Wind farms environmental noise guidelines

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Disclaimer

This publication is a guide only and does not necessarily provide adequate information in relation to every situation. This publication seeks to explain your possible obligations in a helpful and accessible way. In doing so, however, some detail may not be captured. It is important, therefore, that you seek information from the EPA itself regarding your possible obligations and, where appropriate, that you seek your own legal advice.

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1 Introduction

This document aims to help developers, planning and enforcement authorities, government agencies, acoustic engineers and the broader community assess environmental noise impacts from wind farms.

The core objective of the guidelines is to balance the advantages of developing wind energy projects in South Australia with protecting the amenity of the surrounding community from adverse noise impacts.

The Environment Protection Authority (EPA) has undertaken a minor technical review of the guidelines to reflect updates in international standards and multiple research works. In addition, the EPA has taken into consideration the documents listed in the bibliography.

The *Environment Protection (Noise) Policy 2007* (Noise Policy) excludes wind farm noise from its provisions and recognises the fact that developments are primarily intended for rural areas where natural background noise may be very low. Furthermore, noise from wind turbines have unique characteristics that can be present for a large portion of the day.

Shaded boxes throughout this document contain explanatory comments.

General environmental duty

The *Environment Protection Act 1993* (EP Act) requires a duty of care for the environment. This is specified under section 25 states:

> A person must not undertake an activity that pollutes, or might pollute, the environment unless the person takes all reasonable and practicable measures to prevent or minimise any resulting environmental harm.

Guidelines published by the EPA indicate the standard of care likely to be required to secure compliance with the general environmental duty. They have the advantage of flexibility and can be adapted to a range of circumstances.

2 Noise criteria

The general approach in setting noise criteria for new developments is to require compliance with a base noise level. This base noise level is typically set at 5dB(A)[1] lower than the level considered to reflect the amenity of the receiving environment. Designing new developments at a lower level accounts for the cumulative effect of noise from other similar development and for the increased sensitivity of receivers to a new noise source.

A unique characteristic of wind farms is the noise level from each wind turbine generator (WTG) increases with the wind speed at the site. As an offset, the background noise also generally increases under these conditions and can mask noise from the WTG.

Comparisons with a base noise level alone will not be sufficient to indicate the potential impact of a wind farm. A wind farm could comply with this base level at lower wind speeds but exceed this level when the wind speed rises.

Most international and interstate jurisdictions (see examples below) set a base noise level for low wind speeds. Many regulations also ensure that the wind farm noise does not exceed the background noise by more than 5dB(A) as the wind speed increases.

This general approach, adopted in the guidelines, recognises the unique noise-generating characteristics of wind turbines and the particular ambient noise environments of most sites.

Other jurisdictions

Wind turbines and wind farms have been operating in Denmark for over 35 years. Base noise levels are set at 37dB(A) and 39dB(A) for noise sensitive land uses at wind speeds V10m = 6m/s and V10m = 8m/s respectively. The limits are increased for other land uses up to 42dB(A) and 44dB(A) depending on the wind speed.

The New Zealand Standard NZS 6808 sets the predicted base noise level (L_{Aeq}) at 40dB(A). Within Australia, the base noise criteria in Victoria is consistent with these guidelines. New South Wales notes higher density rural residential living and only applies the 'rural living' criterion for receivers. Queensland applies the 'rural living' criterion during night time hours. These jurisdictions also allow for alternative criterion based on background plus 5dB(A).

The World Health Organization (WHO) *Environmental noise guidelines for the European region* (2018) conditionally recommends reducing noise levels produced by wind turbines to below 45dB L_{den}.

Review of these practices shows that noise criteria recommended in the guidelines are among the strictest in the world.

Most wind farms sites are within or next to areas where low ambient noise levels are a significant component of that area's amenity. These might include rural living zones or zones that are not intended to be subject to any other significant ambient noise sources from adjacent premises.

Equally, some rural zones are intended for rural industry or primary production/general farming where the amenity of the area may include noise from industrial sources. The criteria in these guidelines have been established to address such scenarios and have been developed in accordance with the objects of the EP Act.

Where the wind farm sites are within or next to areas where more intensive activity is expected, the base noise level may also be increased to be commensurate with the amenity of that area. It is recommended that the developer discuss such a scenario with the EPA and the relevant planning authority.

2.1 Determining wind farm operating criteria

Part 7 of the Noise Policy refers to guidelines to establish noise limits from a range of noise sources including wind farms. A wind farm typically comprises auxiliary structures such as electrical substations, switches and service yards. These

[1] See Glossary for definition of technical and acoustical terms

additional noise sources constitute an integral part of the development and may contribute toward the environmental impact from the development. Cumulative impact from wind turbines and other components of a wind farm should be predicted and assessed to compare with applicable noise limits under the guidelines. To prevent adverse impacts from the WTG noise, the noise source level should also be compared to the corresponding background noise at the relevant receiver.

All noise criteria within the guidelines refer to noise levels measured externally.

2.2 Noise criteria – new wind farm development

The predicted equivalent noise level ($L_{Aeq,10}$), adjusted for tonality in accordance with these guidelines, should not exceed:

- 35dB(A) at relevant receivers in localities[2] which are primarily intended for rural living*

OR

- 40dB(A) at relevant receivers in localities in other zones

OR

- the background noise ($L_{A90,10}$) by more than 5dB(A).

whichever is the greater, at all relevant receivers for wind speeds from cut-in to rated power of the WTG and each integer wind speed in between. These criteria apply for both day and night time hours, but have been based on conservative night time levels.

The background noise should be as determined by the data collection and wind speed bin analysis procedure recommended under these guidelines (section 3). It should be read from the resultant graph at the relevant integer wind speed. Compliance with the noise criteria should also be demonstrated for approved developments in the zones adjacent to the wind farm.

***Rural living**

A rural living zone is for an area intended as rural-residential 'lifestyle' with high amenity requirements. This area should not be used for primary production purposes other than to produce food, crops or keep animals solely for the occupier's own use, consumption and/or enjoyment. It is expected that these zones have amenity that is quieter than urban residential and land uses that promote primary production.

If there is uncertainty a zone is to be classified as rural living, the EPA will determine this based on the desired and performance outcomes as laid out in the *Planning and Design Code*.

WHO conditional recommendations

The *Environmental noise guidelines for the European region* (WHO 2018) includes guidelines for noise from wind farms, and a conditional recommendation to reduce noise levels produced by wind turbines below 45dB L_{den}.
The WHO recommendations are conditional because of an insufficient number of high-quality studies available on the impacts of wind farm noise. It further concluded that more robust studies are required to support recommendations.

WHO adopts the L_{den} criterion, which consists of averaged hourly levels, in a defined way over a 24-hour period. The $L_{Aeq,10}$ criterion used in the South Australian guidelines and other Australian jurisdictions, averages over a shorter 10-minute period. As such, $L_{Aeq,10}$ is considered a more appropriate measure to reflect immediate impact on residents and adopt for compliance checking.

[2] Refer to Glossary for definition of 'locality'

2.3 Agreements with wind farm developers

Wind farm developers commonly enter into agreements with the owners of private land suitable for a wind farm site. The agreement provides the developer with the appropriate siting and generally awards the landowner with a level of compensation and diversity in their income stream.

The criteria have been developed to minimise the impact on the amenity of premises that do not have an agreement with wind farm developers. Notwithstanding this, the EPA cannot ignore noise impacts on the basis that an agreement has been made between the developer and the landowner. Developers cannot absolve themselves of their obligations under the EP Act by entering into an agreement with a landowner.

If it can be demonstrated that a development is having an 'adverse effect on an amenity value of an area that … unreasonably interferes with the enjoyment of the area', then appropriate action can be taken under the EP Act.

The existence of an agreement will affect the consideration of whether the interference is unreasonable in a given situation. It is unlikely that there will be unreasonable interference if:

- a formal agreement is documented between the parties
- the agreement clearly outlines to the landowner the expected impact of the noise from the wind farm and its effect upon the landowner's amenity
- the likely impact of exposure will not result in adverse health impacts (eg the level does not result in sleep disturbance or provides sufficient amenity outdoors).

In some cases it may be useful to demonstrate audio records of a wind farm noise at the expected levels to potential project stakeholders. It should be explained that they can be affected by this noise for prolonged periods throughout the operation of a wind farm.

Design guidelines for stakeholders

A risk associated with relying on such agreements still remains where the criteria in these guidelines are exceeded. This is because an interpretation of 'unreasonable' is required in any future assessment of the impact of wind farm noise initiated by a complaint from the landowner (or future landowners).

WHO guidelines for community noise (1999) recommend a 30dB(A) indoor limit to prevent negative effects on sleep. The indicative noise criteria as set out in Table 2 of the Noise Policy less 5dB external day time limit of the land use category (after any adjustments for tonality) can be used as a baseline noise level to determine sufficient level of amenity for stakeholders, in addition to the background plus 5dB(A) limits. This will bring the recommended levels in line with other new developments in accordance with the Noise Policy as long as the internal noise levels of 30dB(A) are met for the stakeholder. These base criteria can be considered as benchmarks in deciding on the sufficient level of amenity for commercial stakeholders.

2.4 Staged development

The procedure and criteria presented in these guidelines are for greenfield sites, but a wind farm may be developed over a number of separate stages.

A previous stage of the wind farm that is installed and operating may raise the background noise level at the relevant receivers by up to 5dB(A).

Any subsequent stage in the development of the wind farm site should meet the criteria using the background noise levels as they existed prior to the wind farm. The noise generated by existing WTGs from a previous stage should not be considered as part of the background noise in determining criteria for subsequent stages.

The layout for a subsequent expansion of a wind farm may overlap over the original site. If this new stage of the wind farm belongs to the same owner, it is recommended that the cumulative impact from the entire wind farm be assessed to meet the noise criteria as set in the guidelines (section 2.2).

2.5 Cumulative development

Separate wind farm developments in close proximity to each other may impact on the same relevant receiver.

As with a 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 before the original wind farm site development. The noise generated by existing WTGs from another wind farm should not be considered as part of the background noise in determining criteria for subsequent development.

On an occasion where it is not possible to determine the background noise levels as they existed before the original wind farm development, the background noise criteria should not be utilised for the purposes of predicting the impact of the proposed new wind farm.

2.6 Infrasound and low frequency noise

Sensitive receivers residing in the vicinity of a wind farm may attribute excessive infrasound or low frequency noise from a wind farm as a reason for implied adverse health effects. Medical research dedicated to infrasound found that there are no proven physiological effects at infrasound levels below the perception threshold. There is no evidence that modern wind turbines generate infrasound at levels above the infrasound perception threshold. The EPA comparative study on infrasound (2013) and other investigations indicated that a listener has a greater risk of exposure to higher infrasound levels in other environments than in the vicinity of a wind farm.

Research on low frequency noise from wind turbines in wind turbine controlled environments show that A-weighted SPL magnitudes are well correlated with C-weighted SPL, which is used often for monitoring low frequency noise.

The A-weighted SPL is an appropriate metric to assess wind farm noise. Low frequency noise may be a significant part of the natural background in areas adjacent to wind farms. It is not expected that a listener will experience excessive low frequency noise due to operation of a wind farm if the development is designed to meet the noise criteria as set out in the guidelines (section 2.2).

Perception of low frequency noise may be exacerbated by particular environmental conditions, acoustic properties of dwellings or very low background levels. These situations are not expected to occur for substantial periods during a year. The introduction of another noise criteria to address these rare situations will not be impracticable.

Further information

Typically, infrasound is assessed and reported in accordance with requirements in the International Standard ISO 7196. The standard does not clearly indicate the infrasound perception threshold. However, it states that human perception issues are unlikely if the levels do not exceed 90dB(G). Some research suggests a conservative human perception threshold of 85dB(G) to account for variations in sensitivity of human hearing. Analysis of available data did not show that infrasound emitted by wind turbines exceeds these limits, even if noise is measured close to wind turbines. Natural infrasonic background in the area may be higher than levels associated with the operation of the wind farms.

Low frequency noise may be generated by wind and other ambient noise sources in the area. Some regulations envisage prediction of low frequency noise inside noise affected premises. However, accurate assessment of low frequency noise inside the dwellings is not feasible in many cases. Noise measurements may be affected by the operation of home appliances and residents' activities. It is unlikely that a wind farm will be a source of excessive low frequency noise if designed to meet the strict noise criteria of these guidelines. New South Wales regulation notes that low frequency noise from wind farms should not exceed 60dB(C).

3 Meeting the criteria

This section describes the steps to assess whether wind farm noise impacting on receivers at relevant locations comply with the criteria of the guidelines.

Background noise is measured at relevant receiver locations over continuous 10-minute intervals and particularly over the range of wind speeds at which the WTGs operate. The data must adequately represent conditions at the site and cover approximately 2,000 intervals to provide a sufficient data set for establishing the background-based noise criteria.

Wind speed is measured in intervals that correlate with the background noise measurements. The wind speed data, together with the manufacturer's noise data for the WTG and adopting a suitable model, are then used to calculate noise levels at each integer wind speed from cut-in to rated power, at relevant receiver locations.

The correlated wind speed and background noise data should be post-processed in accordance with section 3.4. The calculated magnitudes are then used in conjunction with the predicted noise levels to assess whether the wind farm will meet the criteria of the guidelines. They also may be further utilised for compliance checking procedures.

3.1 Background noise

What is background noise

Background noise is the 'lull' in the ambient noise environment.

Intermittent noise events such as from flying aircraft, barking dogs, mobile farm machinery and the occasional vehicle travelling along a nearby road are all part of the ambient noise environment but would not be considered part of the background noise unless they were present for at least 90% of the time.

Why is background noise important

It is important to understand the noise environment of the proposed area before the development of a wind farm to best understand its impacts. Existing background noise can mask the noise of new developments such as a wind farm and the level of masking is a critical factor in assessing the impact of a wind farm.

Wind generated noise can provide a masking effect, particularly as it has similar characteristics to wind farm generated noise.

Background noise measurement locations

Background noise measurements should be carried out at locations that are relevant for assessing the impact of WTG noise on nearby premises (relevant receivers).

Relevant receiver locations are premises:

- in which someone resides or has a valid development approval to build a residential dwelling
- at which the predicted noise level exceeds the base noise level for the area [35 or 40dB(A)] for wind speeds up to the speed of the rated power
- that are representative of the worst-case situation when considering the range of premises, eg a house located among a group of nearby houses within a residential zone.

There may be a substantial number of relevant receivers surrounding an existing or proposed wind farm development. Performing background measurements at each location may not be practicable in such cases. Data acquisition can be carried out at selected locations representative of groups of dwellings with apparent similarity in background conditions.

Further information

1 A proposed wind farm site with a zone in its vicinity that is primarily for residential land use and is yet to be fully developed should be discussed with the relevant planning authority and the EPA.

2 These locations will likely be considered relevant receivers, and background noise measurements may be necessary at the zone boundary.

3 Background noise may increase at a greater rate than noise from WTGs at high wind speeds. In this case the wind farm noise at higher wind speeds is expected to be masked by the increasing background noise. The impact will not be adverse and further investigation is not required.

4 The worst-case situation may not always be the closest receiver to the wind farm site. The closest receiver should always be a measurement position but other locations where the background noise environment may differ due to prevailing weather patterns and/or local topography should also be included as relevant receivers.

5 Different possible background noise environments at receivers around a wind farm site should also be discussed with the EPA.

Background noise measurement position

All measurements should be made outdoors. The microphone should be positioned 1.2–1.5 m above the ground and at least 5 m from any significant reflecting surface (other than the ground).

Measurement location selection

The property boundary of the receiving premises is generally not considered a valid measuring position for large rural properties unless a house is located near the boundary or the zone clearly envisages noise sensitive development at such a location.

In general, any area within 30 m of a house and in the direction of the wind farm would be a valid measuring position. Care should be taken to ensure that the area is not screened from the wind farm by a house, shelter or other elements.

Background noise levels can be significantly affected by local conditions, such as the presence of trees and domestic machines nearby. Photographs from multiple directions are to be taken showing the noise measurement positions and associated surroundings, such as buildings, trees and topography. This will ensure that no significant physical changes have been made to the locations since the time of the initial background noise measurements.

Care must be taken when using a measurement position to represent other receivers in the locality. Local conditions such as trees, grass and shrubs should be representative of the area that is being assessed. Background noise measurements should represent the natural background in the immediate vicinity of the relevant receiver; extraneous noise sources (water pumps, air conditioning units, electrical transformers, etc) should not influence the data. Where the selection of the representative point is not straightforward, a conservative approach should be taken by placing the microphone in the quieter location.

Data collection and post-processing data

Equipment

Background noise levels should be collected for continuous 10-minute time intervals synchronised with the wind speed measurements. The data acquisition should be performed using sound level meters or loggers of at least Class 2 certification in accordance with Standard AS IEC–61672. The lower limit of the instrument measurement range must be chosen to provide accurate measurements which might be limited by the noise floor of the data acquisition device.

The meters or loggers must be calibrated on site immediately before and after any measurement period using a calibrator which is suitable for the class of the instrument and complies with AS IEC–60942.

The data acquisition instruments should have a valid calibration within a 24-month period from the last calibration by a NATA accredited laboratory.

Wind

Microphones should be equipped with windshields in accordance with the microphone manufacturer's instructions, and the protection should be sufficient to ensure the noise level threshold of the monitoring equipment does not adversely affect the data used in the analysis. If microphones cannot be appropriately protected, the affected data should not be considered for processing.

As part of the development application, developers should confirm that the reported noise levels are not influenced by high wind speed across the microphone. It is permitted to report noise measurement data at relatively high wind speeds if they have been taken with special windshields. The technical performance proving the accuracy of these windshields should be provided before being utilised for data collection.

Affected data should be identified by monitoring statistical wind speed (that is equalled or exceeded for 90% of the measurement time) at the noise measurement position (1.2−1.5 m above ground level at the relevant receiver) over 10-minute intervals that correspond with the noise level measurement intervals. Not all wind monitoring instruments can provide the wind speed statistical parameters. Statistical wind speed for 10-minute intervals can be derived from wind speed data acquired at a higher time resolution. Reporting of the average wind speed to identify validity of the noise measurements is permissible in case of limited functionality of wind speed measurement instruments. Accuracy of the wind speed measurements should be ±0.5m/s or better. Attention should be paid to noise generated by the wind speed sensors. It is recommended that wind sensors utilised for this purpose do not contain moving parts in order to have less potential for generating extraneous noise.

If wind data from a single wind speed monitoring location is not representative for all noise monitoring locations, wind measurements should be undertaken separately at each location.

This information would then be compared with both the collected data for that interval and the manufacturer's specifications for the windshield performance under those conditions:

- Where manufacturers' specifications indicate that wind-induced noise on the microphone is 10dB(A) or more below the background noise, the data is acceptable.
- Where manufacturers' specifications indicate that wind-induced noise on the microphone is between 10dB(A) and 4dB(A) below the background noise, the affected data may be retained with the wind induced noise subtracted from the measured background.
- Where manufacturers' specifications indicate that wind-induced noise on the microphone is within 4dB(A) of the affected data, the affected data should be discarded and the data should be re-analysed. If the procedure causes SPL magnitude in the wind speed bins (refer to section 3.4) to change significantly, then additional data will need to be collected with an improved windshield.

If it is not possible to obtain manufacturers' data for the windshield used, then data acquired with a typical 90-mm wind shield at local wind speeds above 5 m/s should be discarded.

Rain

Rain periods during monitoring may also adversely affect the collected data. If rain was recorded on the site or in the vicinity during the collection period, the affected data must not be used in the analysis.

The nearest weather station might not provide a sufficient indication of localised conditions in remote areas. A simple method might record rain using a local gauge or collection method that is regularly checked, and all data collected during rain periods are to be discarded. Many modern weather sensors allow for precipitation measurements and their use during noise monitoring programs is advisable.

Data

Data not adversely affected by the effects of wind, rain or extraneous noise sources should be collected for a sufficient period to cover the range of wind speeds and directions generally expected at the wind farm site.

Particular emphasis should be placed on collecting background noise data corresponding to the operating wind speed range of the WTGs.

Sufficient data is considered to be approximately 2,000 measurement intervals (or the equivalent of two weeks' worth of data) where at least 500 points are collected for the worst-case wind direction (refer to section 4.1). If it appears to be impractical to collect 500 valid data points under the worst-case wind direction conditions, the situation should be discussed with the EPA.

Insufficient data due to external impacts

Compliance checking will require the similar noise data collection process to be repeated when the wind farm is operational (section 4).

Background noise varies naturally throughout the year, with different prevailing wind directions, foliage on trees and atmospheric conditions. It is expected that environmental studies such as weather statistics would have been undertaken at wind farm development sites. It is advised that such data be utilised to inform the best time for background noise monitoring to be undertaken to collect the required amount of data. If collection of the noise statistics under the worst-case wind direction requires an unreasonably long monitoring time, less data that still provides a robust correlation between the background noise and wind speed may be acceptable if sufficient evidence is provided to support this claim.

A community may be concerned that measurements undertaken as described in the guidelines may not be representative of noise impacts during other periods throughout the year. The compliance checking procedure may be required to be repeated where a valid concern exists to cover such shortcomings.

The developer must collect representative noise data as best possible. Non-compliance may result in one or more WTGs being stopped or de-rated under certain conditions in order to meet the guidelines.

3.2 Wind speed measurements

Manufacturers of wind turbines publish noise level data for their machines derived through a comprehensive international measurement standard.

Generally the noise level generated by a wind turbine correlates with wind speed at the hub height. Data should be provided for a range of wind speeds from cut-in to the speed of the rated power and each integer wind speed in between.

Wind speeds (in m/s) are to be assessed at the WTG hub height. For the purpose of this guidelines, reporting wind speeds at other heights is permitted where the wind speed at the hub height can accurately be calculated (refer to 'Measurement height' below). The noise level data for each WTG is used as the basis for predicting the total noise level from a wind farm.

Wind speed at the wind farm site and background noise at the relevant receiver must be correlated for comparison. Wind speed measurements must be made in 10-minute intervals to correlate/synchronise with the background noise data collection.

Measurement height

A developer will often measure wind speed at different heights to determine whether wind conditions at the site are suitable for an wind farm development. It may be acceptable to convert the results from a different measurement height (for example meteorological tower sensors) to the hub height provided the wind shear model used to do this is clearly stated and accepted by the EPA. Atmospheric stability conditions should be taken into account to assure accurate conversion of the data from the different heights.

All wind speeds referred to in these guidelines and within any development application submitted to a planning authority should be expressed at the WTG hub height.

All predicted and measured noise levels should be based on noise level data derived from wind speed assessments referring to the WTG hub height.

Measurement location

Preferably, the same location should be used for measuring wind speed and direction for all of the following procedures:

- background noise measurements
- noise predictions
- compliance checking.

The wind speed measurement location at the wind farm site should not:

- be significantly affected by the operation of the WTGs in their final location
- provide lower wind speed results than other locations on the wind farm site, where those locations will house WTGs that affect the noise level at a relevant receiver
- be less representative for noise propagation from the wind farm than other available locations, ie wind sensor from more distant locations should not be referenced instead of wind speed measurements performed at closer location.

For large or topographically diverse wind farm sites, the suitability of the wind speed measurement location may need to be confirmed as part of the development assessment process.

Wind measurements at the WTG nearest to the relevant receiver should be used for compliance/complaints checking procedure if it is not possible to perform measurements at the same location as used for the background noise data acquisition. Evidence that the wind speed and direction sensor is certified for the accurate determination of wind parameters is to be supplied as a part of the application. Accuracy of the wind speed measurements should be ±0.5 m/s, and wind direction measurements ±3º or better.

3.3 Noise level prediction for development applications

The noise level associated with the wind farm should be predicted at all locations identified as relevant receivers under the guidelines, for wind speeds from cut-in speed to the speed of the rated power and each integer speed in between. All noise sources associated with the wind farm operation (eg substations, switch yards) should be taken into account and results of the prediction compared with the noise criteria (section 2.2).

Data during wind speeds outside rated power

WTG manufacturers generally do not test or extrapolate test results above winds speeds of rated power.

The measurement of noise levels under high wind speeds (used to determine the sound power level of a turbine model) is a technically complex task.

Noise induced on the microphone due to air and wind shield interaction, as well as the general background noise, may be substantial at higher wind speeds above the rated power. As a result, the overall noise measurements undertaken during these conditions may not be representative of contribution from the wind farm.

It is unlikely that adverse impacts from the wind farm will be expected at these higher wind speeds if the wind farm is shown to comply with the noise level criteria up to rated power of the WTG.

Propagation model

A suitable model must be selected (or developed) to predict the worst-case noise level at all relevant receivers. Many widely used algorithms are not specifically intended for predicting sound propagation from wind farms and can be used

for a range of environmental noise sources. It is recommended to utilise noise prediction methods in accordance with ISO9613-2 or CONCAWE.

The noise level at the relevant receiver locations should be predicted allowing for the propagating effect of wind (the noise sounds louder downwind than upwind) in the direction from the wind farm to the receiver at each reportable wind speed. This represents a worst-case scenario. In most situations there will be different wind directions and wind speeds between each WTG on a wind farm site and the relevant receiver. These effects will reduce the actual noise level when compared to that predicted under worst-case conditions.

A conservative approach should be used for predicting wind farm noise by calculating noise levels in octave bands from at least 31.5–4,000 Hz, to determine an overall predicted level and using the following inputs:

- atmospheric conditions at 10ºC and 80% humidity
- weather category 6 (if CONCAWE method is utilised)
- hard ground (zero ground factor).

Noise propagation model and parameters as recommended in section 4.3 of the Institute of Acoustics *A Good Practice Guide to the Application of ETSU-R-97 for the Assessment and Rating of Wind Turbine Noise* (May 2013) may be utilised as an alternative to the above input parameters.

If another prediction method and modelling inputs are employed to carrying out the noise level prediction, the details of the model should be clearly stated and the approach discussed with the EPA.

The following information should be provided as part of the development application:

- the propagation model, and any variation of the model, used for the prediction
- an estimate of the model accuracy in dB(A)
- assumptions used as input to the model, including allowances for noise absorption due to air, ground, topographical and wind effects.

Noise levels should be predicted by an acoustic engineer defined for the purposes of the guidelines as an engineer who is eligible for full membership of both the Australian Acoustical Society and the Institution of Engineers Australia.

Sound power data

The sound power level can be regarded as the major acoustic input for the WTG model proposed for the wind farm.

The sound power level data at wind speeds from cut-in speed to the speed of rated power and each integer speed in between should be specified in the development application as determined in accordance with *International Electrotechnical Standard IEC 61400−11*. The sound power level determined in accordance with other relevant standards or procedures might be acceptable for the purpose of the guidelines.

At the time of the development application, the contractual arrangements for a particular WTG model may not have been finalised between the developer and WTG supplier. The wind farm developer must discuss changes to the type, height, location or operation of the WTGs with the relevant planning authority.

Tonality

Tonality is a characteristic that can increase the adverse impact of a given noise source and it can be determined by analysing the frequency spectrum of the wind farm noise.

If tonality is a characteristic of the WTG noise, 5dB(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.

Wind turbine generator selection

Data for acoustic inputs (sound power characteristic) used to predict noise impact are normally included in the development approval conditions. A wind farm developer may consider different options for turbines to be installed on the site before actual construction is undertaken. As such, a final model of turbine may not be finalised during the development application stage of the process. For such cases, the developer may:

- include information and noise impact assessment for a number of possible types of the WTGs to be selected
- present assessment for turbines with the greatest sound power levels
- derive theoretical sound power characteristics in which the development will meet noise criteria in the guidelines, eg solve inverse engineering task for the intended wind farm layout.

The final listed approach allows the developer flexibility in choosing turbines for the development without requiring to resubmit an amended development application.

If the WTG model to be installed differs from that assumed at the time of development application, an updated acoustic report must be provided and approved by the relevant planning authority and the EPA. This updated acoustic report should include the sound power data of the final selected WTG model determined in accordance to the IEC 61400–11 alongside the final configuration layout (if changed) of the wind farm prior to the commencement of construction.

3.4 Data analysis

Background noise and wind speed data

At the completion of the data collection period there should be a minimum of 2,000 pairs of synchronised background noise and wind speed measurements where at least 500 points are collected for the worst-case wind direction (refer to section 4.1). The data should be collected at wind speeds between the cut-in wind speed and the wind speed of rated power.

Data analysis should be performed in wind speed bins. This approach is consistent with the methods as discussed in International Standard IEC 61400–11. The acquired SPLs should be segregated into K wind speed bins:

$$V_k - 0.5 \leq V_i < V_k + 0.5$$

where V_k is an integer for cut-in/rated power wind speed in m/s.

The background SPL (L_B) in the wind speed bin is calculated as the linear average of all background noise data points within the K wind speed bin:

$$L_{B,k} = \frac{1}{M} \sum_{i=1}^{M} L_i$$

where L_i is the background SPL for the i-th measurement and M is the number of background measurement points in the k-th wind speed bin.

Calculation of the background levels, wind farm noise prediction and assessment are not necessary for the cut-in wind speed or speed of the rated power if:

- they lay within the integer wind speed bins

OR

- their magnitudes are less than 0.25 m/s from boundaries of the integer wind speed bins.

Cut-in and/or rated power wind speeds may be close to the boundaries of the integer wind speed bins which also overlap. In this case priority should be given to processing the data in the integer wind speed bins, and the same data points should not be used twice.

Generally background noise demonstrates an incremental trend increasing with wind speed. The graph for each relevant receiver showing the plotted points and calculated background levels should be included in the development application or compliance checking report. An example graph is shown for information (Figure 1).

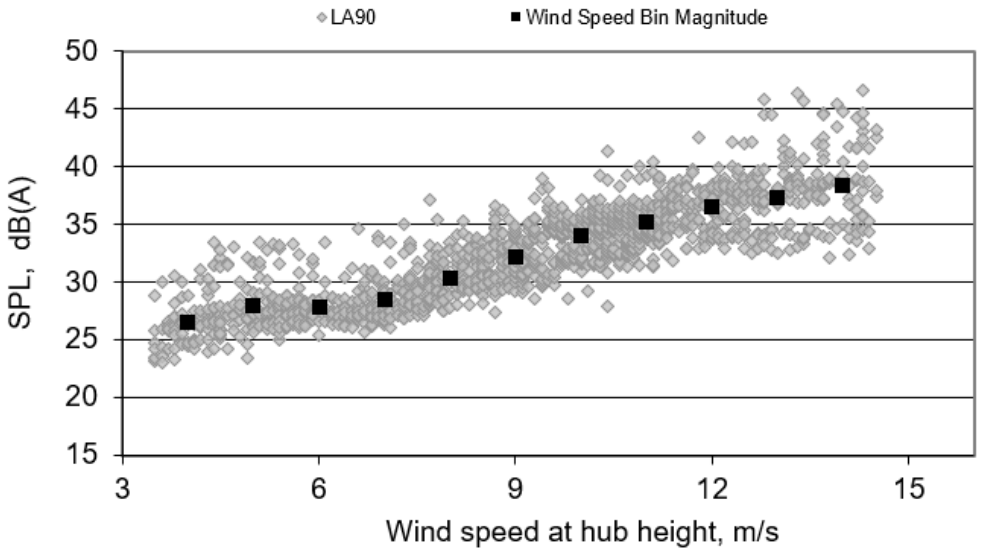

Figure 1 Background noise at the receiver vs wind speed at the wind farm

The predicted noise level should be overlaid on such a graph to determine compliance with the criteria.

Separate processing of the background data for the downwind conditions may be necessary for the compliance checking procedure (refer to the next section).

4 Compliance checking

It is unlikely that worst-case noise propagation conditions utilised for the noise prediction procedures of the guidelines be constant throughout the operation of the wind farm. It is expected that the actual impacts from the wind farm are likely to be less than the predicted impacts.

The prediction process relies on a range of assumptions as inputs, and the procedure given in this section for measuring the actual noise impact is a means of confirming compliance or comparison with the predicted impact.

The measurement of wind farm noise is expected to be difficult due to the masking effect of the ambient noise and its influence on the base noise level descriptor (L_{Aeq}). The background noise descriptor (L_{A90}) is used to mitigate this effect.

Data analysis or further measurement should be chosen depending on results of the noise screening procedure. The flow chart below (Figure 2) provides guidance on compliance checking noise measurements and data reporting.

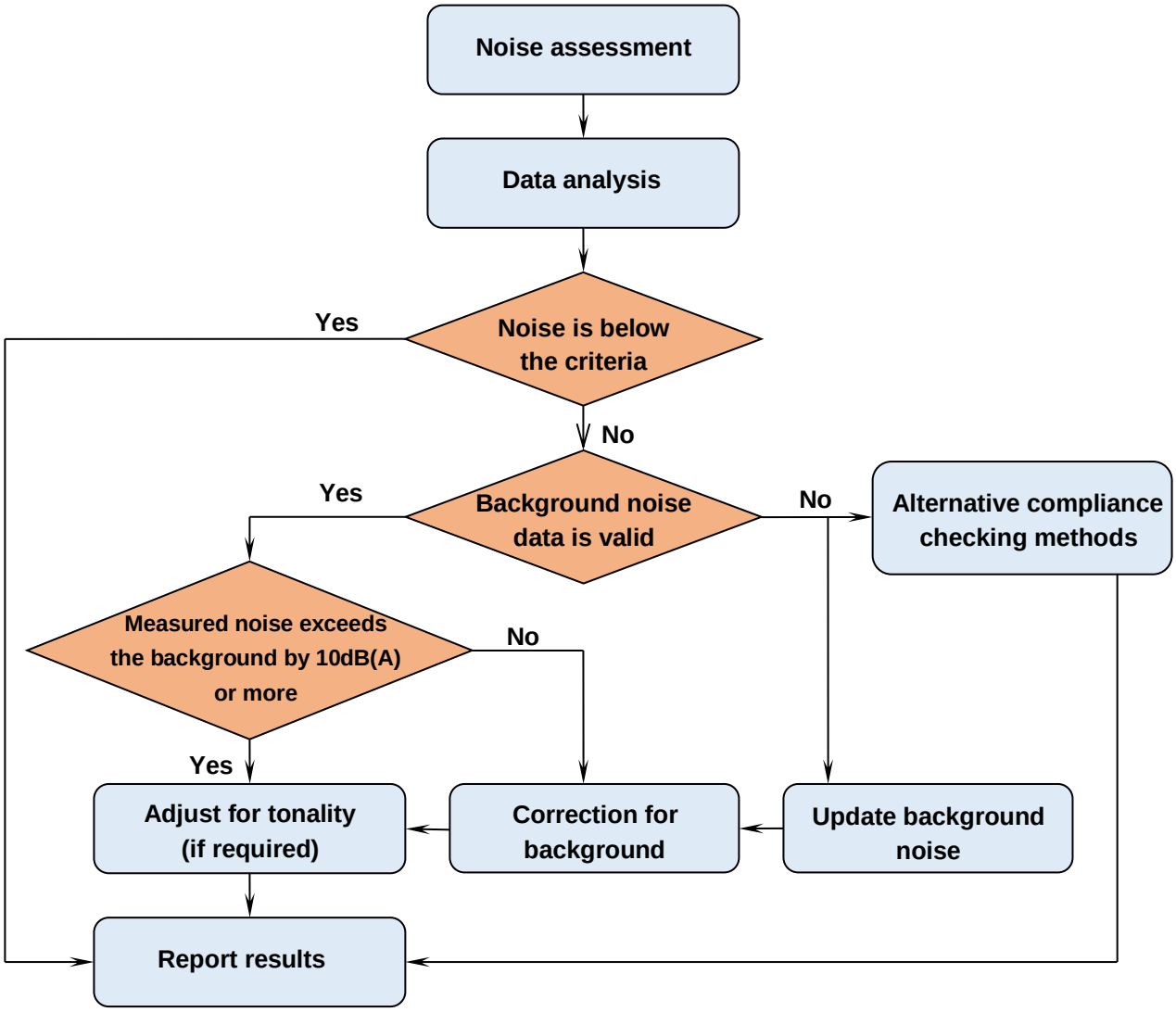

Figure 2 Compliance checking flow chart

4.1 Noise assessment procedure

Wind farm noise screening measurements follow a similar procedure to background noise monitoring (section 3). The $L_{A90,10}$ is measured at relevant receiver locations with the wind farm operating, over continuous 10-minute intervals and over at least the range of wind speeds from the cut-in speed to the speed of the rated power of the WTGs. The data must have at least 2,000 intervals where at least 500 pairs of data correspond to the worst-case wind direction.

Wind speed is measured in accordance with section 3.3 in intervals that correlate with the ambient noise measurements.

Compliance checking should be based on data associated with the worst-case wind direction from the wind farm to the relevant receiver. A wind direction spread of 45° on either side of the direct line between the nearest WTG and the relevant receiver is considered acceptable. This will not always be practical, given prevailing wind conditions. Data measured during known extraneous noise events should not be included in the analysis.

Similarly, cases in which it appears to be impractical to collect 500 valid data points under worst-case wind direction conditions should be discussed with the EPA.

Multiple turbines in close proximity

Choice of the nearest WTG may be ambiguous. As an example, two or more WTGs may be located at similar distance from the receiver and the worst-case scenario for the noise propagation is not obvious. In this case, data post-process should be carried out and reported for each possible worst-case wind direction. It is not expected for this situation to be frequently encountered in practice.

If data adjusted for tonality (if required) is below the criteria, it should be reported as such and no further data analysis or additional noise measurements are required.

4.2 Data analysis of wind farm noise measurements

Data analysis in the wind speed bins should be repeated on the total noise $L_{A90,10}$ and wind speed as described in section 3.4. Data below the cut-in speed should not be included into the array of data points.

A graph or table should be prepared for each relevant receiver indicating combined wind farm and background noise level L_R.

In addition, the graph or table should include information about the criteria previously determined in accordance with the guidelines.

4.3 Criteria

The combined wind farm and background noise level L_R are to be determined from ($L_{A90,\,10}$) data measured in accordance with the compliance checking procedure by the analysis as described in sections 3.3 and 4.2.

The wind farm noise level L_{WF} is to be determined in accordance with one of the procedures described below (if needed). Generally, the data should demonstrate an incremental trend compatible with the sound power characteristic of the WTG in the environment controlled by the wind farm.

In accordance with these guidelines the wind farm noise level (adjusted for tonality if needed) should not exceed:

- 35dB(A) at relevant receivers in localities which are primarily intended for rural living

OR

- 40dB(A) at relevant receivers in localities in other zones

OR

- the background noise ($L_{A90,10}$) by more than 5 dB(A),

whichever is the greater, at all relevant receivers, for wind speeds from cut-in to rated power of the WTG and each integer wind speed in between.

The compliance checking report should contain the graph or table comparing the calculated wind farm noise and the criteria determined in accordance with these guidelines. If the combined wind farm and background noise levels (adjusted for tonality in accordance with section 4.4) are below the criteria, calculation of the wind farm noise level is not necessary. The compliance checking report should contain confirmation that noise criteria based on the previous background measurements (if any) are still valid.

Procedures in sections 4.4 or 4.5 are also waived if the background noise level is at least 10dB(A) below the combined wind farm and background noise level for wind speeds from the cut-in speed to the speed of the rated power. In this case the tonality penalty (if any) should be added directly to the combined noise level L_R and compared with the criteria.

4.4 Correction for background

This is the preferable method for calculation of the wind farm noise $L_{WF,k}$. It should be employed when noise monitoring of the wind farm is done at commissioning or subsequent compliance checking procedures. The method is based on the logarithmic subtraction of the acquired background noise level $L_{B,k}$ (for the worst-case wind direction) from the combined noise level measurements $L_{R,k}$ for each of the wind speed bins:

$$L_{WF,k}=10\ \mathrm{Log}(10^{L_{R,k}/10} - 10^{L_{B,k}/10}).$$

Background levels used here should be derived from the downwind conditions.

The wind farm noise level $L_{WF,k}$ is to be adjusted for tonality in accordance with the guidelines and compared with the criteria. Results of the calculations should be reported in the supplied documentation.

The compliance checking report should contain confirmation that the background noise data based on the previous background measurements (if any) are still valid. Otherwise, the background data acquisition procedure in section 3 should be repeated with WTGs parked or offline with WTG rotor revolutions below 2 rpm. Otherwise alternative compliance checking methods in section 4.5 can be discussed with the EPA.

4.5 Alternative compliance checking procedures

If the method above cannot be used for the compliance checking, alternative techniques may be considered. Advancements in acoustic data acquisition (such as directional noise monitors) represent an opportunity for other methods to separate wind farm noise contribution from other sources.

Attended measurement procedures can be used for compliance measurements at a single receiver. The monitored noise is to be accurately recorded and extraneous noise excluded from the data analysis either during the data acquisition or post-acquisition data processing. Attended monitoring should include at least four site visits with each visit including eight hours of monitoring or more, and equal day and night time periods. Measurements should be taken when the wind direction corresponds to the worst-case scenario. It might require periodical shut down of WTGs to enable a determination of the noise contribution associated with operation of the wind farm.

If an alternative technique enables reliable monitoring of the wind farm noise using the L_{Aeq} descriptor, it should be measured and reported as such. Comparison of the noise criteria with the wind farm noise should also be performed using L_{Aeq} magnitudes. Details of the alternative monitoring program should be discussed with the EPA.

4.6 Tonality

Where, in the opinion of an officer authorised under the EP Act or an acoustical engineer (see definition in Glossary), the wind farm exhibits tonality as a characteristic, the developer or wind farm operator must conduct a tonality test in accordance with a procedure acceptable to the EPA.

An addition of 5dB(A) must be made to the measured noise level from a wind farm where tonality is shown to be a characteristic. It should be noted that the tonal characteristic penalty applies only if it is audible at the relevant receiver. Absence of tone in noise emission if measured close to the WTGs and/or other relevant wind farm elements is sufficient proof that the tone at the receiver is not associated with the wind farm operation.

The tonality assessment procedure is detailed in the International Standard IEC 61400–11. It can be modified for assessing wind farm associated tones at a distant receiver. It should not exclude influence of the background since it may influence the actual audibility of the tone at the receiver. Tonal audibility magnitude $\Delta L_{a,k}$ should be calculated for each of the possible tones. A tone is considered audible if this magnitude exceeds 0dB. The tonal penalty should be applied to the calculated SPL in the wind speed bin where tonal characteristics are detected for at least 10% of the data in that associated wind speed bin.

4.7 Annoying characteristics

The 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 as amplitude modulation or 'swishing'), and the infrequent and short-term braking noise. It is considered that these noise characteristics are inherent to the operation of a wind farm and some level of these characteristics are expected to be observed.

Effects associated with high degrees of either amplitude modulation or low frequency noise are rare and are not expected to impact on receivers. However, such noise characteristics may potentially be exacerbated by different weather conditions or during different seasons. Annoying characteristics that are not fundamental to a typical well-maintained wind farm must be rectified.

Further information

Infrasound was a characteristic of some early wind turbine models and was attributed to turbine blades that were downwind of the main tower. This effect was generated as the blades cut through the turbulence generated around the downwind side of the tower.

Modern designs generally have the blades upwind of the tower. Wind conditions affecting the blades and improved blade design minimise the generation of this effect. The EPA carried out an infrasound monitoring project and extensive literature search and is not aware of excessive infrasound being present at any modern wind farm sites.

Some relevant documents indicate impulsiveness as one of the possible characteristics of wind farm noise. New Zealand Standard NZ 6808–2010 defines impulsiveness as peak level with characteristic time less than 100 ms. The presence of impulsiveness may indicate an issue with existing WTG mechanisms. The EPA is unaware of cases where continuous impulsiveness is a characteristic of noise from a well-maintained turbine.

The Institute of Acoustics of UK has published a method for rating amplitude modulation in WTG noise (2016). This method is endorsed by the EPA to assess wind turbine amplitude modulation. At this point no penalty mechanism is associated for this method of assessment. It has been noted that a 3–5dB peak to trough is typically observed for a standard WTG operation. If amplitude modulation depth higher than this is detected, the source of this increased depth should be investigated and rectified.

It is in the interest of the WTG operators to reduce noise that is not fundamental to a well-maintained wind farm as this may generally indicate faults in the WTG, reducing its efficiency.

4.8 Excessive noise

The operation of the wind farm should comply with the criteria at all relevant receivers. The extent of relevant receivers is confined to those identified during the development assessment stage, and includes those with approved development applications prior to the approval of the wind farm.

The EPA can require the developer to repeat the compliance checking procedure if it receives any complaint that may be valid regarding an unreasonable interference on those premises from noise impacts. An environment protection order as provided under section 93 of the EP Act may be issued to secure compliance with the criteria in the guidelines. This may mean restrictions on the operation of a number of WTGs under certain wind speed or wind direction.

The EPA recognises that there will be natural variations in background noise throughout the year, with different prevailing wind directions, foliage on trees, atmospheric conditions and possibly changes to local landscape such as buildings, trees or topography that may affect compliance with the criteria.

Where this may be the case, the onus of responsibility to prove compliance with noise criteria resides with the developer or the current operator of the wind farm.

A range of alternative compliance checking procedures can remove the influence of background noise to accurately determine the wind farm noise in isolation.

Where measurements of the ambient noise indicate that excessive noise from the wind farm may exist, it is likely that the EPA will restrict operation of the wind farm subject to proof of compliance with the criteria under one of these accepted procedures.

5 Documentation

Development applications for wind farms are referred to the EPA by the relevant planning authority for assessment of the environmental noise impact.

If it appears likely that the criteria under these guidelines will be approached, developers should discuss the development with the EPA at the pre-lodgement stage before submitting the application to ensure they provide all relevant information.

All relevant information on the noise impacts should be included with the application. Possible information requirements are summarised below.

5.1 Predicted noise from the wind farm

1 Make and model of WTGs to be used, including hub height, cut-in wind speed and speed of the rated power.

2 Octave or one-third octave band sound power levels and associated wind speed of WTGs to be used.

3 Positions of all WTGs shown in topographical maps.

4 Positions of other noise sources associated with the wind farm development.

5 Table of WTGs and relevant receivers coordinates including distances and angle directions between the receiver and nearest WTG.

6 Description of the zone category, zone maps for all receivers in (5), as outlined in the *Planning and Design* Code under the *Planning, Development and Infrastructure Act 2016*.

7 Predicted noise levels for those premises in (5) for worst-case wind direction for wind speeds from cut-in speed to the speed of the WTG rated power.

8 The model used and the method for deriving the noise levels in (7).

9 Indication of accuracy of the wind farm noise prediction.

10 Amount of noise reduction, if any, allowed for acoustic screening to estimate the levels in (7).

11 Topographical map of wind farm and affected premises showing labelled noise contour lines.

12 Location of wind measuring position(s) used for noise assessment and compliance purposes.

5.2 Measurement and assessment of background noise

1 Description of noise measuring equipment used including make, model and type and including type and model of windshield used for the microphone.

2 Data demonstrating valid calibration for all equipment at the time of measurements.

3 Noise measurement position including microphone height above ground, location of local weather condition measurements and distance to nearest building structure(s).

4 Photographs and aerial imagery of measurement position showing surrounding features such as trees or building structures.

5 Angle direction between the line connecting the noise measurement point and the nearest WTG and north (measured clockwise).

6 Atmospheric conditions at the wind farm including wind speed and direction, description of weather data measuring equipment used.

7 Local wind speed data at the noise measurement site.

8 Time and duration of monitoring.

9 Sampling time for wind and noise measurements.

10 Total number of data pairs measured (wind farm speed and background noise level) and number of data pairs measured at the worst-wind conditions between the cut-in wind speed and speed of the rated power.

11 Graphical plot of data similar to the example in section 3.4.

5.3 Compliance checking

1 Description of all noise monitoring equipment, including type of microphone and windshield used.

2 Data demonstrating valid calibration when measurements were taken.

3 Noise measurement position including microphone height above ground, location of local weather condition measurements, distance to nearest building structure(s) and WTG(s).

4 Photographs and aeriel imagery of noise measurement position taken before the wind farm was installed (at the noise modelling stage) and at the time of compliance checking, showing the noise measurement position and associated surroundings, such as buildings, trees and topography.

5 Angle direction between the line connecting the noise measurement point and the nearest WTG and north (measured clockwise).

6 Description of atmospheric conditions, wind speed and direction, measuring equipment used and the location on the wind farm, including height above ground level.

7 Make and model of WTGs monitored, including hub height, cut-in wind speed and speed of the rated power.

8 Details of which WTGs were operating during compliance check.

9 Time and duration of monitoring period.

10 List of all monitored data showing wind speed, wind direction and noise level.

11 Presence of any audible annoying noise characteristics.

12 Graphical plots of relevant data in accordance with section 4.

13 Conclusion highlighting correspondence to the criteria.

6 Bibliography

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Acts and other state documentation

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Planning, Development and Infrastructure Act 2016, South Australia.

Statewide Wind Farms Development Plan Amendment 2012, South Australia.

7 Glossary

A-weighted	frequency weighted as specified in Standard AS IEC 61672.1–2019 Electroacoustics – Sound level meters (or its equivalent)
acoustic engineer	a person eligible for full membership of both the Institution of Engineers Australia and the Australian Acoustical Society
authorised officer	a person appointed to be an authorised officer under Division 1 of Part 10 of the *Environment Protection Act 1993*
ambient noise	the total noise in a given environment
background noise	measured ambient noise, in the absence of the noise under investigation, which is equalled or exceeded for 90% of the measurement time interval. Expressed as $L_{A90,T}$, where T refers to the measurement time interval in minutes.
base noise level	means an $L_{Aeq,10}$ of 35dB(A) or 40dB(A) depending on the receiver zoning
calculated background noise	background noise level $L_{B,k}$ at a receiver calculated for the *k*-th wind speed bin from the measured background noise data in accordance with these guidelines
calculated wind farm noise	wind farm noise level $L_{WF,k}$ calculated for the *k*-th wind speed bin from the measured total and background noise data in accordance with the guidelines
combined wind farm and background noise	total wind farm and background noise level $L_{R,k}$ at a receiver calculated for the *k*-th wind speed bin from the measured data in accordance with these guidelines
dB(A)	the noise level in decibels, obtained using the 'A' weighted network of a noise level meter as specified in *Standard AS IEC 61672.1–2004 Electroacoustics – Sound level meters*, or its equivalent
dB(G)	the noise level in decibels, obtained using the 'G' weighted network of a noise level meter as specified in *International Standard ISO 7196 Acoustics – Frequency-weighting characteristics for infrasound measurements*
equivalent noise level	the equivalent continuous A-weighted sound pressure level, over the measurement time interval. Expressed as $L_{Aeq,T}$, where T refers to the measurement time interval in minutes
G- weighted	frequency weighted as specified in *International Standard ISO 7196 Acoustics– Frequency-weighting characteristics for infrasound measurements*
IEC	International Electrotechnical Commission
impulsive noise	noise containing impulse components as part of its characteristics, comprising a single pressure peak, a sequence of such peaks, a single burst with multiple pressure peaks, whose amplitude decays with time, or a sequence of such bursts
L_{den}	day–evening–night–weighted sound pressure level as defined in section 3.6.4 of *ISO 1996 – 1:2016 Description, measurement and assessment of environmental noise*

locality	means an area to which the Planning and Design Code applies (whether described in the planning and design code as a zone or a subzone) that is: a made subject to a set of land use rules by provisions of the Planning and Design Code; and b not itself further divided by the Planning and Design Code into areas that are made subject to separate sets of land use rules.
low frequency noise	a noise with perceptible and definite content in the audible frequency range below 250 Hz
measurement place	a place at the receiver where the noise level is to be measured
predicted noise level	the $L_{Aeq,10}$ wind farm noise level at a receiver predicted in accordance with these guidelines
premises	any land, or the whole or part of a building or structure
receiver	premises that may be affected by the noise source, other than premises on the same land as the noise source
SPL	sound pressure level
T	measurement time interval; taken to be 10 minutes unless stated otherwise
tonal noise	noise with perceptible and definite pitch or tone
V_{10m}	wind speed measured in metres per second (m/s) at the wind farm site at 10 m above the ground
WTG	wind turbine generator
wind farm	a group of WTGs installed in the same region and all managed by the same operator. It is not necessary that all WTGs are located on the same premises
wind farm noise	the L_{WF} wind farm noise level at a receiver calculated from the measured data in accordance with these guidelines
zone	an area of land delineated as a zone, sub-zone or otherwise in the relevant planning and design code under the *Planning, Development and Infrastructure Act 2016*, that is subject to a set of land use rules under that Plan