table 13 Examples of wind shear calculations

z_0 (m)	V_{30}/V_{10}	V_{40}/V_{10}	V_{10} (m/s)	V_{30} (m/s)	V_{40} (m/s)
0.01	1.16	1.20	4.17	4.83	5
0.01	1.16	1.20	8	9.28	9.6
0.05	1.21	1.26	3.96	4.80	5
0.05	1.21	1.26	8	9.68	10.08
0.30	1.31	1.40	3.57	4.68	5
0.30	1.31	1.40	8	10.48	11.2

10-Minute Average Wind Speed (m/s)
The wind speed measured by a calibrated cup anemometer at a specified height above ground level, averaged over a 10-minute period.

APPENDIX A

PRACTICE TO DATE IN CONTROLLING NOISE EMISSIONS FROM WIND GENERATORS BY REFERENCE TO PLANNING CONDITIONS AND COVENANTS IN PLANNING AGREEMENTS

Deli Farm, Delabole
(North Cornwall District Council)

A.1 **(a)** The following conditions to regulate noise emissions were attached to a planning permission for the erection of ten wind turbine generators, issued by the Council on 1 August 1991:

1. Wind generators shall not commence productive operation at a wind speed of less than 5 metres per second at a hub height of 25 metres above ground level unless otherwise agreed by the Local Planning Authority.

2. Subject to the provisions of Condition 6 hereof the noise level expressed on a 10-minute L50 basis from the combined effect of the wind turbine generators as measured at any dwelling beyond a distance of 350 metres from any of the turbines shall not exceed 39dBA during low speed operation or 45dBA during high speed operation when measured over a ten minute period with a precision grade sound level meter of at least a type 1 quality using a half inch diameter microphone in free field conditions 1.2 metres above ground level and at least 3.6 metres from any wall, hedge or reflective surface using a slow time weighted response, or if after the turbines commence operation variations to these limits are agreed in writing by the Planning and Development Officer (on the grounds that it would appear that no noise nuisance would be created at the varied levels) then such agreed variations shall be complied with.

3. The change over speed from low (32rpm) to high (48rpm) or from high to low speed operation shall not occur at a wind speed of less than 8 metres per second at hub height (25 metres above ground).

4. The noise emitted from the wind turbine generators as heard at any dwelling shall not be irregular enough to attract attention, contain distinguishable discrete continuous notes or distinct impulses, such as to cause a nuisance to the occupiers of any dwelling beyond a distance of 350 metres from any of the wind turbine generators.

5. All practicable means shall be employed to the satisfaction of the Local Planning Authority in order to prevent and minimise the creation of any nuisance by noise emission during the erection, operation and use of the

wind turbine generators. "Practicable" shall have the meaning given to it by the Environmental Protection Act 1990.

6. Noise emitted from the turbines as measured on any point of the boundary of the permitted camp site Lower Pendavey which is shown hatched black on the approved location plan (and when measured over a ten minute period with a precision grade sound level meter of at least a Type 1 quality using a half inch diameter microphone in free field conditions 1.2 metres above ground level and at least 3.6 metres from any wall, hedge or reflective surface using a slow time weighted response) shall not exceed the ambient L50 plus 5dBA.

All the above conditions were imposed for the following reason:

To ensure that noise emitted by the operation of the turbines does not have a detrimental effect on the amenities of a locality and, in particular, on the local residents living in the vicinity of the site.

(b) In addition to the planning conditions the following covenants and agreements were made in a Planning Obligation (the clause numbering has been altered for this Report):

Covenants

1. Upon receiving notification from the Planning and Development Officer for the time being of the Council ("the Planning and Development Officer") that a nuisance or annoyance is in his reasonable opinion being caused to occupiers of dwellings beyond a distance of 300 metres from any of the turbines the Owners will as soon as reasonably practicable take all necessary steps to abate such nuisance or annoyance to the reasonable satisfaction of the Planning and Development Officer.

2. No turbines shall be erected on the site unless they are of the MS-3 (Refined) type at present manufactured and supplied by the Wind Energy Group Limited and strictly in accordance with the specification of the same annexed hereto or such other type as may be approved in writing by the Planning and Development Officer (such approval not to be unreasonably withheld).

3. No wind turbine generator shall be erected in a position which is closer than 350 metres from any dwelling existing at the date of this Agreement.

4. Before any of the turbines are brought into use the First Owner shall submit and obtain the written approval of the Planning and Development Officer (such approval not to be unreasonably withheld) for a scheme for the monitoring of noise emissions and background noise levels and for the keeping of records of such noise emissions and

background noise levels and thereafter the said records shall be kept in accordance with the said scheme and shall be made available at all reasonable times for inspection by the Planning and Development Officer and it is hereby agreed that in the event that a scheme is not approved in writing by the Planning and Development Officer within 28 days of such submission the question of whether the scheme is reasonable can be referred to arbitration in accordance with clause X hereof.

5. They will comply with the following requirements relating to noise:

(i) except as provided by Clause 5 (iv) and subject to the provisions of Clause 7 (iv) hereof the L50 noise level resulting from the combined effect of the wind turbine generators as measured at any dwelling beyond the distance of 350 metres from any of the turbines shall not exceed 39dBA during low speed operation or 45dBA during high speed operation when measured in accordance with the method described in Clause 7 (i).

(ii) the noise emitted from the turbines as heard at any dwelling shall not be irregular enough to attract attention, contain distinguishable discrete continuous notes or distinct impulses such as to cause (in the reasonable opinion of the Planning and Development Officer) a nuisance to the occupiers of any such dwelling beyond a distance of 350 metres from any of the turbines within the area defined in Clause 5 (i).

(iii) all practicable means shall be employed to the reasonable satisfaction of the Planning and Development Officer in order to minimise the creation of any nuisance by noise emission during the erection, operation and use of the turbines. "Practicable" shall have the meaning given to it by section 79 of the Environmental Protection Act 1990.

(iv) noise emitted from the turbines and measured at any point on the boundary of the site with the property known as Lower Pendavey (for the purposes of identification only hatched black on the plan marked "B" annexed hereto) and when measured in accordance with the method described in Clause 7 (i) (during such time as the camping site on the said property may be operated under any planning permission or site licence which may at any time be implemented) shall not exceed the ambient L50 level plus 5dBA.

6. The owners will allow the Planning and Development Officer and his authorised representatives (being only employees or suitably qualified agents of the Council) to have such access as he or they require to the

Site at all reasonable times for the purposes of monitoring compliance by the Owners with their obligations herein.

Agreements

7.

(i) The level of noise emissions referred to in this Agreement shall be measured over a ten minute period with a precision grade sound level meter (of a least a Type 1 quality) using a half inch diameter microphone in free field conditions 1.2 metres above ground level and at least 3.6 metres away from any wall hedge or reflective surface (using a slow time weighted response).

(ii) If the turbines in operation on the Site shall be of the type referred to in Clause 2 measurements under this Agreement of noise levels at the slower speed of operation and the higher speed of operation of the turbines shall be made with average hub height wind speeds of 6 metres and 9 metres per second respectively.

(iii) If the turbines in operation on the Site shall be of a type other than that referred to in Clause 2 the scheme to be submitted under Clause 4 shall include proposals for an alternative basis of measurement to that described in Clause 7 (ii).

(iv) Following a reasonable period of operation of the turbines if upon representations by the First Owner the Planning and Development Officer is of the opinion that other levels of noise emission ("the Alternative Levels") than specified in Clause 5(i) and Clause 5(iv) would give rise to no nuisance to dwellings beyond a distance of 350 metres from any of the turbines the parties hereto shall conclude a Supplemental Agreement whereby the First Owner the Second Owner the Third Owner and the Fourth Owner shall jointly and severally covenant to comply with the Alternative Levels in place of the levels specified in the said Clauses.

(v) Clause X of this Agreement (*an arbitration provision*) shall apply to any disagreement between the First Owner and the Council arising under Clause 7 (iv) hereof.

(vi) For the purposes of this Agreement the change over speed from low (32rpm) to high (48 rpm) or from high to low speed operation shall not occur at a wind speed of less than 8 metres per second at hub height (25 metres above ground).

8. For the avoidance of doubt it is hereby agreed that this Agreement does not prevent the Council or the Owners or any of them from exercising any other powers or taking any legal proceedings under any other legislation including the Environment Protection Act 1990 in respect of any noise nuisance.

Cold Northcott
(North Cornwall District Council)

A.2 (a) The following conditions were attached to a planning permission issued by the Council on 12 February 1992 for the erection of 23 horizontal axis wind turbines:

1. The cut in wind speed for wind turbine generator operations shall not be less than 5 metres per second measured at hub height of 25 metres above ground level unless otherwise agreed with the Local Planning Authority.

2. The noise level expressed on a ten minute L50 basis from the cumulative site of the wind turbine generators as measured at any dwelling beyond a distance of 380 metres from any of the turbines shall not exceed levels of 40dB(A) during low speed operation or 45dBA during high speed operation when the ambient noise level at the location is not greater than 35dB(A) when measured in accordance with the following method: the level of noise emissions referred to in this Agreement shall be measured over a ten minute period with a precision grade sound level meter (of at least a Type 1 quality) using a half-inch diameter microphone in free field conditions 1.2 metres above ground level and at least 4 metres from any wall or other reflective surface (using a slow time weighted response). If after the Turbines commence operation variations to these limits are agreed in writing by the Planning and Development Officer (on the grounds that it would appear that no noise nuisance would be created at the varied levels) then such agreed variations shall be complied with.

3. Subject to the provisions of Condition 2 noise emitted from the Turbines as measured at any dwelling beyond 380 metres and when measured over a ten minute period with a precision grade sound level meter of at least a Type 1 quality using a half inch diameter microphone in free field conditions 1.2 metres above ground level and at least 4 metres from any wall or other reflective surface using a slow time weighted response shall not exceed the ambient L50 plus 5dBA.

4. The change-over speed from low (32 rpm) to high (48 rpm) or from high to low speed operation shall not occur at a wind speed of less than 8 metres per second measured at hub height 25 metres above ground.

5. There shall be no audible tonal component to the noise emitted by the turbines so as to cause a nuisance to the occupiers of any dwelling beyond a distance of 380 metres from any of the wind turbine generators.

6. The Best Practicable Means shall be employed to the satisfaction of the Local Planning Authority in order to prevent and minimise the creation of any nuisance by noise emission during the erection operation and use of the wind turbine generators "Best Practicable Means" shall have the meaning given to it by Section 79(9) of the Environmental Protection Act 1990.

All the above planning conditions were imposed for the following reason:

To ensure that noise emitted by the operation of the turbines does not have a detrimental effect on the amenities of the locality and in particular on the local residents living in the vicinity of the site.

(b) In addition to the planning conditions the following covenants and agreements were made in a Section 106 TCPA 1990 Obligation (the clause numbering has been altered for this Report):

1. No turbines shall be erected on the Site until details and engineering specifications of the precise type of turbine have been agreed in writing by the Planning and Development Officer for the time being of the Council and thereafter no other type of turbines shall be erected unless it has been subsequently approved in writing by the Planning and Development Officer (such approval not to be unreasonably withheld).

2. No wind turbine generator shall be erected in a position which is closer than 380 metres from any dwelling existing at the date of this Agreement.

3. Before any of the Turbines are brought into use the Leaseholder shall submit and obtain the written approval of the Planning and Development Officer (such approval not to be unreasonably withheld) for a scheme for the measurement of machine noise emissions and for the keeping of records of such noise emissions and thereafter the said records shall be kept in accordance with the said scheme and shall be made available at all reasonable times for inspection by the Planning and Development Officer and it is hereby agreed that in the event that the scheme is not approved in writing by the Planning and Development Officer within 28 days of such submission the question of whether the scheme is reasonable can be referred to arbitration in accordance with Clause X hereof

4. To comply with the following requirements relating to noise:

   (i) Subject to the provisions of Clause 5(iv) hereof the L50 noise level resulting from the combined effect of the wind turbine generators as measured at any dwelling beyond a distance of 380 metres from any of the Turbines shall not exceed 40dB(A) during low speed operations or 45dB(A) during high speed operation when measured in accordance with the method described in Clause 5(i).

(ii) The noise emitted from the Turbines as heard at any such dwelling within the area defined in Clause 4(i) shall not be irregular enough to attract attention, contain distinguishable discrete continuous notes or distinct impulses such as to cause (in the reasonable opinion of the Planning and Development Officer) a nuisance to the occupiers of any such dwelling beyond a distance of 380 metres from any of the Turbines within the area defined in Clause 4(i).

(iii) The best practical means shall be employed to the reasonable satisfaction of the Planning and Development Officer in order to minimise the creation of any nuisance by noise emission during the erection operation and use of the turbines. "Best Practicable Means" shall have the meaning given to it by Section 79 (9) of the Environmental Protection Act 1990.

Agreement

5(i) The level of noise emissions referred to in this Agreement shall be measured over a ten minute period with a precision grade sound level meter (of at least a Type 1 quality) using a half inch diameter microphone in free field conditions 1.2 metres above ground and at least four metres from any wall, hedge or reflective surface (using a slow time weighted response).

5(ii) If the Turbines in operation on the Site shall be of a 2-speed type measurements under this Agreement of noise levels at the slowest speed of operation and the higher speed of operation of the Turbines shall be made with average hub height wind speeds of 6 metres and 9 metres per second respectively.

5(iii) If the Turbines in operation on the Site shall be of a type other than the 2-speed type the scheme to be submitted under Clause 3 shall include proposals for an alternative basis of measurement to that described in Clause 5(ii) to the satisfaction of the Planning and Development Officer.

5(iv) Following a reasonable period of operation of the Turbines if upon representations by the Owner and Leaseholder the Planning and Development Officer is of the opinion that other levels of noise emission ("the Alternative Levels") than specified in Clause 4(i) would give rise to no nuisance to dwellings beyond a distance of 380 metres from any of the Turbines the parties hereto shall conclude a Supplemental Agreement whereby the Owner covenants to comply with the Alternative Levels in place of the levels specified in the said Clauses.

5(v) Clause X of this Agreement (*an arbitration provision*) shall apply to any disagreement between the Owner and/or the Leaseholder and the Council arising under Clause 5(iv) hereof.

5(vi) For the purposes of this Agreement the changeover speed from low (32 rpm) to high (48 rpm) or from high to low speed operation shall not occur at a wind speed of less than 8 metres per second measured at hub height of 25 metres above ground.

Rhyd-y-Groes, Ynys Mon/Anglesey (Cyngor Bwrdeistref Ynys Mon)

A.3 The following conditions relating to noise were attached to a planning permission issued by the Council on 2 November 1992 for the erection of 24 wind turbines:

1. No wind generator shall be erected in a position which is closer than 400 metres from any dwelling existing at the date of this permission.

2. The level of noise emissions referred to in condition 5 shall be measured over six periods of ten minutes within a total of one hour with a precision grade sound level meter (incorporating best current practice) using a half inch diameter microphone in free field conditions, 1.2 metres above ground level and at least 3.6 metres from any wall, hedge or reflective surface (using a slow time weighted response).

3. In order to evaluate compliance with the level of noise emissions referred to in condition 5 background sound pressure level measurements shall be made:

(a) during the hour before or the hour after the measurements referred to in condition 2 and

(b) such background sound pressure level measurements shall be expressed on an L(a)eq index.

4. The measurements made in accordance with conditions 2 and 3 shall both be correlated with wind speeds measured at hub height over the same periods as described in condition 3.

5. When measured in accordance with the method described in condition 2 the level of noise emissions resulting from the combined effect of the wind generators as measured at any dwelling existing at the date of this permission beyond a distance of 400 metres from any of the turbines shall not exceed 40dBL(a)eq measured at 5 metres per second at hub height.

6. The level noise emitted by the combined effect of the wind generators (when measured and correlated in accordance with condition 2, 3 and 4) shall be demonstrated at the request of the Local Planning Authority on commissioning and thereafter every twelve months.

The reason given for the position of the above planning conditions is:

> To ensure that the development will be satisfactory from an amenity and architectural point of view

Penrhys, Rhondda
(Rhondda Borough Council)

A.4 The following condition was attached to a planning permission dated 2 April 1993 granted on appeal against the refusal of the Council to grant planning permission for the erection of 12 turbines:

"The level of noise emissions resulting from the combined effect of the wind turbine generators as measured at any dwelling (in existence at the date of this letter) beyond a distance of 400 metres from any of the wind turbine generators shall not exceed 7.5dBL(A)90 above the background sound pressure levels measured in accordance with a method to be agreed by the planning authority."

Four Burrows, Cornwall
(Carrick District Council)

A.5 The following conditions relating to noise were imposed on the grant of planning permission dated 6 August 1993 on appeal against the refusal of the Council to grant planning permission for the erection of 15 wind turbine generators:

1. The level of noise emissions referred to in condition 4 shall be measured using the LA90 10 minutes level over a minimum of 6 consecutive periods of 10 minute with a precision grade sound level meter of at least type 1 quality, (incorporating best current practice), using a half inch diameter microphone in free field conditions, 1.2 metres above ground level and at least 3.6 metres from any wall, hedge or reflective surface (using a slow time weighted response). The LA90 ten minute

level at a hub height wind speed of 5m/sec shall be derived using a linear regression of the measured noise levels.

2. In order to evaluate compliance with the level of noise emissions referred to in condition 4 background sound pressure level measurements shall be made: (a) during the hour before or the hour after the measurements referred to in condition 1; and (b) such background sound pressure measurements shall be made on an LA90 10 minute index.

3. The measurements made in accordance with conditions 1 and 2 shall both be correlated with wind speeds measured at hub height over the same periods as described in condition 1. The background noise level shall be derived for a hub height wind speed of 5m/sec by use of a linear regression undertaken upon the measured noise levels.

4. When measured in accordance with the method described in condition 1 the level of noise emissions resulting from the combined effect of the wind turbine generators as measured at any dwelling existing at the date of this permission shall not exceed the following LA90 10 minute noise levels with the on-site measured wind speed of 5m/sec at hub height:

Four Burrows	42dB(A)
Four Burrows Farm	40dB(A)
Silver Valley	37dB(A)
Chybucca	37dB(A)
Causilgey	37dB(A)
Carvinack Brake	40dB(A)
Carvinack	37dB(A)
Creegmeor Farm	40dB(A)

5. The level of noise emitted by the combined effect of wind generators (when measured and correlated in accordance with conditions 1 to 3), shall be demonstrated at the request of the local planning authority on commissioning and thereafter every 12 months.

6. If the noise emissions resulting from the wind farm as measured at any residential property referred to in condition 4 contain a distinguishable tonal character as defined in "The Assessment of Audible Tones Second Draft, Carrick District Council", the noise limits specified in condition 4 shall be reduced by 5dB.

Bryn Titli, Powys
(Radnorshire District Council)

A.6 The following conditions relating to noise were imposed on the planning permission granted by the Council on 9 August 1993 to erect 22 wind turbines:

1. When measurements are made in accordance with the method described in condition 2 the level of noise emissions resulting from the combined effect of the wind turbine generators as measured at any dwelling existing at the date of this permission beyond a distance of 400 metres from any of the turbines shall not exceed 40dB(A)Leq (5 minutes) at an on-site measured wind speed of 6 metres per second at hub height, or 5dBA above the Laeq (5 minutes) background as measured in accordance with condition 3 whichever is the greater.

2. The level of noise emissions, referred to in condition 1 shall be measured over 5 periods of five minutes within a total of one hour with a precision grade sound level meter of at least type one quality (incorporating best current practice) using a half inch diameter microphone in free field conditions 1.2 metres above ground level and at least 3.6 metres from any wall, hedge or reflective surface (using a fast time weighted response). The wind farm sound pressure measurements shall be recorded as LAeq 5 minute values.

3. In order to evaluate compliance with the level of noise emissions referred to in condition 1 background sound pressure level measurements shall be made:

(a) Over 5 x 5 minute periods during the hour before or the hour after the measurements referred to in condition 2.

(b) Such background sound pressure measurements shall be recorded as LAeq, 5 minute values.

(c) Measurements of the LA90, 5 minute noise levels shall also be monitored throughout the measurement period to assist in the validation of the LAeq, 5 minute measurements.

4. The measurements made in accordance with conditions 2 and 3 shall both be correlated with wind speeds measured at hub height over the same periods as described in conditions 2 and 3. The target wind speed for the measurements shall be 6 metres per second. The data pairs shall be used to determine a best fit relationship between LAeq and hub height wind speed.

5. The level of noise emitted by the combined effect of the wind generators shall be demonstrated at the request of the Local Planning

Authority on commissioning. The tests shall be carried out in the vicinity of Dolhelfa Ganol or other relevant dwelling as may be agreed.

6. Tonal noise shall be measured for audibility using the methodology described in BS 7135: Part I Annex D (or equivalent) and shall be measured at a distance of not less than 550 metres from the nearest wind turbine.

7. The tonal (narrow band) spectrum shall be measured in accordance with condition 6 over a period 2 minutes between the frequencies of 0Hz (Hertz) and 2kHz (Kilohertz) and with a maximum measurement bandwidth of 6.25Hz (Hertz).

8. If tonal noise from any of the wind turbines (when measured in accordance with conditions 6 and 7) exceeds the threshold of audibility by more than 8dB then the level of permissible noise emission referred to in condition 1 shall be reduced by 5dB.

The reason given for the imposition of the above planning conditions is:

In order to secure a satisfactory means of noise measurement to safeguard the residential amenity of local residents.

St Breock Downs, Wadebridge
(North Cornwall District Council)

A.7 The following conditions were imposed on the planning permission granted on 1 September 1993 on an appeal against the failure of the Council to determine a planning application for the erection of 11 wind turbines:

1. No wind turbine generators shall be erected in a position closer than 550m from any dwelling existing at the date of this permission.

2. No wind turbine generator shall start producing electricity at a wind speed of less than 5 metres per second measured at a hub height of 35 metres above ground level without the prior written approval of the local planning authority.

Trysglwyn Fawr, Amlwch, Ynys Mon/Anglesey
(Cyngor Bwrdeistref Ynys Mon)

A.8 The following conditions relating to noise were imposed on the grant of planning permission on appeal dated 10 December 1993 against the refusal of the Council to grant planning permission for the erection of 15 wind turbines:

1. No wind turbines shall be erected in a position which is less than 400 metres from any occupied dwelling existing at the date of this permission, except the participating properties of Trysglwyn Fawr and Taldrwst Mawr unless otherwise agreed in writing with the local planning authority.

2. The level of noise emissions resulting from the combined effect of the wind turbines hereby approved as measured at any dwelling existing at the date of this permission, except the participating properties Trysglwyn Fawr and Taldrwst Mawr, shall not exceed 40dB(A) L(A)eq 5 minutes at an on-site measured wind speed of 5 metres per second at hub height.

3. The level of noise emissions, referred to in condition 2, shall be measured in accordance with a noise monitoring scheme to be agreed in writing with the local planning authority.

4. If tonal noise from any of the turbines hereby permitted, when measured in accordance with condition 3, exceeds the threshold of audibility by more than 8dB then the level of permissable noise emission referred to in condition 2 shall be reduced by 5dB.

5. The level of noise emitted by the combined effect of the turbines hereby permitted shall be demonstrated at the request of the local planning authority on commissioning and annually thereafter in accordance with the noise monitoring scheme referred to in condition 3.

Carland Cross, Mitchell, Cornwall
(Carrick District Council)

A.9 No conditions relating to noise were imposed on the planning permission issued by the Council on 29 April 1992. Control over noise emissions is exercised through a Planning Obligation dated 29 April 1992 and the following covenants were given to the developer (the clause numbering has been altered for this Report):

1. No Turbines shall be erected on the site until the details and engineering specifications of the precise type of Turbine have been approved in writing (such approval not to be unreasonably withheld) by the Chief Planning Officer for the time being of the Council ("the Chief Planning

Officer") and thereafter no other type of Turbine shall be erected unless it has been approved in writing by the Chief Planning Officer (such approval not to be unreasonably withheld or delayed).

2. No Turbines shall be erected in a position which is closer than 350 metres from any dwelling existing at the date of this Agreement.

3. None of the Turbines shall be brought into use until:

(i) a scheme for the measurement of machine noise emissions and hub height wind speeds to operate for a period of two years from the date of the Turbines coming into use and for the keeping of records of such noise emissions and wind speeds ("the Scheme") is submitted for the approval of the Chief Planning Officer and

(ii) written approval to the Scheme is provided by the Chief Planning Officer (such approval not to be unreasonably withheld or delayed) and upon the Turbines being brought into use the Scheme as approved shall be implemented and the said records shall be kept in accordance with the Scheme and shall be made available at all reasonable times for inspection by the Chief Planning Officer.

4. (i) Subject to the provisions contained in clause 5(c) hereof the L90dB(A) noise level resulting from combined effect of the Turbines as measured within 10 metres of the facade at any dwelling at or beyond a distance of 350 metres from any of the Turbines shall not cause the prevailing background noise level to be increased by more than 7.5dB(A) when measured in accordance with the method described in clause 5 hereof; and

(ii) notwithstanding clause 4(i) above if the noise emitted from the Turbines as heard and measured at any such dwelling at or beyond a distance of 350 metres from any of the Turbines contains distinguishable discreet continuance (sic) notes or distinct impulses as specified in paragraph 7.2 of BS 4142 1990, then the noise from any of the turbines shall not cause the prevailing background noise level (L90dB(A)) to be increased by more than 2.5dB(A) when measured in accordance with the method described in clause 5 hereof.

(iii) (a) In the event that the noise levels specified in the sub-clauses 4(i) or 4(ii) above or both whichever apply are exceeded when measured in accordance with the method described in clause 5 the best practical means shall be employed to the reasonable satisfaction of the Chief Planning Officer in order to reduce within 14 days of the date of the completion of the said measurement or within such longer period as may be allowed by the Chief Planning Officer the noise emission to the levels specified in sub-clauses 4(i) or 4(ii) hereof or both whichever apply during the operation and use of the Turbines. "Best Practicable Means" shall have the meaning given to it by Section 79(9) of the Environmental Protection Act 1990.

(b) If at the expiry of the period specified in sub-clauses 4iii(a) above the noise levels specified in sub-clause 4(i) or 4(ii) or both whichever apply continue to be exceeded then the Owners and Leaseholder shall forthwith use whatever means are necessary to comply with sub clauses 4(i) or 4(ii) or both whichever apply.

5. (a) The L90dB(A) noise level emissions referred to in this Agreement shall be measured over a ten minute period with a precision grade sound level meter of at least Type 1 quality using a half inch diameter microphone calibrated in accordance with paragraph 4.1 and 4.2 of BS4142 1990 positioned in free field conditions 1.2 metres above ground level and at least 3.6 metres from any wall hedge or reflective surface using a fast time weighted response.

(b) The standard of measurement applied in this Agreement shall be as specified in paragraph 5.4.1 of BS4142 1990 with regard to prevailing weather conditions over the measurement period.

(c) The increase in the L90dB(A) background noise level referred to in this Agreement shall be determined as the difference of the noise levels measured in accordance with the method described in Clause 5(a) and 5(b) with the Turbines in operation and the Turbines stopped. The measurement period shall be consecutive where practicably possible and the average of 4 such measurements shall constitute a result.

Gonnhilly, Cornwall
(Kerrier District Council)

A.10 (a) The following condition relating to noise was attached to a planning permission issued by the Council on 7 December 1992 for the erection of 14 wind turbine generators:

"All practicable means shall be employed by the developer for preventing and minimising the emission of dust or smell or the creation of noise during the tipping of excavated material derived from carrying out the development hereby permitted".

(b) In addition to the planning conditions the following covenants were given in a Planning Obligation (the clause numbering has been altered for this Report):

1. All practicable means shall be employed by the owner and/or the operator of the wind turbine generators for preventing and minimising the emission of dust, smoke and fumes and the creation of noise during the approved use of site. The word "practicable" and the phrase "practical means" in this Agreement shall have the meanings assigned to them in Section 79(9) of the Environmental Protection Act, 1990, as defined hereafter. The provisions of this paragraph include the installation of and maintenance of effective silencers on all plant and machinery.

Definition

Section 79(9) of the Environmental Protection Act, 1990:

"Practicable" means reasonably practicable having regard among other things to local conditions and circumstances, to the current state of technical knowledge and to the financial implications; the means to be employed include the design, installation, maintenance and manner and periods of operation of plant and machinery, and the design, construction and maintenance of buildings and structures.

2. Each of the wind turbine generators the subject of this Agreement shall be erected within 10 metres of the positions shown on the submitted drawings and shall not be relocated from such positions without the prior written approval of the Council, such approval being within the absolute discretion of the Council.

3. Notwithstanding the provisions of Paragraph 2 of this Schedule no wind turbine generators shall be sited closer than 370 metres to any residential premises existing at the date of this Agreement, which the Owner shall identify on a 1:2500 scale plan to be submitted to the Council for approval within two months of the date of this Agreement.

4. No wind turbine generator shall commence productive operation at a wind speed of less than 5 metres per second at a hub height of 32 metres above existing ground level without the prior written approval of the Council.

5. If the noise emitted by the wind farm at any distance greater than 370 metres from an individual wind turbine generator contains:

(i) any distinguishable, discrete, continuous notes (whine, hiss, screech, hum or similar noise);

(ii) distinct impulses (bangs, clicks, clutters, thumps or similar noises);

(iii) a characteristic noise sufficiently irregular to attract attention;

an arbitrary reduction of 5dB(A) shall be applied to the noise limit defined in Paragraph 8 of this Schedule.

6. The Sound Power Level of any wind turbine generator during the approved use of the site calculated from measurements at 50 metres from that wind turbine generator by the method in the attached IEA booklet 4 "Acoustics Measurement of Noise Emission from Wind Turbines" shall not exceed a value of 99dBA for a hub height wind speed of 8.8 metres per second. Alternatively, if wind speed is available at a height of 10 metres then the corresponding wind speed is 8 metres per second. The calculation shall be made using at least 5 measurements over individual time periods of not more than 10 minutes, to be agreed in advance by the Council within a wind speed range of plus or minus 2 metres per second of the reference wind speed noted of either 8.8 or 8 metres per seconds respectively.

7. When measured in accordance with the method described in Paragraph 8 hereof the combined level of noise from all the wind turbine generators at any time shall not exceed 36dBA as measured at any dwelling existing at the date of the grant of the Planning Permission beyond a distance of 370 metres from any wind turbine generator.

8. The noise level shall be measured 1.2 metres above the ground at least 3.6 metres from any wall, hedge or reflective surface using a Precision grade sound level meter of Type 2 or better equipped with a ½" microphone. The measurement shall be made as LA90 for a time period of not more than 10 minutes, to be agreed in advance by the Council.

At least five measurement periods in the hub height wind speed range of 5 to 8 metres per second shall be used to provide a regression line for predicting the noise level at 5 metres per second.

The noise measurement may be carried out only when all wind turbine generators are operating and the wind speed in any measurement period is averaged over all the wind turbine generators if agreed in advance by the Council.

Llangwyryfon, Dyfed
(Cyngor Dosbarth Ceredigion)

A.11 The following conditions relating to noise were attached to a planning permission issued by the Council in 1992 for the erection of 20 wind turbine generators:

1. At the critical wind speed (ie the speed at which the noise radiated by the total complement of wind turbines and blades is most substantially in excess of ambient noise) the noise from the wind park, as measured externally at any dwelling house, shall not exceed 45dB(A).

2. In the event of any noise complaint, investigated and judged by the authority to be justified, the developer will demonstrate that the best practical means are being, or will be, employed to limit and/or reduce noise emissions.

3. Notwithstanding conditions 1 and 2 above the basis for the reasonableness of a noise complaint shall be L50 plus 5dB(A) at the external wall of any dwelling house.

4. The developer will undertake measurements of noise levels during the first year of the operation of the wind turbines in a scheme to be agreed by the local planning authority to determine the characteristics of noise radiation. The data produced in accordance with the scheme shall be forwarded to the local planning authority on request.

The reason given for the imposition of the above planning conditions is:

To ensure a minimum level of noise disturbance.

APPENDIX B

PRACTICE TO DATE IN CONTROLLING NOISE EMISSIONS FROM WIND GENERATORS IN THE USA

Alameda County (Resolution Z-7500, February 1992)

- *No electric wind generator shall be located closer than 1000 feet (304.8 metres) in an upwind (generally south-westerly to west-south-westerly) direction or closer than 300 feet in any other direction from any existing dwelling or building site. These setbacks may be reduced by a maximum of 50% with the written, notarised and recorded concurrence of the affected property owner.*

- *The following procedures should be adhered to in the event of a reasonable complaint that noise levels from an operating wind turbine or wind farm exceed the levels described in the application, or that noise levels from a rebuilt wind turbine or wind farm exceed either 55dB(A) (L_{dn}) or 70dB(C) (L_{dn}) at the exterior of any dwelling unit within a minimum distance of 1000 feet:*

    1. *A hearing shall be scheduled between the Permittee and the Zoning Administrator*

    2. *A qualified firm shall be engaged to make a site-specific study and furnish a report and recommendation as to the Permittee's conformance with all applicable noise regulations.*

    3. *The permittee shall attempt in good faith to negotiate a resolution of this matter with the party making the allegation.*

    4. *Until the conclusion of the complaint proceedings, one fourth of the wind turbines authorised to be constructed and maintained in closest proximity to the dwelling or building site of the party making the allegation shall not be operated.*

- *Acoustic measurement and reporting procedures shall attain or exceed the minimum standards for precision described in AWEA First Tier standard. The Zoning Administrator, in consultation with the County Environmental Health Services, shall establish criteria for noise samples and measurement parameters (e.g., the duration of the data collection, time of day, wind speed, atmospheric conditions and direction) following the guidelines established by Wyle Research.*

Contra Costa County

In 1985, Contra Costa County adopted a WECS (Wind Energy Conversion System) ordinance as Chapter 88-3 of the County code. This ordinance can be summarised as follows:

- *According to Section 88-3.404, a WECS located on residential property may operate only between the hours of 08:00 Hrs and 1800 Hrs.*

- *According to Section 88-3.602, a minimum WECS setback of three times overall machine height (measured from grade to the top of the structure, including the uppermost extension of any blades) or 500 feet, which ever is the greater, shall be maintained from exterior project boundaries. A minimum WECS setback of 1000 feet shall be maintained from any existing legal off-site residence or General Plan designated residential areas.*

- *According to Section 88-3.612, no WECS shall create noise which exceeds 65dB(A) L_{eq} (over any averaging time), as measured at the lot line.*

Solano County

The *Wind Turbine Siting Plan & Environmental Impact Report*, prepared in 1987, found that:

- *Although the majority of the county was already at 50dB(A) CNEL or greater, a 50dB(A) CNEL standard for noise generated at neighbouring residencies was adopted as a standard for WECS to preserve compatibility with other General Plan criteria for stationary noise sources.*

- *A 47dB(A) Leq standard was established under the assumption that, under typical WECS operating conditions, it would be equivalent to a 50dB(A) CNEL (i.e. a wind turbine operating 50 % of the time, as is typical during the productive season in the Altamont area, would produce a CNEL about 3dB(A) higher than the 24-Hour average L_{eq}).*

- *Typical noise impact areas adjacent to WECS extend from 1000 {305 m} to 1800 {550 m} feet from the nearest wind turbines based upon standards described above. Actual setbacks are determined on a case-by-case basis, based on computer noise modelling for the specific turbine models and array patterns proposed.*

- *WECS developers must develop a noise monitoring program in co-operation with the County Division of Environmental Management and, if necessary, impose noise mitigations (eg revised spacing patterns of turbine).*

The final recommendations contained within the report are a compromise between all of the standards which have been adopted by the Tri-Counties.

The recommendations on noise are as follows:

Establish a consistent noise level standard for WECS near residencies. A noise level standard of 55dB(A) CNEL should be established, measured at existing residencies or potential residential development sites.

This standard would be a compromise between Solano County's 50dB(A) CNEL (47dB(A) L_{eq}) and Contra Costa County's 65dB(A) L_{eq}.

The use of a 55dB(A) noise level standard would provide for a slight increase above ambient noise levels in many cases, but would not exceed state exposure standards for residential areas or significantly deteriorate the rural atmosphere of the wind resource areas, given the natural noise of the wind and other activity in the area. Wyle Research WR 88-19 provides that 60dB(A) may be appropriate, but a 55dB(A) standard should be considered in areas that were especially quiet prior to installation of wind turbines.

The L_{dn}, day-night average noise level, is a 24-hour average L_{eq} with a 10dB(A) weighting added to noise which is emitted during the hours of 22:00-07:00 to account for the greater nocturnal sensitivity of people.

The CNEL (Community Noise Equivalent Level) allows a correction to be applied for increased sensitivity during the evening as well as the night. A 5dB penalty is applied for noise emitted during the 19:00-22:00 period.

If we compare these criteria levels in terms of 24-hour L_{eq} then the table below details the relative levels:

L_{eq} dB(A)	L_{dn} dB(A)	CNEL dB(A)
25	31.40	31.66
35	41.40	41.66
45	51.40	51.66

Riverside County

Resolution No. 93-378
Amending and Superseding Resolution No. 86-180
Adopting Technical Specifications and Criteria for the Measurement and Projection of Noise from Commercial WECS Projects.

The County of Riverside is within the state of California. On the 5th October 1993 the above resolution was passed concerning the development of wind turbines and the assessment of noise that they radiate. This resolution covers the testing and assessment of the noise that is emitted by wind turbines, and proposes a method for the determination of the noise levels that may be expected from the development of a wind farm.

Included within the resolution are the following definitions:

a) *Observed representative noise level: the measured noise level excluding pseudo-noise, wind noise, vegetation noise and transient noise events from sources other than the subject noise source.*

b) *Pseudo-noise: the noise perceived by the microphone and originating from the air flow turbulence around the diaphragm of the microphone.*

c) Vegetation noise: the noise resulting from the rattling of leaves and other vegetation excited by the wind.

d) Wind noise: the noise of the wind itself originating from turbulence in the air.

Recommendations are made for the measurement of the emitted noise from the wind turbines. However, these follow neither the guidance that is given within the IEA method of turbine evaluation nor the Danish Statutory Order, measurements being performed at a height above ground level of 5'. This compares with the ground board measurement method that is used for the determination of the sound power level of a wind turbine within the IEA and Danish Statutory Order.

Measurements are required of the L_{A90}, L_{A50} and L_{Aeq} noise levels using a slow time weighting. The procedure for determining the A-weighted noise level from the turbine considers the measured L_{A90} noise levels to determine the signal to noise ratio of the measured noise. This allows any corrections to be assessed and applied to the measured noise if the background noise level at the measurement position is near that of the wind turbine when it is operating. It is proposed within the resolution that if the turbine noise level is greater than 10dB above the background noise level then no correction need be applied. If the noise level is between 3dB and 10dB above the background noise level when the wind turbine is not operating then the intensity subtraction should be used. This method is outlined within BS 4142 for the correction of measured noise levels when performing an assessment. When the measured noise level from the turbine is not more than 3dB above the background noise level then cross-correlation techniques should be used. However, it is also stressed that this procedure is not preferred and will not be accepted if other procedures are feasible.

Measurements are also required to determine the directivity of the emitted noise from the wind turbines. This requires that measurements are made at the four positions around the wind turbine and are correlated with the downwind measurement position.

To assess the tonal characteristics of the wind turbines, one-third octave noise measurements are also required. These measurements are required to cover the frequency bands from 20 Hz up to at least 8000 Hz. These measurements are to be performed for an operating condition of an average power output of 30 % ± 15 % of the maximum rated power of the wind turbine.

Noise measurements of the wind turbine are required to cover three operating conditions. These are defined as low (20 % ± 5 % of maximum rated power {MRP}), medium (50 % ± 10 % MRP) and high (90 % ± 10 % MRP) wind speed conditions. However, although a minimum measurement period of 30 minutes is proposed there is no attempt to correlate the measured wind speed with the measured noise level. Therefore, the measurements would appear to be an attempt to obtain an indicative noise level rather than a precise measurement of the emitted noise from the wind turbine.

Measurements are also proposed to determine the reference level of the wind turbine noise at a distance of 400' downwind of the wind turbine. These measurements are to be made when the low wind speed conditions are prevailing. It is then proposed to use the near-turbine noise measurements to predict the noise level from the wind turbine at the high wind speed condition. It is this level that is then used to determine the maximum noise level from the wind farm. These noise levels are determined by the use of the L_{A90} noise level that has been measured.

The County proposes to use this data to determine the noise level from the proposed wind farm development at the high wind speed condition. This is because the noise limits that are proposed for Riverside County are set as not to be exceeded noise levels. The prediction of the noise levels by the County will be used for the granting of permits to build. However, a measurement methodology is proposed for the assessment of a working wind farm where measurements of the L_{A90} noise level should be performed for a minimum of 30 minutes. The noise criteria are set out as follows:

TECHNICAL SPECIFICATIONS AND CRITERIA FOR SUBSTANTIAL CONFORMANCE

For wind farms with an original residential noise limit of 50 or more dB(A), the replacement WECS shall result in substantially fewer potential cumulative noise impacts as projected at the nearest residence on land designated residential in December, 1985 version of the Western Coachella Valley Plan (WCVP).

For wind farms with an original residential noise limit of 45 or less dB(A), the replacement WECS shall result in the same or substantially fewer potential cumulative noise impacts as projected to the nearest residence regardless of the underlying WCVP designation. "Same or substantially fewer potential cumulative noise impacts" shall be defined as follows:

A NON-MEASUREMENT METHOD

To elect this method the project shall comply with the following criteria:

a) The foundation of each replacement WECS including tower shall be topographically elevated above the nearest appropriate residence less than the height specified in Table A.

b) More than half of the permitted turbines shall be removed.

c) The permitted noise level for the original WECS permit shall not be less than 60dB(A)

d) The replacement WECS shall not exceed a maximum power output of 500kW. The maximum rated power output of each replacement WECS shall be provided along with tower height, total height, hub height and rotor diameter.

e) Minimum distance (as measured from the nearest WECS to nearest appropriate residence), associated maximum number of turbines and associated maximum height of WECS above the nearest appropriate residence shall conform to Table A

Table A		
Minimum Distance in feet	*Maximum Number of Turbines*	*Maximum Height (topographical) in feet*
2,000	*10**	*100*
3,000	*25**	*125*
4,000	*50**	*150*
5,000	*110**	*175*
6,000	*200**	*200*

** Can be increased (based upon the reference noise value of 70dB(A), includes 5dB(A) pure tone penalty at a slant distance of 150 feet per turbine), if noise level of the array of turbines projected (use model specified in Section 2.C. hereof with atmospheric absorption loss of 1dB(A) per 1,000 feet) to nearest appropriate residence does not exceed 55dB(A).*

B MEASUREMENT METHOD

The measurement for each replacement and remaining WECS shall be made in accordance with Section 2. hereof in terms of L_{A90} at 90% of rated power, or in accordance with the latest committee's approved version of AWEA - "Standard Procedure for Measurement of Acoustic Emissions from Wind Energy Conversion Systems" reporting the reference noise in terms of L_{Aeq} (-2dB for ground reflection) at wind velocity of 10 metres per second.

a) A-Weighted Criteria

Using the replacement and remaining WECS noise reference data for single wind turbines the modelling for projected noise levels from commercial WECS shall be done in accordance with Section 2. hereof with reference noise levels adjusted to 100 metres slant distance. Pure tone shall be defined as specified in Ordnance No. 348, Subsection d(12) of Section 18.41, a.2.

The new noise limit shall be the greater of one of the following:

a. No more than that allowed by present County ordinance (45dB(A) and pure tone criteria), or

b. 5dB(A) below original noise limit or latest substantial conformance noise limit, and

if WECS exhibit pure tone , a 5dB(A) penalty shall apply, and

if replacement WECS are at a greater height (topographically) above the nearest appropriate residence than specified in Table A, a 5dB(A) penalty shall apply, and

if less than four WECS are available for field verification, a 5dB(A) penalty shall apply.

b) *Low Frequency Noise Criteria*

The projected cumulative low frequency noise to the nearest appropriate residence shall not exceed the following criteria using the model specified in B deleting those sections on atmospheric attenuation loss.

The PC weighted level (as designated in "A Proposed Metric for Assessing Potential of Community Annoyance from Wind Turbine, Low Frequency Noise Emissions" SERI November 1987) of 75dB for non-impulsive and 67dB for impulsive sources representing annoyance thresholds shall be the criteria.

To determine the "PC Weighted" level at the interior of the building, steps 1 through 4 shall be adhered to as outlined in the above test under the heading of "Suggested procedure for estimating the interior LF annoyance potential of a given turbine design" and in addition, a 5dB penalty shall be added to the results of step 4.

Kern County, California

Kern County has a number of wind farms within its district. Noise has been addressed within Section 16.64.140 of the County Ordinance. It reads as follows:

J *Where a residence , school, church, public library or other sensitive or highly sensitive land use, as identified in the noise element of the county general plan, is located within one (1) mile in a prevailing downwind direction or within one-half (½) mile in any other direction of a project's exterior boundary, an acoustical analysis shall be prepared by a qualified acoustical consultant prior to the issuance of any building permit. The consultant and the resulting report shall be subject to review and approval by the county health department. The report shall address any potential impacts on sensitive or highly sensitive land uses.*

In addition, the acoustical report shall demonstrate that the proposed development shall comply with the following criteria:

1. *Audible noise due to wind turbine operation shall not be created which causes the exterior noise level to exceed forty-five (45) dB(A) for more than five (5) minutes out of any one (1) hour time period ($L_{8.3}$) or to exceed fifty (50) dB(A) for any period of time when measured within fifty (50) feet of any existing residence, school, hospital, church or public library.*

2. *Low frequency noise or infrasound from wind turbine operations shall not be created which causes the exterior noise level to exceed the following limits when measured within fifty (50) feet of any existing residence, school, hospital, church or public library.*

One-third Octave Band Centre Frequency (Hz)	*Sound Pressure Level (dB)*
2 to 16	*70 (each band)*
20	*68*
25	*67*
31.5	*65*
40	*62*
50	*60*
63	*57*
80	*55*
100	*52*
125	*50*

3. *In the event audible noise due to wind turbine operations contains a steady pure tone, such as a whine, screech or hum, the standards for audible noise set forth in subparagraph (1) of this subsection shall be reduced by five (5) dB(A). A pure tone is defined to exist if the one-third octave band sound pressure level in the band, including the tone, exceeds the arithmetic average of the sound pressure levels of the two (2) contiguous one-third octave bands by five (5) dB(A) for centre frequencies of five hundred (500) Hz and above, by eight (8) dB(A) for centre frequencies between one hundred sixty (160) Hz and four hundred (400) Hz , or by fifteen (15) dB(A) for centre frequencies less than or equal to one hundred twenty-five (125) Hz.*

4. *In the event the audible noise due to wind turbine operations contains repetitive impulsive sounds, the standards for audible noise set forth in subparagraph (1) of this subsection shall be reduced by five (5) dB(A).*

5. *In the event the audible noise due to wind turbine operations contains both pure tone and repetitive impulsive sounds, the standards for audible noise set forth in subparagraph (1) of this subsection shall be reduced by a total of five (5) dB(A).*

6. *In the event the ambient noise level (exclusive of the development in question) exceeds one (1) of the standards given above, the applicable standard shall be adjusted so as to equal the ambient noise level. For audible noise, the ambient noise level shall be expressed in terms of the highest whole number sound pressure level in dB(A) which is exceeded for no more than five (5) minutes per hour ($L_{8.3}$). For low-frequency noise or infrasound, the ambient noise level shall be expressed in terms of the equivalent level (L_{eq}) for the one-third octave band in question, rounded to the nearest whole decibel. Ambient noise levels shall be measured within fifty (50) feet of potentially affected existing residences, schools, hospitals, churches or public libraries. Ambient noise level measurement techniques shall employ all practical means of reducing the effects of wind-generated noise at the microphone. Ambient noise level measurements may be performed when wind velocities at the proposed project site are sufficient to allow wind turbine operation, provided that the wind velocity does not exceed thirty (30) mph at the ambient noise measurement location.*

7. *Any noise level falling between two (2) whole decibels shall be the lower of the two.*

APPENDIX C

BACKGROUND NOISE

This appendix presents results from a background noise survey and discusses the issues involved in obtaining reliable data.

Fig A1 details a time history of measurements performed at a dwelling neighbouring a proposed wind farm site, these measurements undertaken using a 5-minute time period. Wind speed measurements were also measured in 5-minute periods at an anemometer position approximately 400 metres from the dwelling. Measurements were performed over 10 days. During this time the wind blew from the south, west and north.

Fig A2 details the wind speed and direction data that were collected. The dwelling was situated to the north and east of the proposed wind turbines. Therefore, during the survey period the wind direction was such that the worst-case propagation conditions would be expected from the turbines towards the dwelling.

Fig A3 details the regression analysis performed upon all the measured data, with rainfall removed, to derive the prevailing background noise level at the measurement position. The wind speed data have been corrected to provide the expected hub height wind speed for the proposed wind turbines that were to be installed. It will be noted that a high order polynomial has been used to derive the prevailing background noise level. Care must be used when deriving the prevailing background noise level at the extremes of the data, ie at the low and high speed ends of the curve. It may be seen from Figure 3 that at very low wind speeds the derived line is increasing with decreasing wind speed. An alternative to a polynomial is a log curve of the form

$$L_{pb} = 10 \log (10^{A/10} + 10^{(B+C \log V)/10})$$

where L_{pb} = background noise level as a function of wind speed, dB(A)
A = constant equal to the background noise present with no wind, dB(A)
B and C = constants describing the contribution to the background noise from wind induced sources.
V = wind speed at turbine hub-height, m/s.

This curve has been derived by assuming the background noise is made up of a fixed level which does not vary with wind speed plus a contribution from wind-induced sources whose sound power varies with V^x. Curves of this form have the advantage that they tend to predict reliable levels for wind speeds at which no experimental data have been obtained.

Fig A4 details the spread of the measured data around the derived prevailing background noise level. It may be seen that the spread indicates a normal distribution around the line. It may also be seen from this Figure that the derived prevailing background noise level is 5dB higher than the measured background noise level for about 9% of the measurements. If the allowable turbine noise level above the background noise level were 5dB and it is assumed the turbine noise is constant, then it would be expected that for 9% of the operating period of the wind farm, wind turbine noise levels may exceed the prevailing background noise levels by 10dB or more.

Fig A5 details the regression analysis performed for the data collected during the evening and night-time periods. It may be seen that a lower correlation exists for this data than that derived for the all data regression line shown in Fig A3.

Fig A6 details the spread of the measured data around the derived regression line. Again, it may be seen that the derived prevailing background noise level is 5dB higher than the measured background noise level for about 9% of the time.

Fig A7 details the regression analysis performed upon the evening and night-time noise data when the wind was blowing from the development towards the dwelling, a south-westerly wind. This would be the wind direction from which the maximum noise impact from the proposed site may be expected to occur because the dwelling would be downwind of the development, although comparison with the curve for all directions shows the background noise levels to be about 2dB greater when the wind is in this direction than on average. The correlation between the measured background noise levels and the measured wind speed has greatly improved and there is a significant reduction in the scatter of the noise data around the derived line.

Fig A8 details the spread of the measured data around the derived regression line. It may be seen that the spread is greatly reduced. Furthermore, it may be seen that the derived prevailing background noise level is 5dB higher than the measured background noise level for less than 1% of the time. If an allowable turbine noise level is set at 5dB above the derived prevailing background noise level, then it should be expected that the actual background noise level will be exceeded by 10dB or more for less than 1% of the operating time at the most sensitive operating condition, ie approximately 5 minutes in every 8 hours for the critical wind speed.

The example that has been given in Figs A1 to A8 is for a dwelling that does not have any significant noise sources from sources not associated with the wind. (It may be noted that a single high L_{A90} noise level is plotted within Figs A3 and A5. This was most likely due to the running of an engine within the farmyard which was adjacent to the measurement position.) Steady sources like water were not audible at this position. Such sources can significantly change the scatter of the measured data.

Figs A9 and A10 detail the regression analysis for a dwelling positioned close to a water source. It may be seen that a significant proportion of the measurements are centred around 33-35dB L_{A90}. Fig A10 detailing the spread of the measured data around the derived prevailing background noise level indicates that measured data never fall below the derived prevailing background by more than 4dB. However, the figure also indicates that a criterion of + 5dB upon the prevailing background noise level will result in the background noise level being exceeded by 8dB or more for 30% of the operating period.

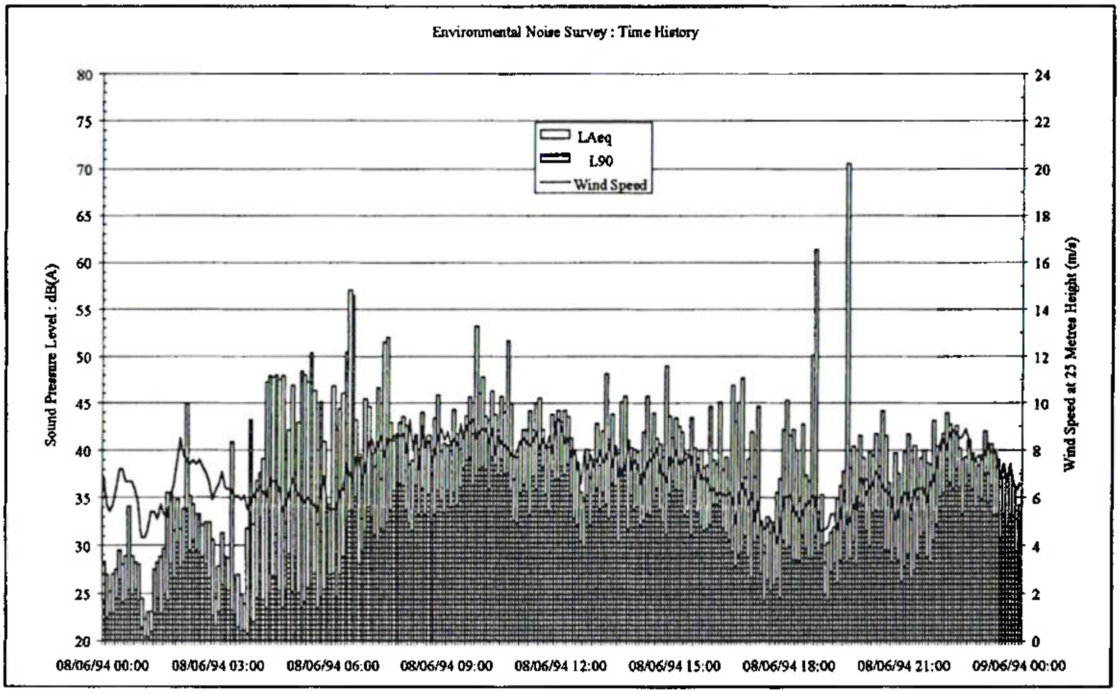


Figure A1 Typical time history measurements: single day shown only

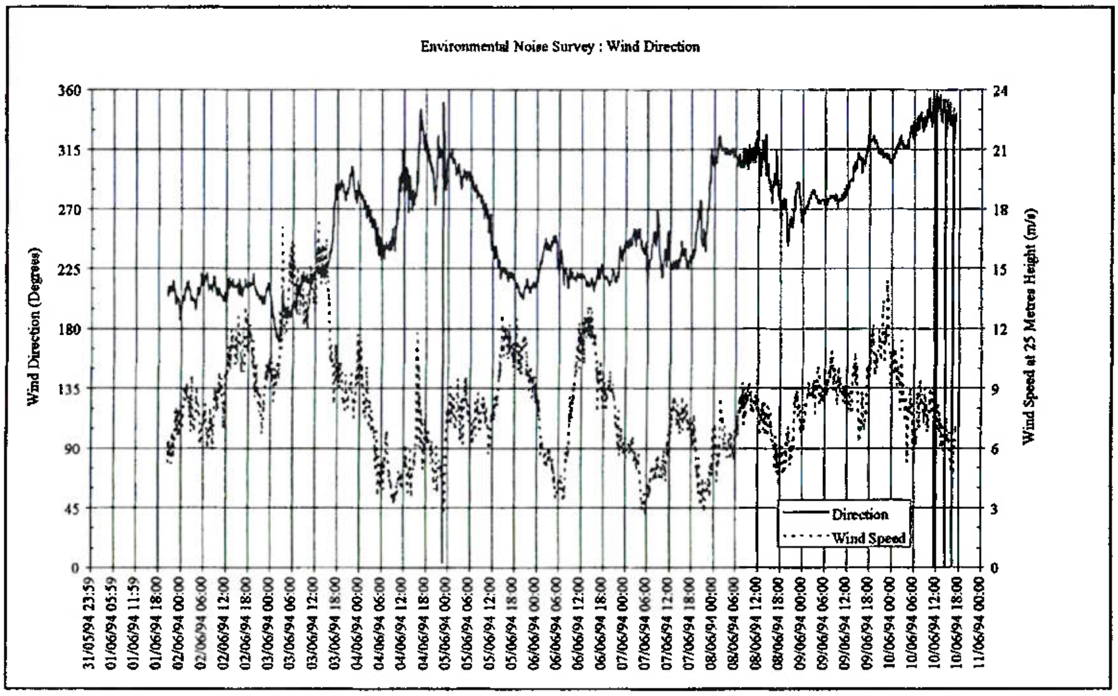


Figure A2 Typical time history of measured wind data from anemometer before site construction

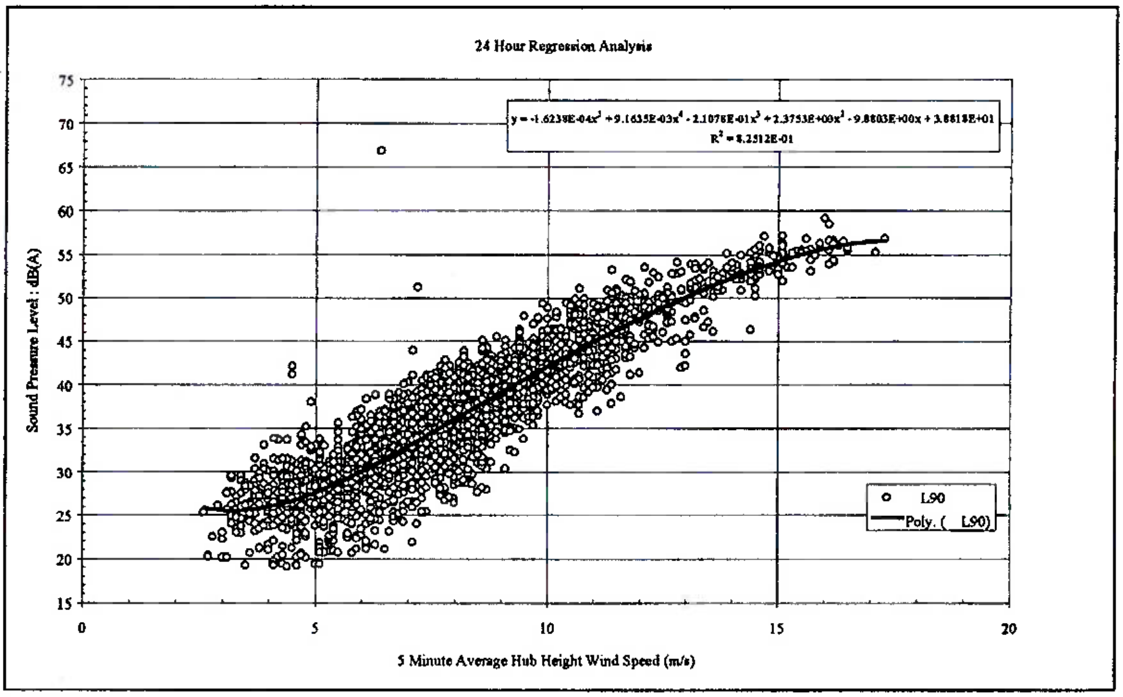


Figure A3 Regression analysis of all measured wind speed and noise data to determine the prevailing background noise level

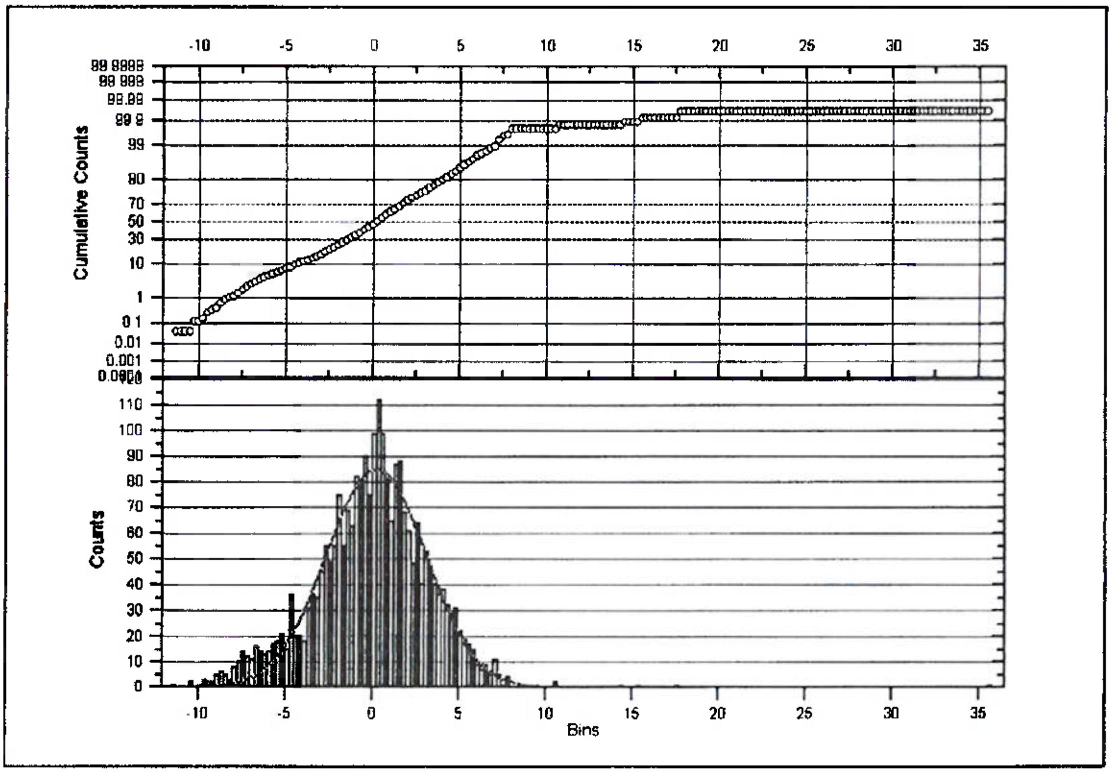


Figure A4 Deviation of measured levels around derived regression line plotted in Figure A3

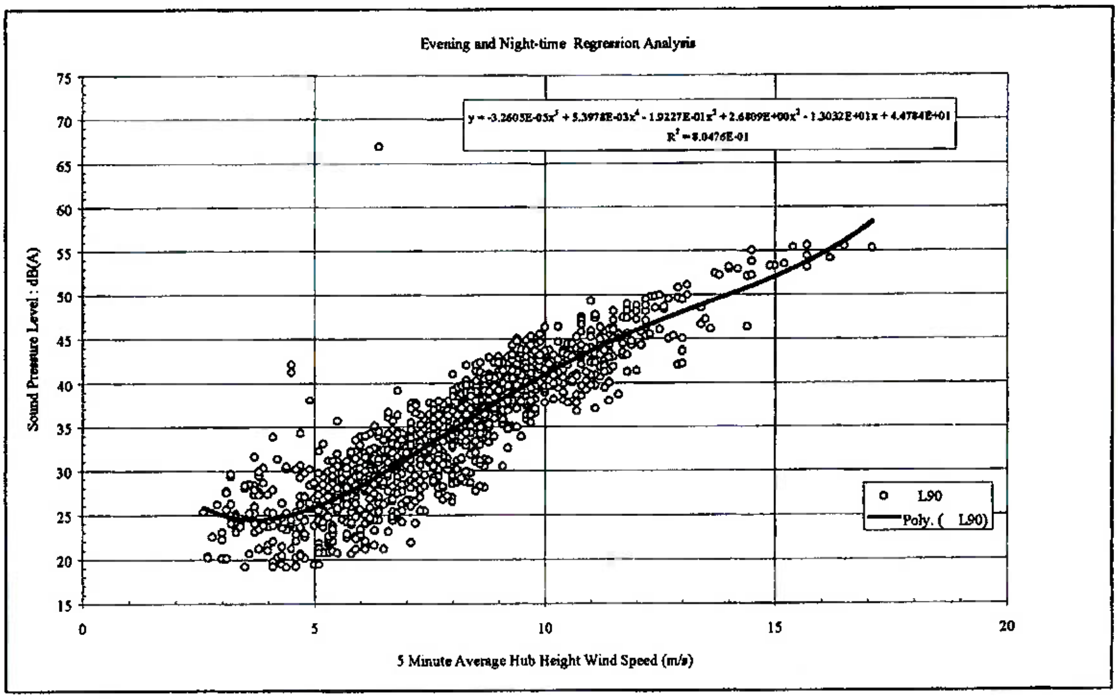


Figure A5 Regression analysis of evening and night-time measured wind speed and noise data to determine the prevailing evening and night-time background noise level

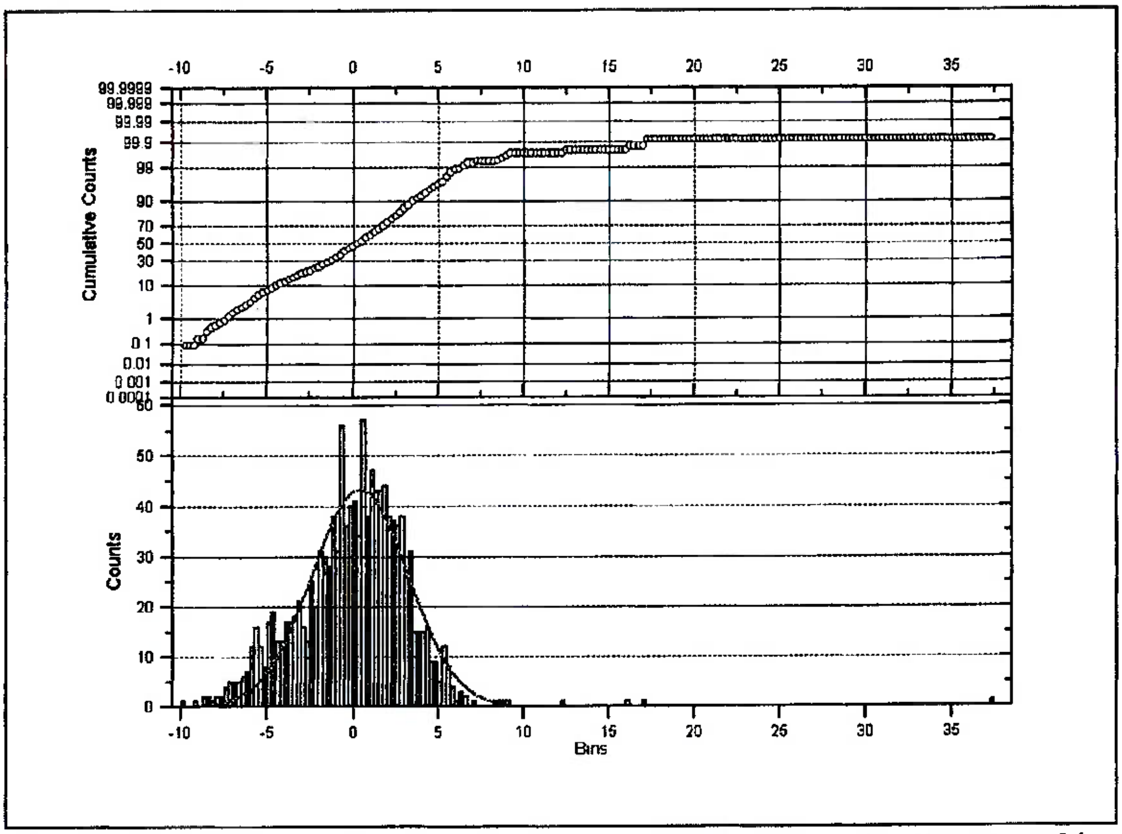


Figure A6 Deviation of measured levels around derived regression line plotted in Figure A5

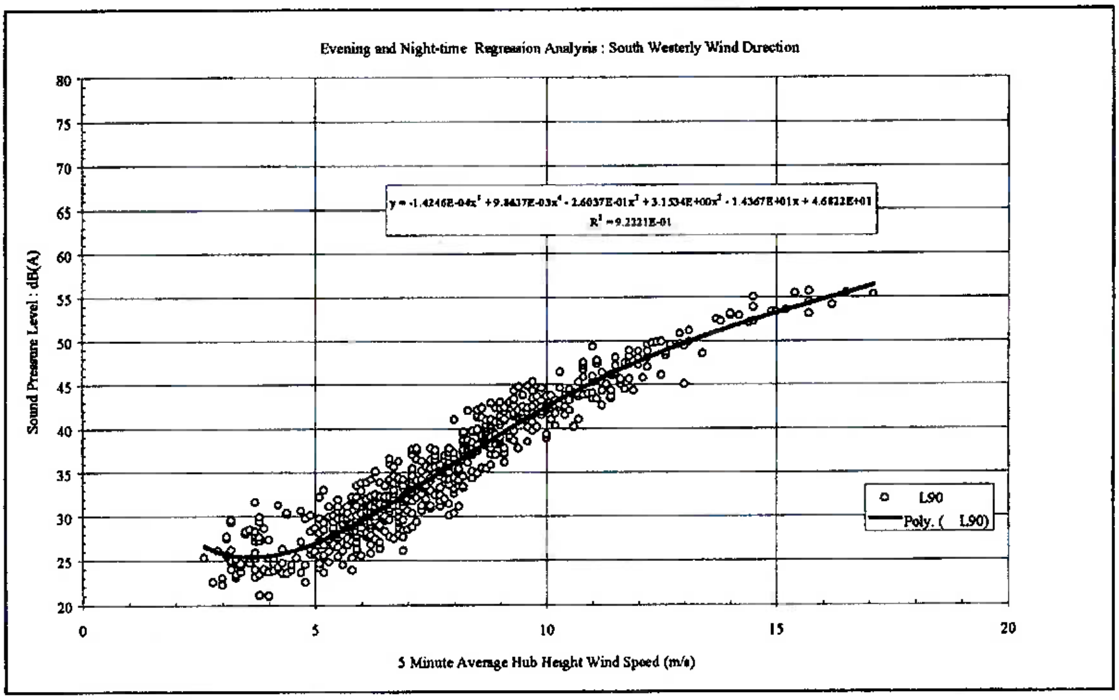


Figure A7 Regression analysis of all measured wind speed and noise data for south-westerly wind direction to determine the prevailing background noise level

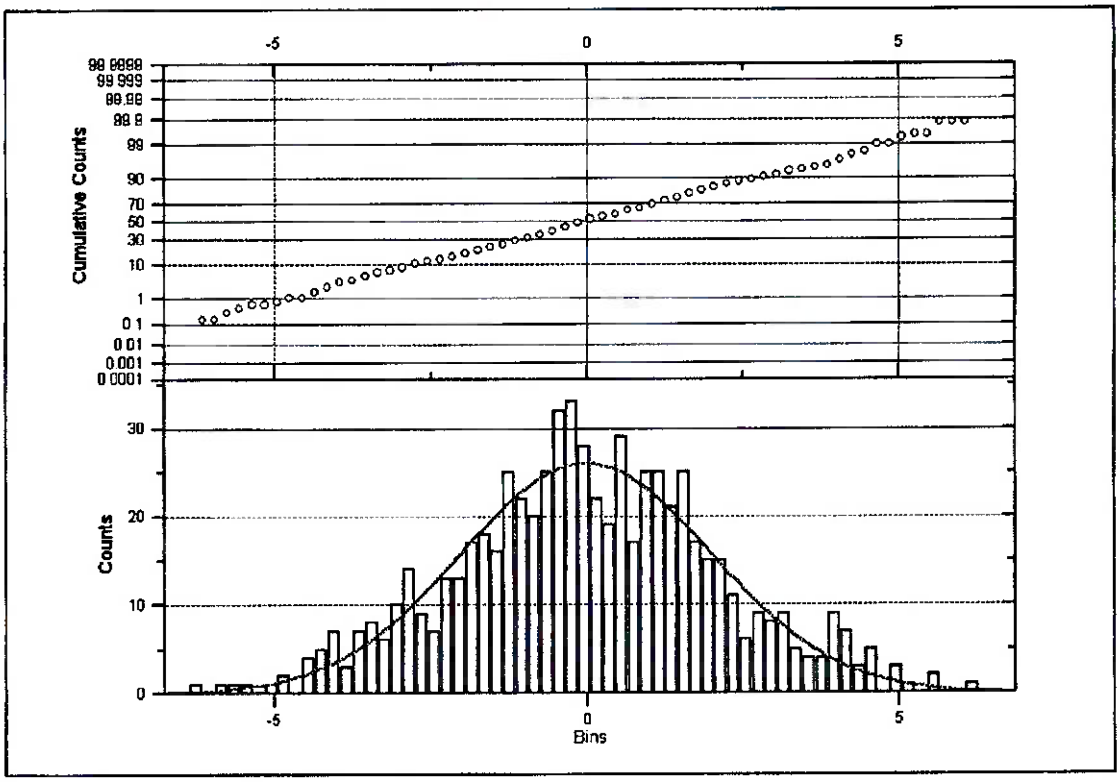


Figure A8 Deviation of measured levels around derived regression line plotted in Figure A7

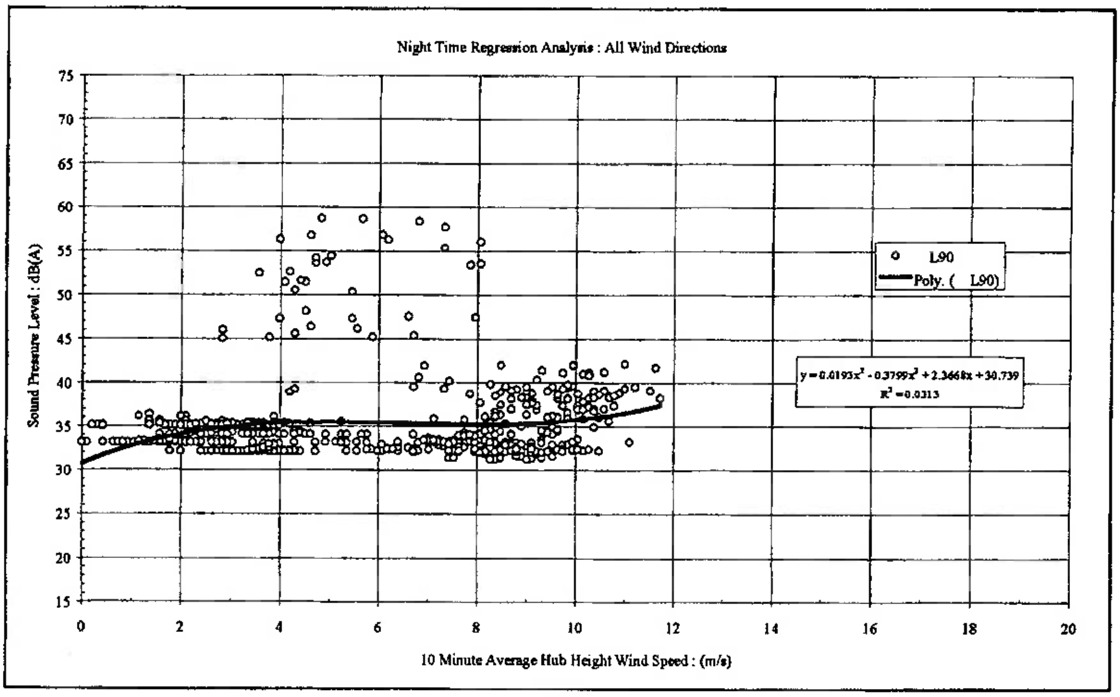


Figure A9 Regression analysis of evening and night-time wind speed and noise data to determine the prevailing evening and night-time background noise level

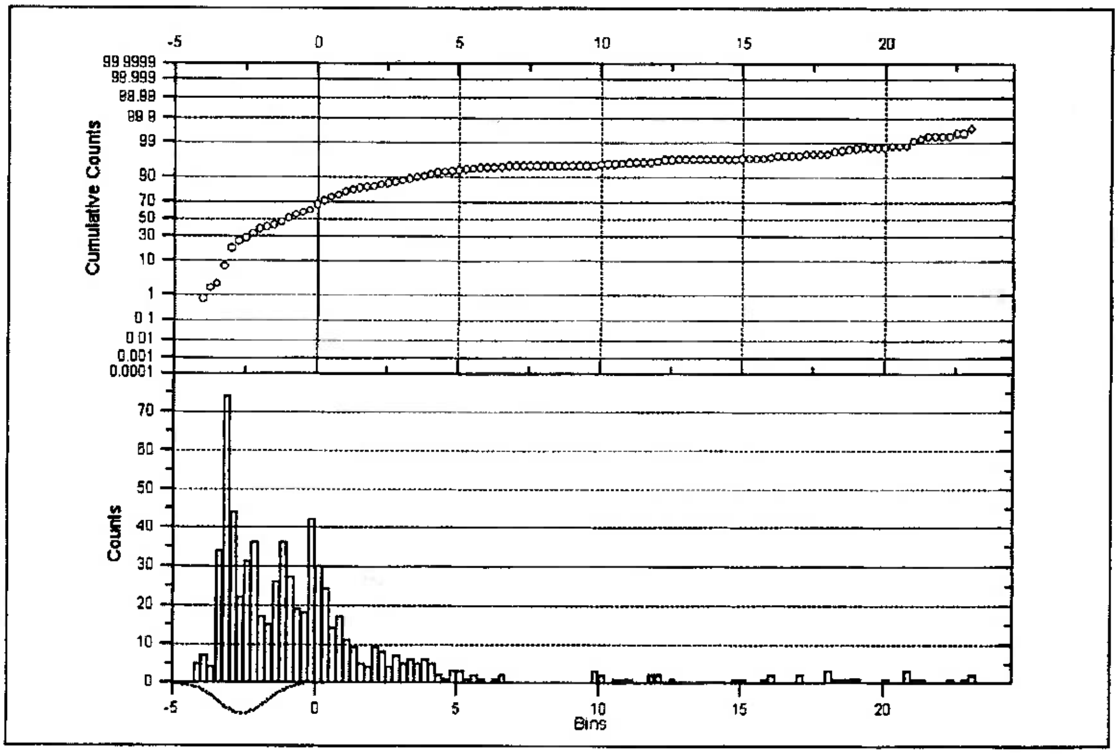


Figure A10 Deviation of measured levels around derived regression line plotted in Figure A9