MARSHALL DAY Acoustics

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

Commissioned by Sustainable Energy Authority of Ireland (SEAI)

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

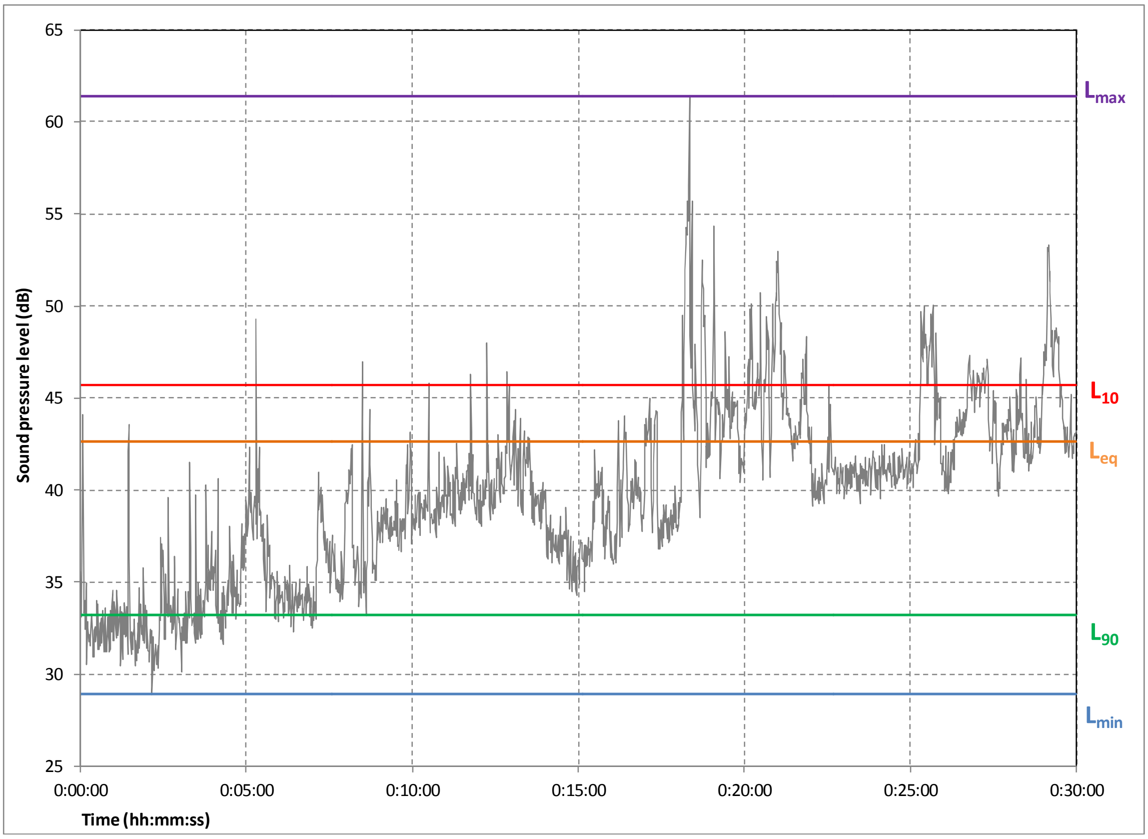

Figure 1: Example of noise indices that may be used to measure a time-varying sound level

[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	85–90	85 dB is the level at which hearing damage (8 hrs.) begins
Recreational Vehicles, TV	70–90	
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))

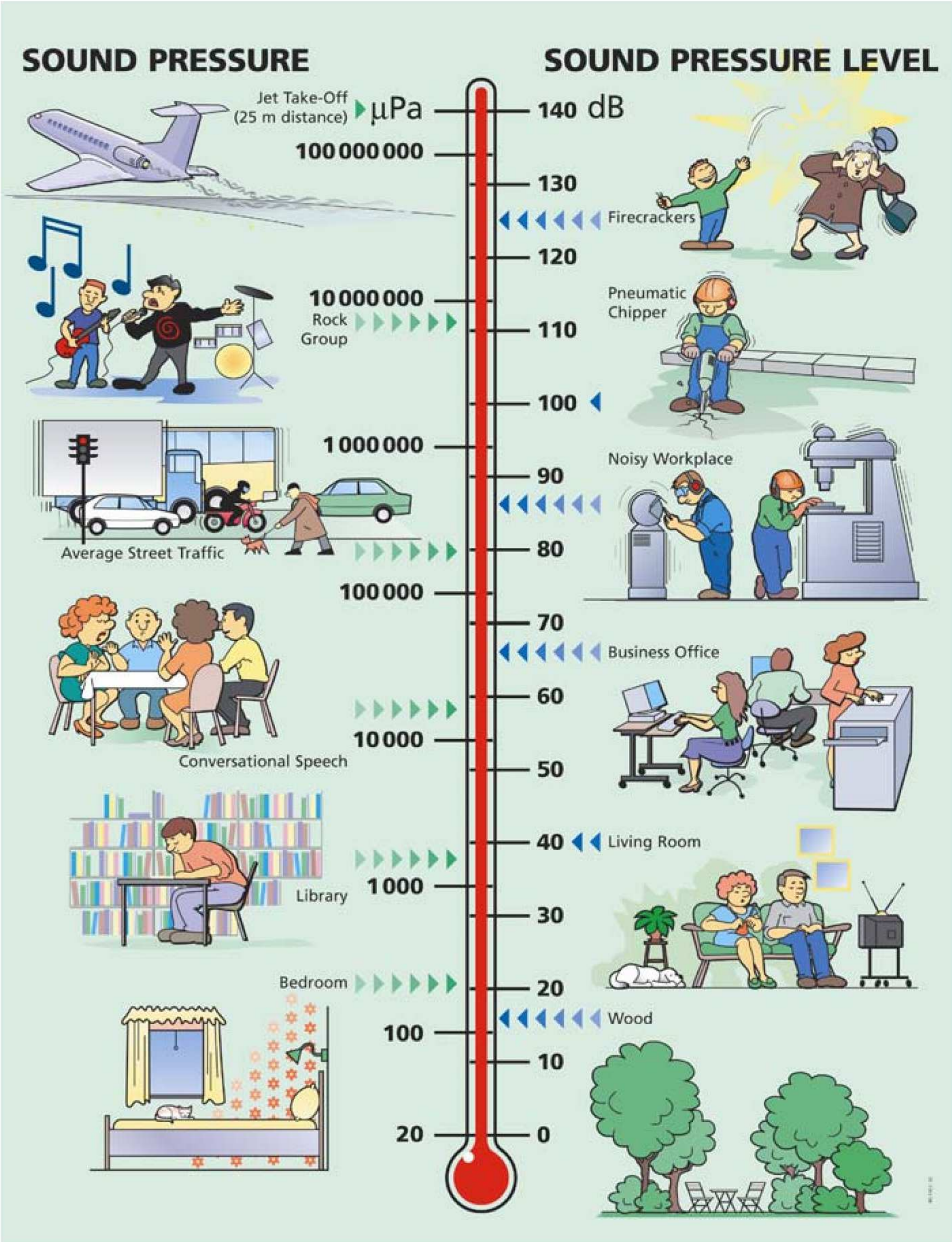

Figure 3: Example A-weighted noise levels for a range of common activities[5]

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:

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[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:

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[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.

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[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

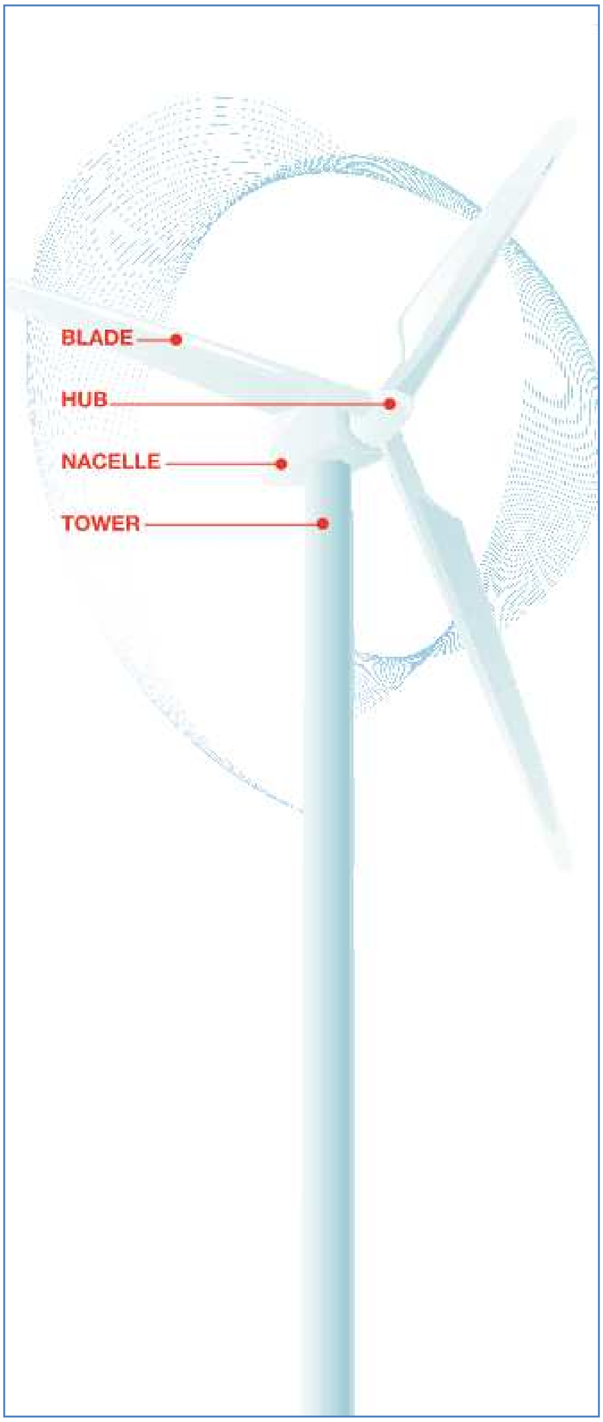

Figure 5: Schematic of a wind turbine[35]

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)

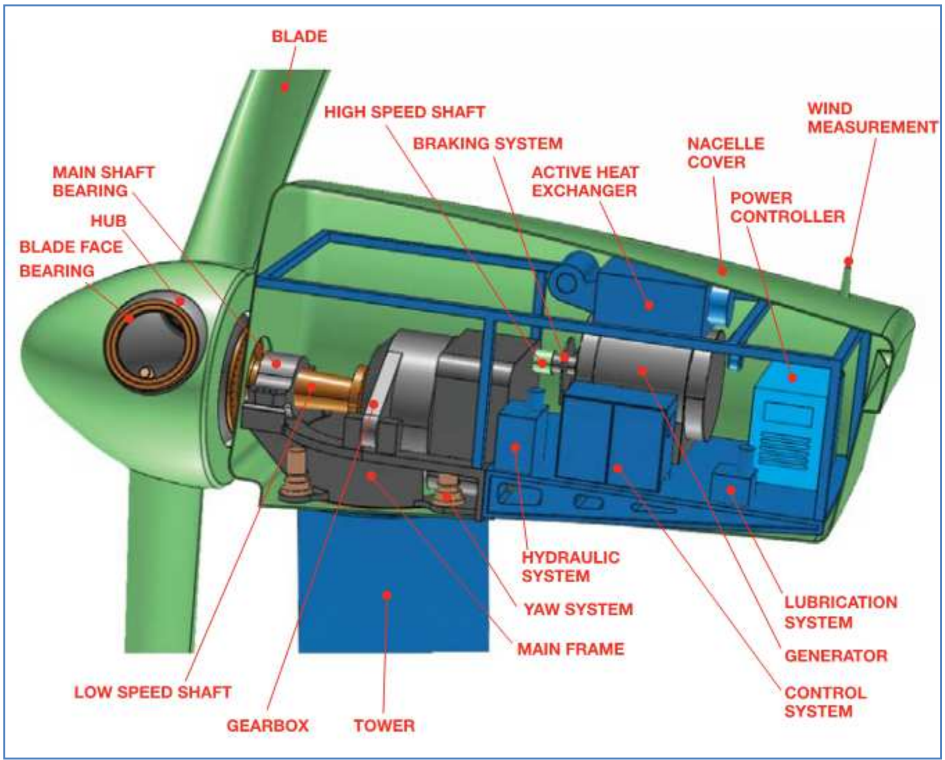

Figure 6: Anatomy of a wind turbine[36]

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.

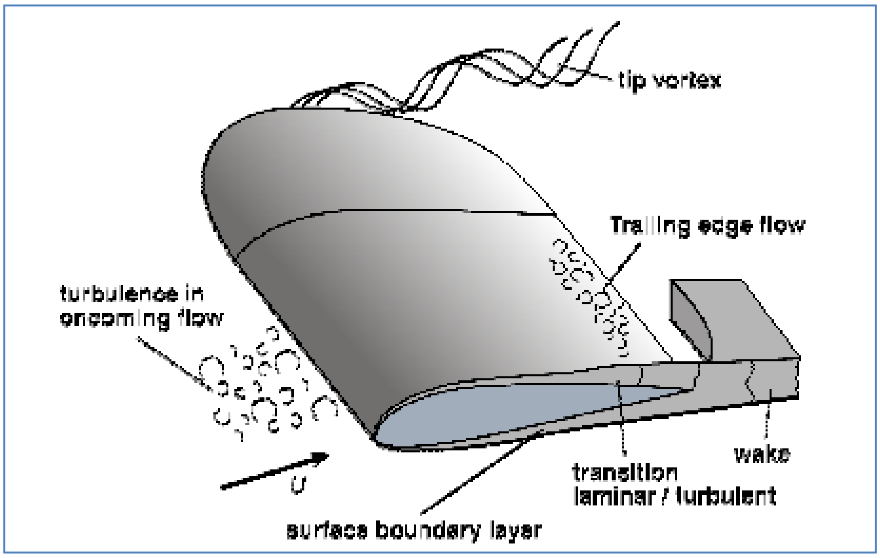

Figure 7: Turbine blade aerodynamic noise generation[38]

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)

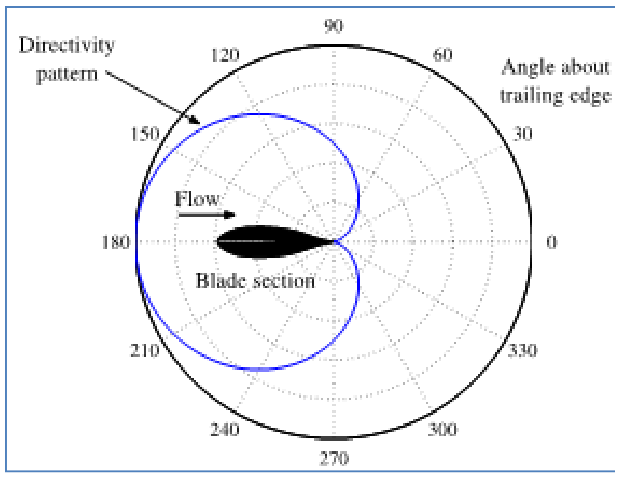

Figure 8: Trailing edge noise directivity pattern[41]

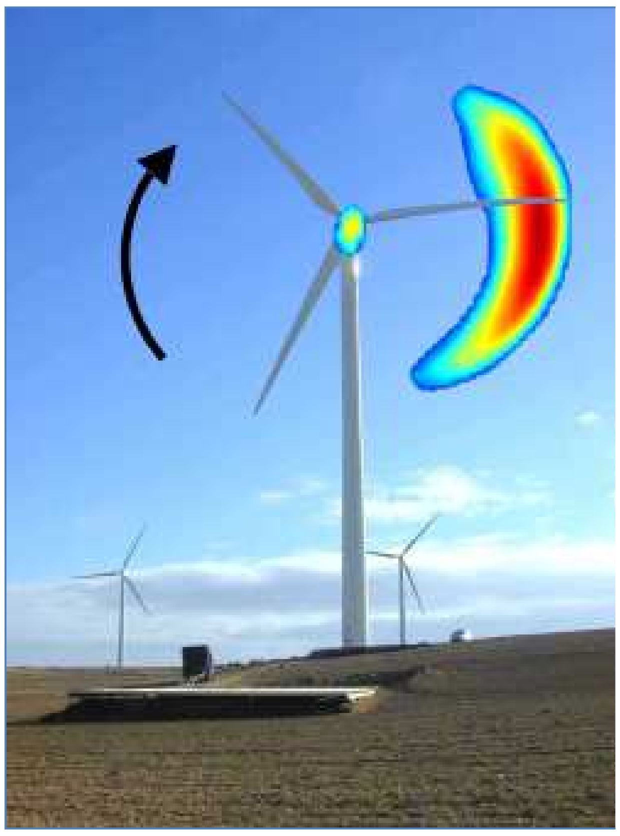

Figure 9: Wind turbine sound source localisation (clockwise rotation)[42]

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

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

Noise directivity from the blade or aerofoil trailing edge is considered to be the cause of the characteristic 'swish' associated with wind turbine sound.

Due to its directivity pattern, trailing edge noise is directed towards a receiver at ground level during the down stroke of the blade, and away from a receiver on the ground during 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.

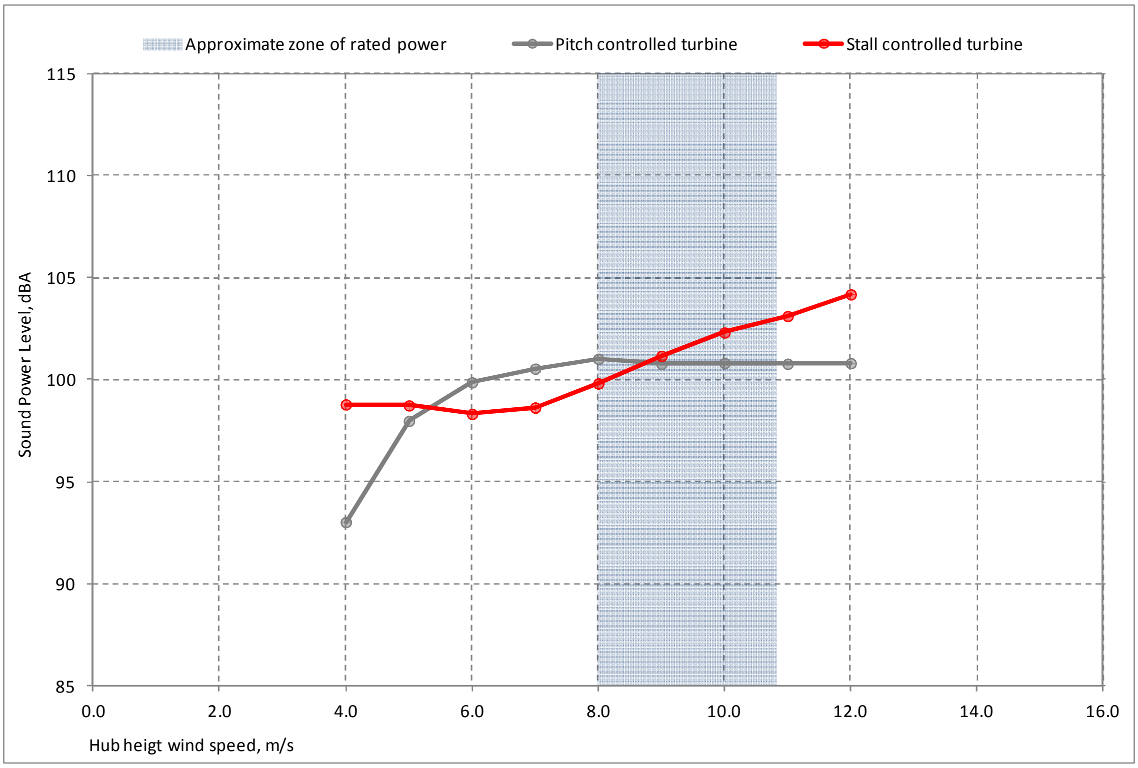

Figure 10: Example sound power level curves for pitch controlled and stall controlled turbines[46]

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.

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[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)

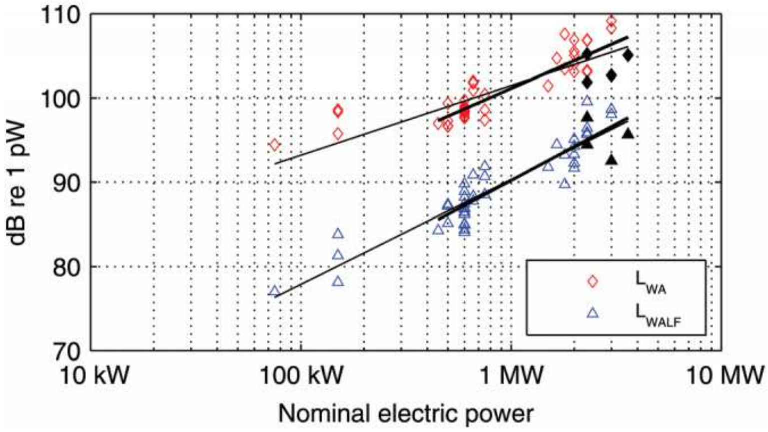

FIG. 1. (Color online) Apparent sound power levels (L_{WA} and L_{WALF}) in the reference direction as a function of turbine size. Wind speed is 8 m/s. Regression lines: all turbines included (thin lines), four turbines below 450 kW excluded (bold lines). Black-filled marks are for turbines 1–4.

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

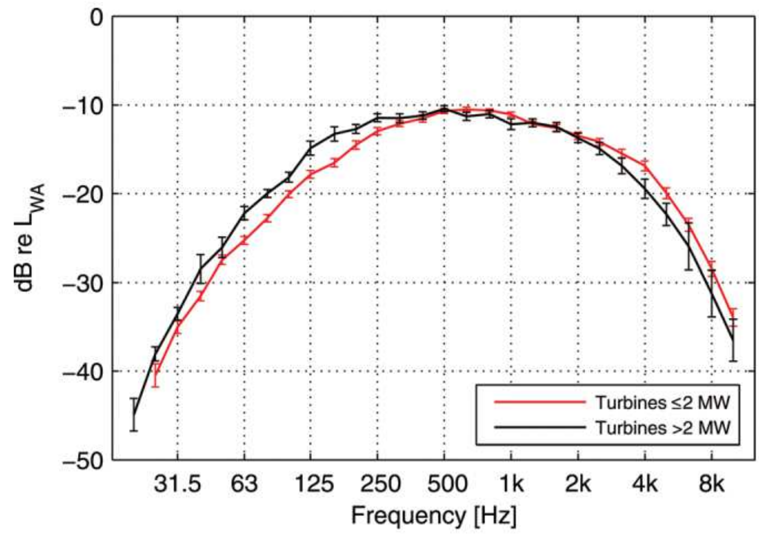

FIG. 4. (Color online) Normalized A-weighted apparent sound power levels in one-third-octave bands, means of two groups of turbines: ≤ 2 MW and > 2 MW. Error bars indicate ±1 standard error of mean.

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.

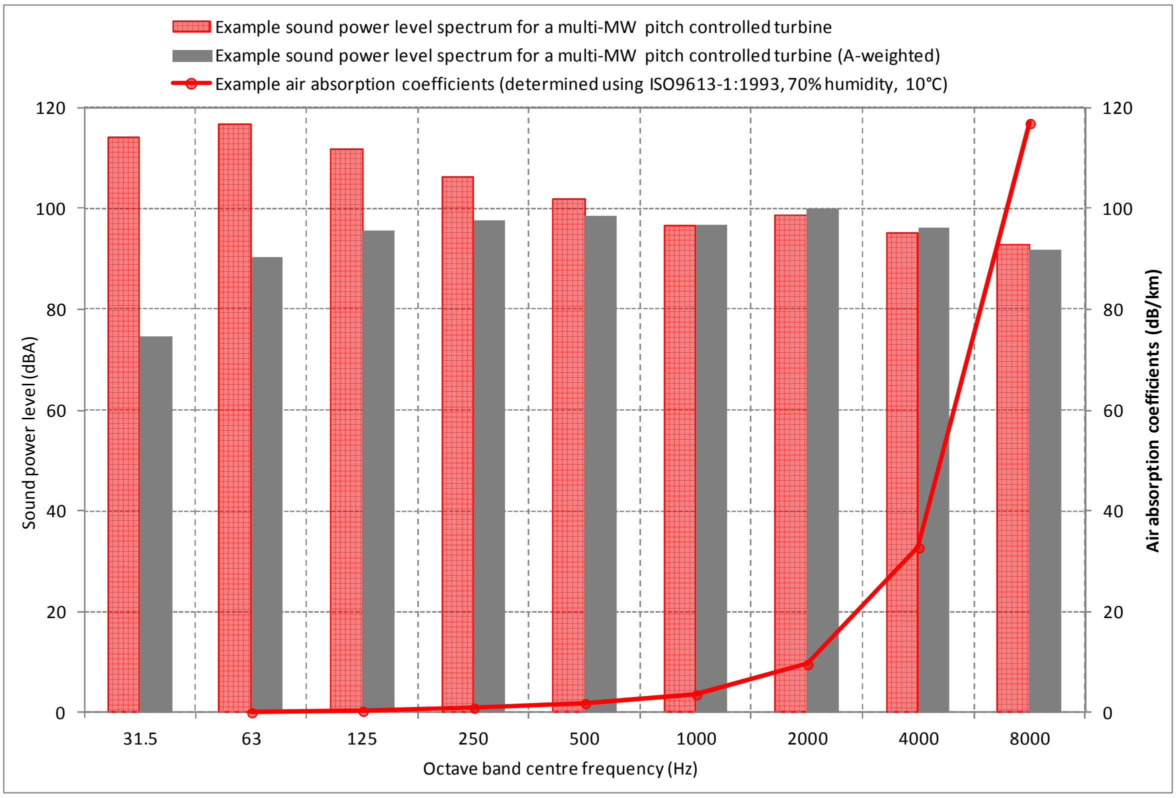

Figure 13: Example sound power level spectrum compared with air absorption coefficients

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.

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[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.

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[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].

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[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)

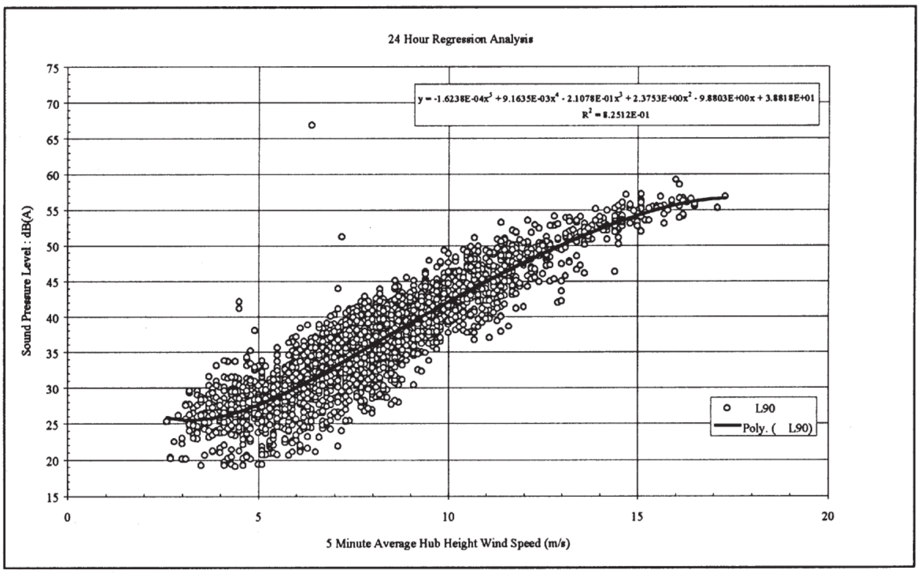

Figure A3 Regression analysis of all measured wind speed and noise data to determine the prevailing background noise level

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*".

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[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.

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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.*

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[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.*

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

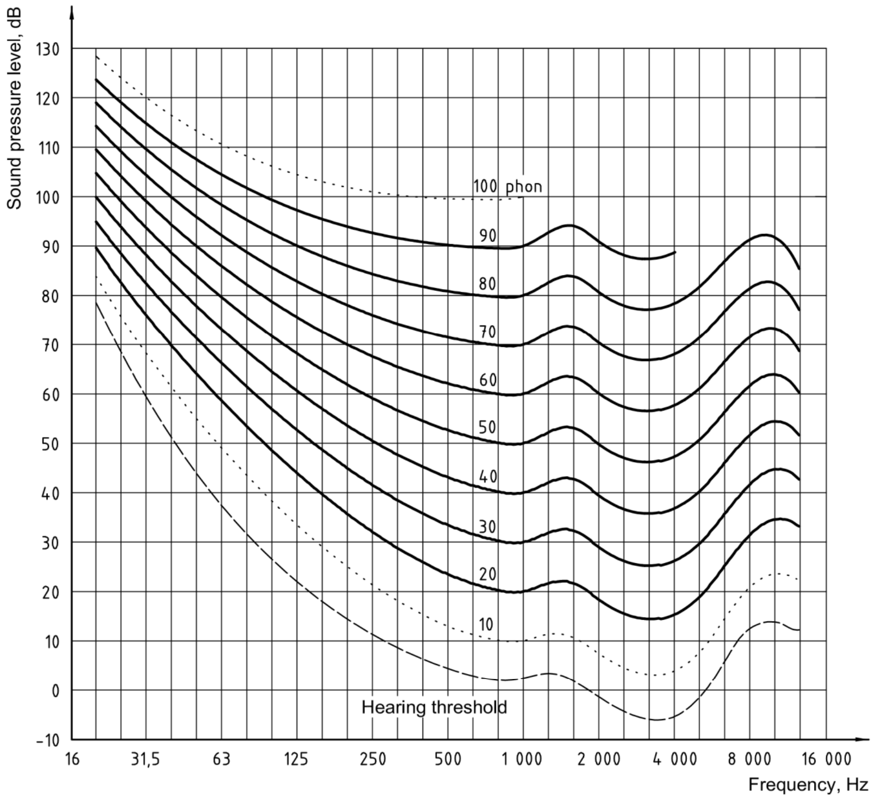
[96] For example, the South Australia EPA Waterloo Wind Farm Noise Study: http://www.epa.sa.gov.au/environmental_info/noise/wind_farms/waterloo_wind_farm_noise_study

[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)

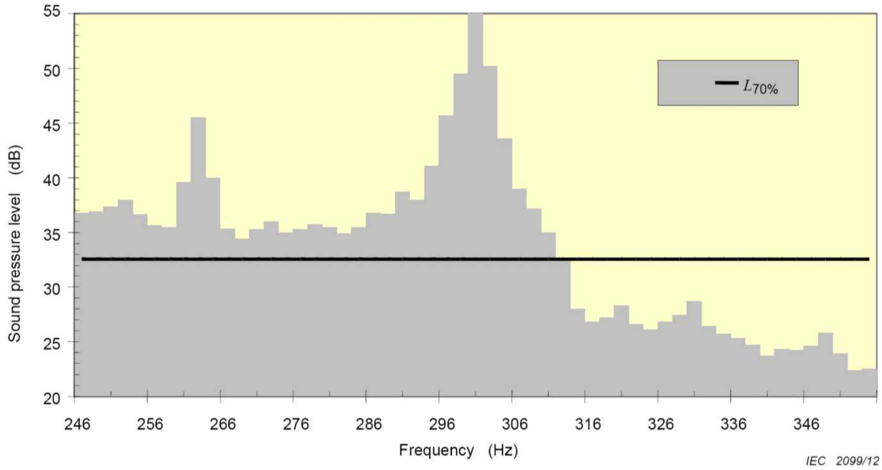


Figure 8 – Illustration of $L_{70\,\%}$ level in the critical band

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.*

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[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].

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[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.*

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[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)

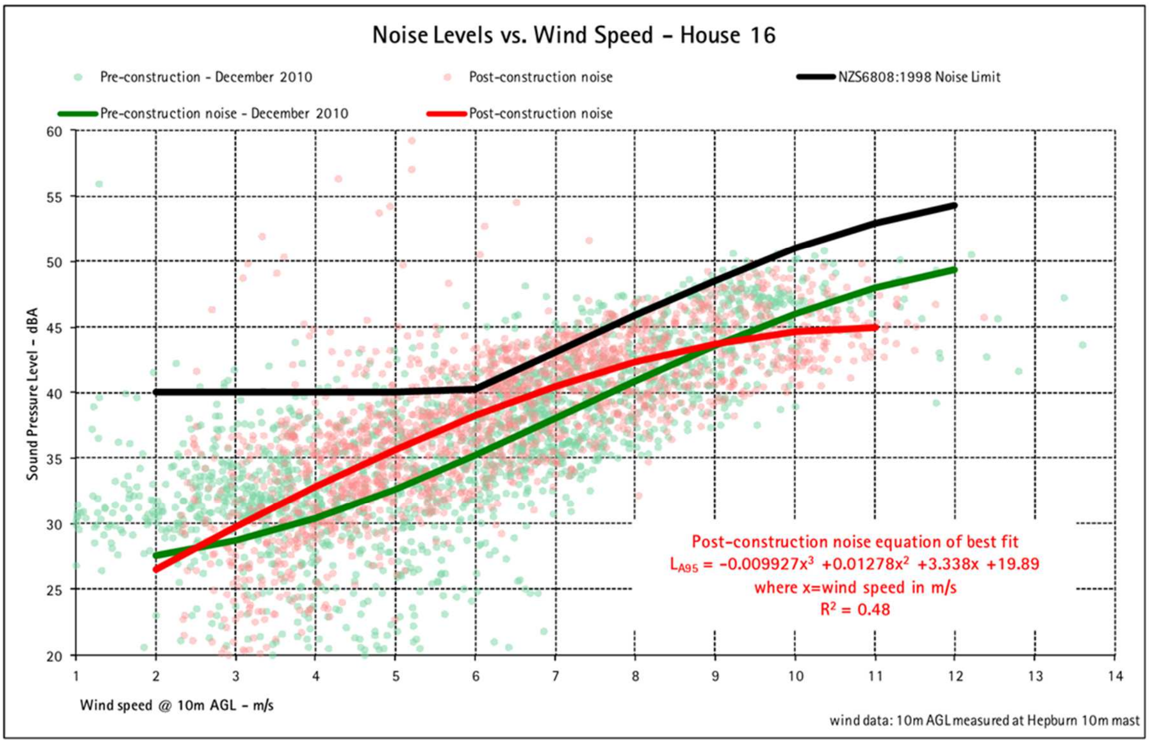

Figure 17: Example of post-construction measured background noise levels[139]

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.*

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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.

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[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:

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[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.

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[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.

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[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. […]"*

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[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.

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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.

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[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.

Table 8: Review of noise discussions in WEDG06

Section 5.6 Noise, paragraphs 1 & 2

> *There are two distinct noise sources associated with the operation of wind turbines; aerodynamic noise caused by blades passing through the air, and mechanical noise created by the operation of mechanical elements in the nacelle - the generator, gearbox and other parts of the drive-train. Aerodynamic noise is a function of many interacting factors including blade design, rotational speed, wind speed and inflow turbulence; it is generally broadband in nature and can display some "character" (swish). Mechanical noise from a wind turbine is tonal in nature.*
>
> *Advances in turbine technology and design have resulted in reduced noise emissions. Aerodynamic refinements that have combined to make turbines quieter include the change from lattice to tubular towers, the use of variable speed operations, and the switch to 3 blade turbine designs. Improvements in gearbox design and the use of anti-vibration techniques in the past ten years have resulted in significant reductions in mechanical noise. The most recent direct drive machines have no high-speed mechanical components and therefore do not produce mechanical noise.*

Identified issue	Comments
"The most recent direct drive machines have no high-speed mechanical components and therefore do not produce mechanical noise"	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.
"...include the change from lattice to tubular towers, the use of variable speed operations, and the switch to 3 blade turbine designs"	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.

Section 5.6 Noise, paragraph 3

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. Wind turbines do not operate below the wind speed referred to as cut-in speed, usually around 5 metres per second. Larger and variable speed wind turbines emit lower noise levels at cut-in speed than smaller fixed speed turbines. Noise from wind turbines is radiated more in some directions than others, with areas down-wind experiencing the highest predicted noise levels. At higher wind speeds noise from wind has the effect of largely masking wind turbine noise.

Identified issue	Comments
"Turbine noise increases as wind speeds increase, but at a slower rate than wind generated background noise increases."	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.
"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."	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.
"Wind turbines do not operate below the wind speed referred to as cut-in speed, usually around 5 metres per second"	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.

Section 5.6 Noise, paragraph 4

Good acoustical design and carefully considered siting of turbines is essential to ensure that there is no significant increase in ambient noise levels at any nearby noise sensitive locations. Sound output from modern wind turbines can be regulated, thus mitigating noise problems, albeit with some loss of power.

An appropriate balance must be achieved between power generation and noise impact.

Identified issue	Comments
"Good acoustical design and carefully considered siting of turbines is essential to ensure that there is no significant increase in ambient noise levels at any nearby noise sensitive locations. "	"*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*."
"Sound output from modern wind turbines can be regulated, thus mitigating noise problems, albeit with some loss of power. "	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.
"An appropriate balance must be achieved between power generation and noise impact. "	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.

Section 5.6 Noise, paragraph 5

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. Noise limits should apply only to those areas frequently used for relaxation or activities for which a quiet environment is highly desirable. Noise limits should be applied to external locations, and should reflect the variation in both turbine source noise and background noise with wind speed. The descriptor [$L_{A90, 10min}$]*, which allows reliable measurements to be made without corruption from relatively loud transitory noise events from other sources, should be used for assessing both the wind energy development noise and background noise. Any existing turbines should not be considered as part of the prevailing background noise.*

Identified issue	Comments
"Noise impact should be assessed by reference to the nature and character of noise sensitive 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.
"Noise limits … should reflect the variation in both turbine source noise and background noise with wind speed."	With modern pitch-controlled turbines there is less need to introduce the complexity of a wind-speed dependent, relative noise limits.
"Any existing turbines should not be considered as part of the prevailing background noise."	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*."

Section 5.6 Noise, paragraph 6

In general, a lower fixed limit of 45 dB(A)10 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. However, 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. Instead, in low noise environments where background noise is less than 30 dB(A), it is recommended that the daytime level of the LA90, 10min of the wind energy development noise be limited to an absolute level within the range of 35-40 dB(A).

Identified issue	Comments
"In general, a lower fixed limit of 45 dB(A) or a maximum increase of 5 dB(A) above background noise at nearby noise sensitive locations is considered appropriate to provide protection to wind energy development neighbours."	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.
"in very quiet areas, the use of a margin of 5 dB(A) above background noise at nearby noise sensitive properties is not necessary to offer a reasonable degree of protection"	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.
"In low-noise environments where background noise is less than 30 dB(A), it is recommended that the daytime level of the L_{A90}, 10min of the wind energy development noise be limited to an absolute level within the range of 35 – 40 dB(A)."	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.

Section 5.6 Noise, paragraph 7

Separate noise limits should apply for day-time and for nighttime. 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.

Identified issue	Comments
"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."	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.

Section 5.6 Noise, paragraph 8

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. Planning authorities may seek evidence that the type(s) of turbines proposed will use best current engineering practice in terms of noise creation and suppression.

Identified issue	Comments
"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"	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.
"Planning authorities may seek evidence that the types of turbines proposed will use best current engineering practice in terms of noise creation and 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.

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[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.

Table 13: Additional items recommended for inclusion in wind farm noise assessment guidance

Item	Comment	Example resolution
Involved receivers*	Provide additional guidance regarding involved receivers including a definition of involved receiver, guidance on suitable noise limits for involved receivers and what agreements may need to be in place between the receiver and wind farm developer to reflect any negotiated 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.
Split limits for daytime and night time	Consider whether there is value in separate noise limits for daytime and night-time periods. Different limits for day and night can theoretically have the benefit of enhanced amenity protection or wind farm operational flexibility, depending and what limit values are selected. However, in practical terms, a common limit for day and night may provide a net benefit of practicality 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).
Cumulative noise limits	Provide direct discussion of potential cumulative noise impacts from more than one wind farm and 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.
Reverse sensitivity/ Encroachment	Consider provision of additional guidance about reverse sensitivity and encroachment, such as can occur when residential dwellings or other noise sensitive land uses are proposed in proximity to an approved or operating wind farm. In some jurisdictions, residential developments are not permitted within a certain predicted noise level contour of the wind farm. This is comparable to the mechanisms often employed to prevent encroachment around other types of noise-generating infrastructure. The suitability of such methods depends on the planning framework employed 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.

* Property owners who are part of or neighbouring 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

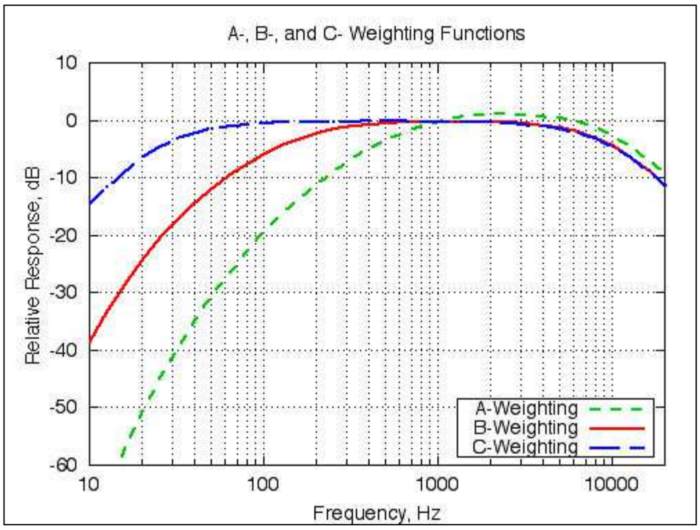
Ambient — The ambient noise level is the noise level measured in the absence of the intrusive noise or the noise requiring control. Ambient noise levels are frequently measured to determine the situation prior to the addition of a new noise source.

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. $dB = 20 \times \log(P/P_r)$

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

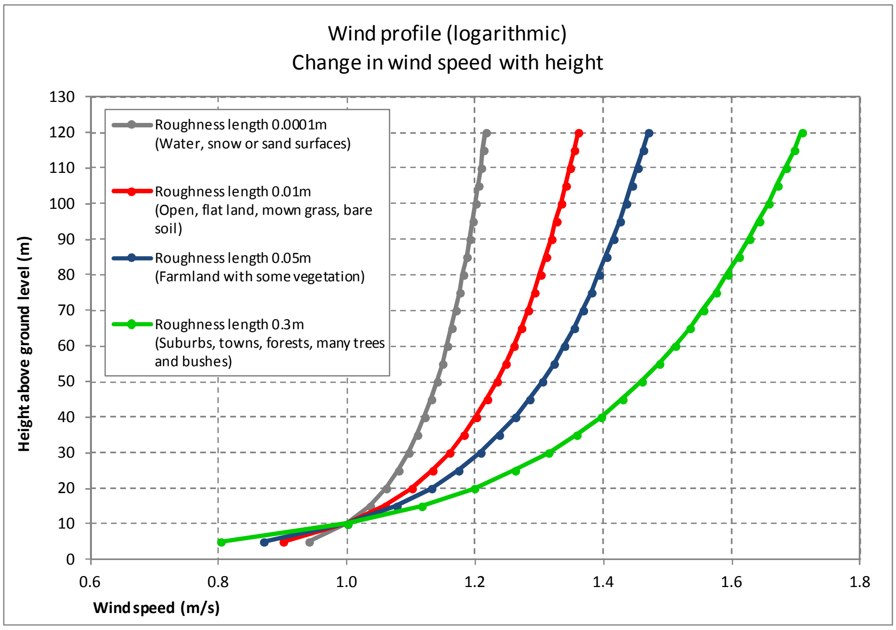


Figure 18: Example wind profiles

[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.

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[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

Table 16: Summary of wind farm noise limits across jurisdictions

Jurisdiction		Noise limit category[201]	Receiver Land use description or land zoning where noise limit applies	Relative limit	Absolute limit	Period[202]	Comment
Australia	South Australia[203]	F3	All except 'rural living'	+5 dB, L_{A90}	40 dBA	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.
			Rural living[204]	+5 dB, L_{A90}	35 dBA	All	
	Victoria[205]	F3	All except 'high amenity areas'	+5 dB, L_{A90}	40 dBA	All	
			High amenity areas[206]	+5 dB, L_{A90}	35 dBA	Night	
Canada	Ontario[207]	F3	Class 3 Area[208]	+7 dB, L_{A90}	40 dB L_{Aeq}	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.*
			Class 2 Area[209]	+7 dB, L_{A90}	40 dB L_{Aeq}	All	
			Class 1 Area[210]	+7 dB, L_{A90}	45 dB L_{Aeq}	All	
	Quebec[211]	F3	Single family residential properties in rural areas[212]	Equal to background level, L_{Aeq}	40 dB L_{Aeq}	Night	
					45 dB L_{Aeq}	Day	
	Alberta [213]	F3	Category 1[214]	+5 dB, L_{Aeq}	40-46 dB L_{Aeq}	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.
					50-56 dB L_{Aeq}	Day	
		F3	Category 2[215]	+5 dB, L_{Aeq}	45-51 dB L_{Aeq}	Night	
					55-61 dB L_{Aeq}	Day	
		F3	Category 3[216]	+5 dB, L_{Aeq}	50-56 dB L_{Aeq}	Night	
					60-66 dB L_{Aeq}	Day	

201 Refer to Table 14 in Appendix E for category designations.

202 Typically Day period span 0600-0700 hrs through until 2200-2300hrs. Night periods typically span from 2200-2300hrs until 0600-0700hrs.

203 SAG2009

204 Described in SAG2009 as a "*rural–residential 'lifestyle' area intended to have a relatively quiet amenity"*

205 NZS6808:2010

206 Described in NZS6808:2010 as locations "*where a plan (e.g., local planning instrument) promotes a higher degree of protection of amenity related to the sound environment of a particular area"*

207 ONG2008

208 Described as " *a rural area with an acoustical environment that is dominated by natural sounds having little or no road traffic"*

209 Described as " *an area with an acoustical environment that has qualities representative of both Class 1 and Class 3 Areas, and in which a low ambient sound level, normally occurring only between 23:00 and 07:00 hours in Class 1 Areas, will typically be realizedas early as 19:00 hours.*

210 Described as "*an area with an acoustical environment typical of a major population centre, where the background noise is dominated by the urban hum*

211 Government of Quebec 2006, *Note d'instruction 98-01*

212 Translation from French

213 Energy Resources Conservation Board (Province of Alberta, Canada) 2007, *Directive 038 Noise Control*

214 Described in Directive 038 Noise Control *as "dwelling units more than 500 m from heavily travelled roads and/or rail lines and not subject to frequent aircraft flyovers"*

215 Described in Directive 038 Noise Control *as "dwelling units more than 30 m but less than 500 m from heavily travelled roads"*

216 Described in Directive 038 Noise Control *as "dwelling units less than 30 m from heavily travelled roads and/or rail lines and/or subject to frequent aircraft flyovers"*

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			Rural living[204]	+5 dB, L_{A90}	35 dBA	All	
	Victoria[205]	F3	All except 'high amenity areas'	+5 dB, L_{A90}	40 dBA	All	
			High amenity areas[206]	+5 dB, L_{A90}	35 dBA	Night	
Canada	Ontario[207]	F3	Class 3 Area[208]	+7 dB, L_{A90}	40 dB L_{Aeq}	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.*
			Class 2 Area[209]	+7 dB, L_{A90}	40 dB L_{Aeq}	All	
			Class 1 Area[210]	+7 dB, L_{A90}	45 dB L_{Aeq}	All	
	Quebec[211]	F3	Single family residential properties in rural areas[212]	Equal to background level, L_{Aeq}	40 dB L_{Aeq}	Night	
					45 dB L_{Aeq}	Day	
	Alberta[213]	F3	Category 1[214]	+5 dB, L_{Aeq}	40-46 dB L_{Aeq}	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.
					50-56 dB L_{Aeq}	Day	
		F3	Category 2[215]	+5 dB, L_{Aeq}	45-51 dB L_{Aeq}	Night	
					55-61 dB L_{Aeq}	Day	
		F3	Category 3[216]	+5 dB, L_{Aeq}	50-56 dB L_{Aeq}	Night	
					60-66 dB L_{Aeq}	Day	

[201] Refer to Table 14 in Appendix E for category designations.

[202] Typically Day period span 0600-0700 hrs through until 2200-2300hrs. Night periods typically span from 2200-2300hrs until 0600-0700hrs.

[203] SAG2009

[204] Described in SAG2009 as a "*rural–residential 'lifestyle' area intended to have a relatively quiet amenity*"

[205] NZS6808:2010

[206] Described in NZS6808:2010 as locations "*where a plan (e.g., local planning instrument) promotes a higher degree of protection of amenity related to the sound environment of a particular area*"

[207] ONG2008

[208] Described as " *a rural area with an acoustical environment that is dominated by natural sounds having little or no road traffic*"

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[210] Described as "*an area with an acoustical environment typical of a major population centre, where the background noise is dominated by the urban hum*

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[212] Translation from French

[213] Energy Resources Conservation Board (Province of Alberta, Canada) 2007, *Directive 038 Noise Control*

[214] Described in Directive 038 Noise Control *as "dwelling units more than 500 m from heavily travelled roads and/or rail lines and not subject to frequent aircraft flyovers"*

[215] Described in Directive 038 Noise Control *as "dwelling units more than 30 m but less than 500 m from heavily travelled roads"*

[216] Described in Directive 038 Noise Control *as "dwelling units less than 30 m from heavily travelled roads and/or rail lines and/or subject to frequent aircraft flyovers"*

Jurisdiction	Noise limit category[201]	Receiver Land use description or land zoning where noise limit applies	Relative limit	Absolute limit	Period[202]	Comment
Denmark[217]	F1	Dwellings in open countryside	N/A	42 dB L_{Aeq}	All	Limit applies at 6m/s at 10m AGL
				44 dB L_{Aeq}	All	Limit applies at 8m/s at 10m AGL
		Noise-sensitive land use[218]	N/A	37 dB L_{Aeq}	All	Limit applies at 6m/s at 10m AGL
				39 dB L_{Aeq}	All	Limit applies at 8m/s at 10m AGL
France[219]	F3	Inside dwellings	+5-7 dB	25 dBA	All	The relative thresholds inside dwellings apply across a range of single octave bands from 125 Hz to 4000 Hz.
		Outside dwellings	+5 dB(A)	30 dBA	Day	A minimum setback distance of 500m also applies[220].
			+3 dB(A)	30 dBA	Night	
Germany[221]	F1	Spa areas, for hospitals and nursing homes	N/A	45 dB L_{Aeq}	Day	Germany does not have wind farm specific noise limit, and legislative noise limits for general noise sources apply.
				35 dB L_{Aeq}	Night	Peak limits also apply and the legislation states:
		Purely residential areas	N/A	50 dB L_{Aeq}	Day	*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).*
				35 dB L_{Aeq}	Night	
		General residential areas and small residential estate areas	N/A	55 dB L_{Aeq}	Day	
				40 dB L_{Aeq}	Night	
		Core areas, village areas and mixed-use Zones	N/A	60 dB L_{Aeq}	Day	
				45 dB L_{Aeq}	Night	
		Commercial zones	N/A	65 dB L_{Aeq}	Day	
				50 dB L_{Aeq}	Night	
		Industrial areas	N/A	70 dB L_{Aeq}	All	
Ireland[222]	F3	All except low noise environments	+5 dB, $L_{A90(10min)}$	45 $L_{A90(10min)}$	All	Section 3.0 for further details.
		Low noise environments[223]	+5 dB, $L_{A90(10min)}$	35-40 $L_{A90(10min)}$	All	

[217] DSO1284

[218] Described in DSO1284 as *"Areas that are actually used for or designated in district plans or town planning regulations for residential, institutional, holiday home, camping or allotment purposes or areas designated in district plans or town planning regulations for noise-sensitive recreational activities."*

[219] See: (Bowdler & Leventhall, Wind turbine noise, 2011)

[220] See: (Haugen, 2011), p. 12.

[221] Germany, *Sixth General Administrative Provision to the Federal Immission Control Act (Technical Instructions on Noise Abatement - TA Lärm)*, Joint Ministerial Gazette (GMBl) No. 26/1998, 26 August 1998, p. 503.

[222] WEDG06

[223] Described in WEDG06 as "*...where background noise is less than 30dBA*"

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
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
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.

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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

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