Annex H

Noise Specialist Report

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ENVIRONMENTAL NOISE IMPACT STUDY INTO THE PROPOSED ESTABLISHMENT OF A WIND FARM IN THE ROGGEVELD IN THE WESTERN AND NORTHERN CAPE

PREPARED FOR

ERM Southern Africa (Pty) Ltd

December 2010
Revised
March 2011

EXECUTIVE SUMMARY

A Noise Impact Assessment (NIA) was conducted into the proposed establishment by G7 Renewable Energies (Pty) Ltd. of A wind farm in the Roggeveld spanning the Western and Northern Cape. The investigation into the potential impact of noise was based on noise emission data provided of the turbines and measured L_{Aeq} and A-weighted sound spectra of wind generated noise at the same speed.

The results of the NIA indicated that where wind energy turbines were to be located closer than 600 m from the wind farm site boundaries the L_{Aeq} beyond the boundary would exceed the ambient (residual) sound level by 7 dB or more. In such instances this would be adjudicated to be a "disturbing noise" in terms of the The Noise Control Regulations and noise mitigation procedures would be legally required to be implemented. In terms of SANS 10328 the associated intensity of noise impact would be **Medium**.

The results of the calculations indicated that at several dwelling locations within the Roggeveld site boundaries it was probable that the noise from the wind turbines would be audible and could be considered to be intrusive.

These findings were considered to represent the best estimates based on available data.

Practical noise mitigation procedures are limited to increasing the distance between the turbines and the wind energy farm site boundaries. With regard to identified dwellings within the site boundaries ensuring adequate sound insulation of the dwelling structure could also be considered.

Based on the findings it is recommended that consideration be given to ensuring wind turbines are located no closer than 600 m from the wind energy farm site boundaries. With regard to the identified dwellings within the wind energy farm boundaries it is recommended that further, more detailed studies be conducted, to determine the most practical means of reducing the noise impact at each of the dwellings. Consideration should be given to relocation of wind turbines and/or improving the sound insulation of the dwellings.

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GLOSSARY

This glossay contains terms used in the measurement and assessment of sound, or noise. Their meanings are in certain instances loosely described to facilitate understanding.

Terms defined in SANS 10103:

Ambient noise
the totally encompassing sound in a given situation at a given time, and is usually composed of sound from many sources, both near and far. It includes the noise from the noise source(s) under investigation.

A-weighted intensity level, L_{IA}
(often referred to as sound level or noise level with A-weighting understood to be incorporated)
the intensity level, in decibels, relative to a reference sound intensity, and incorporating an electrical filter network (A-weighted) in the measuring instrument corresponding to the human ear's different sensitivity to sound at different frequencies.

Equivalent continuous A-weighted sound level, $L_{Aeq,T}$
A formal definition is contained in SANS 10103. The term "equivalent continuous" may be understood to mean the "average" A-weighted sound level measured continuously, or calculated, over a period of time, T.

Equivalent continuous rating level, $L_{Req,T}$
the equivalent continuous A-weighted sound level, $L_{Aeq,T}$, measured or calculated during a specified time interval T, to which is added adjustments for tonal character, impulsiveness of the sound and the time of day. An adjustment of 5 dB is added for any tonal character, if present. If the noise is of an impulsive nature an adjustment of 5 dB is added for regular impulsive noise and 12 dB for highly impulsive noise. Where neither is present, the $L_{Req,T}$ is equal to the $L_{Aeq,T}$.

Reference intensity, I_{ref} or I_0
is the threshold of audibility or minimum perceptible intensity of sound = 10^{-12} watt/m^2 at 1000 Hz

Reference time interval
The time interval to which an equivalent continuous A-weighted sound level, $L_{Aeq,T}$, or rating level of noise, $L_{Req,T}$, is referred. Unless otherwise indicated, the reference time interval is interpreted as follows:

- Day-time: 06:00 to 22:00hrs T=16 hours when $L_{Req,T}$ is denoted $L_{Req,d}$
- Night-time: 22:00 to 06:00hrs T=8 hours when $L_{Req,T}$ is denoted $L_{Req,n}$

Residual noise (often referred to as background noise)
The ambient noise that remains at a given position in a given situation when one or more specific noises (usually those under investigation) are suppressed or absent.

District
This is related to, but not necessarily equal to, "land-use zoning" applied in urban and regional planning. For example, mixed-use zoning may comprise a central business district and a residential district.

Terms defined in the Noise Control Regulations:

Ambient sound level means the reading on an integrating impulse sound level meter taken at a measuring point in the absence of any alleged disturbing noise at the end of a total period of at least 10 minutes after such meter was put into operation.

Disturbing noise means a noise level that exceeds the ambient sound level measured continuously at the same measuring point by 7 dB or more.

Certain terminologies used in the Noise Control Regulations and in the SANS 10328 and 10103 have similar sounding, but not equal, meanings. Thus,

Noise Control Regulations:		SANS 10103:
Ambient sound level	is equivalent to	Rating level of residual noise
Noise level	is equivalent to	Rating level of ambient noise

In order to avoid confusion **residual noise**, as defined in SANS 10103 is used in this report.

Other terms:

Hz
Abbreviation of the unit hertz used to denote cycles per second of the frequency of sound.

Infrasound
Sound at frequencies lower than 20 Hz.

Low frequency sound
Although not specifically defined, it is universally understood to mean sound extending from approximately the lowest audible frequency of 20 Hz to 200 Hz.

Masking
When exposed to sound from two or more sources, sound from one of the sources may reduce the audibility of the other sound(s) compared to that when listening to each sound separately.

1 INTRODUCTION

G7 Renewable Energies (Pty) Ltd. is proposing to establish a wind energy farm in the Roggeveld spanning the Western and Northern Cape Province. Jongens Keet Associates (JKA) has been appointed to conduct a Noise Impact Assessment (NIA) into the potential impact of noise that might emanate from the operation of the wind farm .

This report describes the required procedures to conduct an NIA; a description of the study area; the results of residual (ambient) sound measurements; the procedures used; and the prediction and assessment of the impact of noise on land within and surrounding the proposed wind farm site.

2 LEGISLATIVE FRAMEWORK AND REGULATORY GUIDELINES

A noise impact investigation and assessment is conducted in accordance with procedures contained in Section 8 of the South African National Standard (SANS) 10328, *Methods for environmental noise impact assessment* as prescribed under the National Environmental Management Act, 1998 (Act 107 of 1998) (NEMA).

The procedures, described in greater detail in 2.1 through 2.4, may be summarised as follows:

SANS 10328 contains procedures to be followed to estimate the predicted impact that noise emanating from a proposed development will have on potentially affected land based on objective, scientific principles. The purpose of the investigation is to determine and quantify the acoustical impact of a proposed development. The predicted impact is assessed in accordance with SANS 10103, *The measurement and rating of environmental noise with respect to annoyance and to speech communication*, by determining whether the rating level of the predicted noise will exceed the residual (background) noise level on that land and/or the typical rating level of noise pertaining to the particular district and relating this excess to the estimated response by a community of the respective district to the noise.

It is to be noted that a noise impact beyond the site boundaries is assessed in terms of a particular district whether the land is occupied or not. In both instances it impacts on the use and therefore the value of the land.

SANS 10328 stipulates that a NIA must include legal requirements, if any, and that other relevant and suitable literature may be consulted.

The legal requirements in the Western Cape are contained in the Noise Control Regulations applicable to the Province of the Western Cape (NCR-WC), Notice No. 627/1998, Provincial Gazette 5309, 20 November 1998. In the Northern Cape the National Noise Control Regulations (NCR), Government Notice Number R 55 of 14 January 1994 are applicable. With regard to the present NIA the contents of each are identical and are thus referred to as the NCR. The NCR stipulates that no person may produce or cause a disturbing noise. In essence, the noise emanating from a particular source may not cause the ambient (prevailing) noise level in an area to increase by 7 dB or more.

SANS 10103 is in line with World Health Organisation (WHO) Guidelines for Community Noise (WHO 2002) and a relevant summary is therefore included.

2.1 *SOUTH AFRICAN NATIONAL STANDARDS*

In accordance with SANS 10328, the predicted impact that noise emanating from a proposed development would have on surrounding land is assessed by determining whether the daytime rating level, $L_{Req,d}$, and/or the night-time rating level, $L_{Req,n}$, of the predicted ambient noise would exceed the typical rating level of noise on that land as indicated in Table 2 of SANS 10103. If the rating level of the ambient noise under investigation exceeds the typical rating level, it is probable that the noise is annoying or otherwise intrusive to a community exposed to the noise. This excess is then related to the probable response of a community to the noise as indicated in Table 5 of SANS 10103. Tables 2 and 5 of SANS 10103 are reproduced on this and the following page.

In estimating the response of a community (such as residents) in a particular district to a particular noise under investigation Table 5 of SANS 10103 incorporates the diversity of response of individuals of a particular community to the same noise level. The estimated response to an excess of $L_{Req,T}$ of noise under investigation over the residual or typical $L_{Req,T}$ is thus not in discrete 5 dB changes, but in overlapping ranges of excess.

SANS 10103 (2008), Table 2 — Typical rating levels for noise in districts

1	2	3	4	5	6	7
Type of district	**Equivalent continuous rating level ($L_{Req.T}$) for noise,** dBA					
	Outdoors			**Indoors, with open windows**		
	Day-night $L_{R,dn}$[a]	**Day-time** $L_{Req,d}$[b]	**Night-time** $L_{Req,n}$[b]	**Day-night** $L_{R,dn}$[a]	**Day-time** $L_{Req,d}$[b]	**Night-time** $L_{Req,n}$[b]
a) Rural districts	45	45	35	35	35	25
b) Suburban districts with little road traffic	50	50	40	40	40	30
c) Urban districts	55	55	45	45	45	35
d) Urban districts with one or more of the following: workshops; business premises; and main roads	60	60	50	50	50	40
e) Central business districts	65	65	55	55	55	45
f) Industrial districts	70	70	60	60	60	50

NOTE 1 If the measurement or calculation time interval is considerably shorter than the reference time intervals, significant deviations from the values given in the table may result.

NOTE 2 If the spectrum of the sound contains significant low frequency components, or when an unbalanced spectrum towards the low frequencies is suspected, special precautions should be taken, and specialist attention is required. In this case the indoor sound levels may significantly differ from the values given in columns 5 to 7. (See also annex B.)

NOTE 3 In districts where outdoor $L_{R,dn}$ exceeds 55 dBA, residential buildings (e.g. dormitories, hotel accommodation and residences) should preferably be treated acoustically to obtain indoor $L_{Aeq,T}$ values in line with those given in Table 1.

NOTE 4 For industrial districts, the $L_{R,dn}$ concept does not necessarily hold. For industries legitimately operating in an industrial district during the entire 24 h day/night cycle, $L_{Req,d} = L_{Req,n}$ = 70 dBA can be considered as typical and normal.

NOTE 5 The values given in columns 2 and 5 are equivalent continuous rating levels and include corrections for tonal character, impulsiveness of the noise and the time of day.

NOTE 6 The noise from individual noise sources produced, or caused to be produced, by humans within natural quiet spaces such as national parks, wilderness areas and bird sanctuaries, should not exceed a maximum A-weighted sound pressure level of 50 dBA at a distance of 15 m from each individual source.

SANS 10103 (2008), Table 5 — Categories of community/group response

1	2	3
Excess ($\Delta L_{Req,T}$)[a] dBA	**Estimated community/group response**	
	Category	**Description**
0 – 10	Little	Sporadic complaints
5 – 15	Medium	Widespread complaints
10 – 20	Strong	Threats of community/group action
>15	Very strong	Vigorous community/group action

NOTE Overlapping ranges for the excess values are given because a spread in the community reaction may be anticipated

$\Delta L_{Req,T}$ should be calculated from the appropriate of the following:

1) $\Delta L_{Req,T}$ = $L_{Req,T}$ of ambient noise under investigation MINUS $L_{Req,T}$ of the residual noise (determined in the absence of the specific noise under investigation).
2) $\Delta L_{Req,T}$ = $L_{Req,T}$ of ambient noise under investigation MINUS the maximum rating level for the ambient noise given in table 1.
3) $\Delta L_{Req,T}$ = $L_{Req,T}$ of ambient noise under investigation MINUS the typical rating level for the applicable district as determined from table 2.
4) $\Delta L_{Req,T}$ = Expected increase in $L_{Req,T}$ of ambient noise in an area because of a proposed development under investigation.

For very low frequencies, indoors, rating procedures contained in Annex B of SANS 10103 are applied to determine whether the low frequency noise can be adjudicated as disturbing.

Appendix A contains A-weighted sound pressure levels of some typical noise sources and the average subjective human response to changes in sound level often loosely referred to as "loudness".

2.2 *IMPACT QUALIFIERS*

The **intensity** of a predicted noise impact was determined in relation to the categories of community response contained in Table 5 of SANS 10103 and is qualified as follows:

None	Predicted $L_{Req,T}$ does not exceed the typical $L_{Req,T}$
Low	Predicted $L_{Req,T}$ exceeds the typical $L_{Req,T}$ by between 0 & 5 dB
Medium	Predicted $L_{Req,T}$ exceeds the typical $L_{Req,T}$ by between 5 & 10 dB
High	Predicted $L_{Req,T}$ exceeds the typical $L_{Req,T}$ by more than 10 dB

2.3 *WORLD HEALTH ORGANISATION*

The World Health Organisation (WHO) contains the following summary of thresholds for noise nuisance in terms of outdoor daytime L_{Aeq} in residential districts (WHO 2002):

- At 55-60 dBA noise creates annoyance.
- At 60-65 dBA annoyance increases considerably.
- Above 65 dBA constrained behaviour patterns, symptomatic of serious damage caused by noise, arise.

As a consequence, WHO recommends a maximum outdoor daytime L_{Aeq} of 55 dBA in residential areas and schools "*in order to prevent significant interference with normal activities of local communities*". It further recommends a maximum night-time L_{Aeq} of 45 dBA outside dwellings (WHO 2002). No distinction is made as to whether the noise originates from road traffic, from industry, or any other noise source. These recommended maximum levels correspond to the typical daytime rating levels for ambient noise in an urban district referred to in Table 2 of SANS 10103.

The WHO further recommends that indoors in sleeping areas the $L_{Aeq,T}$ should be no greater than 30 dBA during night time so as to avoid negative effects on sleep. These include difficulty in falling asleep, sleep quality and adverse after-effects such as headache and tiredness.

2.4 *NOISE CONTROL REGULATIONS*

In terms of Clause 3 (c) of the Noise Control Regulations:

"No person shall make changes to existing facilities or existing use of land or buildings or erect new buildings, if these will house or cause activities that will, after such changes or erection, cause a disturbing noise, unless precautionary measures to prevent the disturbing noise have been taken to the satisfaction of the local authority."

In terms of Clause 4 of the Noise Control Regulations:

"No person shall make, produce or cause a disturbing noise, or allow it to be made, produced or caused by any person, animal, machine, device or apparatus or any combination thereof."

2.5 *DIFFERENT PROCEDURES IN DETERMINING NOISE IMPACT AND DISTURBING NOISE*

It is to be noted that two disparate assessments need to be presented in a NIA, namely, an assessment of noise impact in terms of SANS 10328 and whether a disturbing noise prevails, or would prevail, in terms of the NCR.

The impact of noise in this study is predicted in accordance with SANS 10328. Clause 8.4.1 of SANS 10328 states: "…calculate the noise impact by determining the difference between the future expected rating level and the typical rating level." The influence of residual noise is excluded. This in contrast to SANS 10103 in which the estimated community response is calculated from the difference between either the future expected rating level and the typical rating level, or the rating level of residual noise, whichever is appropriate. Consideration of the latter is included in this report.

For practical reasons the outdoor rating levels are usually considered but the associated indoor rating levels also apply and would be more relevant inside residential dwellings. Refer to Table 2 of SANS 10103. However, it would be impractical to conduct indoor sound measurements in numerous residences of a potentially affected district to determine the residual (ambient) levels.

The presence of a disturbing noise, in accordance with the NCR, is determined by calculating the difference between the "noise level" due to the source under investigation and the "ambient sound level". The latter term is equivalent to "rating level of residual noise" defined in SANS 10103. Refer to the Glossary for definitions and convention used in this study.

3 STUDY APPROACH

The environmental noise impact investigation and assessment of the wind farm on surrounding land was conducted in accordance with Section 8 of SANS 10328. A summary of the procedure is outlined hereunder.

1. Determine the land use zoning surrounding the site and identify all potential noise sensitive receptors that could be impacted upon by activities relating to operation of the wind farm.
2. Determine the existing residual (ambient) levels of noise within the study area.
3. Determine the typical rating level for noise at identified noise sensitive sites.
4. Identify all noise sources, relating to the operation of the proposed wind farm that could potentially result in a noise impact at the identified noise sensitive sites.
5. Determine the sound emission and nature of the sound emission from the identified noise sources.
6. Calculate the expected rating level of noise due to the wind turbines on the identified noise sensitive land.
7. Calculate and assess the noise impact on surrounding land and noise sensitive receptors in terms of SANS 10103; the NCR; and the WHO.
8. Investigate alternative noise mitigation procedures, where appropriate.
9. Prepare and submit an environmental noise impact report containing the procedures and findings of the investigation.

The question of the influence of noise on wildlife is often raised. There remains inadequate quantitative information to suggest that noise that humans label as disturbing, or any other noise generated by humans, has any effect on wildlife other than exercising their primary instincts to avoid being in the immediate vicinity of humans. The physical clearance of land and construction of the wind farm is likely to have a greater impact on wildlife in the vicinity than any noise associated with such activities. Procedures to determine and assess the impact of noise on fauna are not included in SANS 10328 and SANS 10103 nor do the impact on fauna form part of the NCR or any International Standard relating to noise that the author is aware of. No quantitative assessment of the impact that noise associated with the wind farm might have on fauna can therefore be provided in this study.

3.1 NOISE PROPAGATION CALCULATIONS

The calculation of the predicted equivalent continuous A-weighted level, $L_{Aeq,T}$, of noise at various distances from the noise sources (wind energy turbines) is summarised hereunder.

- A 3-dimensional digital elevation model (DEM) was generated of the land extending approximately 4 km beyond the proposed wind farm boundaries.
- The 3-D location of each noise source, namely each wind turbine, was entered in the DEM with the elevation of each turbine 80 m above local ground elevation.

- The 1/3rd octave frequency band Sound Power Level emission spectrum available for a 2.1 MW turbine at a wind speed of 6 m/s was used for the calculations.
- The attenuation of noise with distance from each source was calculated in accordance with SANS 10357, *The calculation of sound propagation by the Concawe method*, with meteorological category 6. This category represents conditions most favourable for the propagation of noise from noise source(s) to receiver. Refer to 4.2.
- From the calculated L_{Aeq} at 2 m above ground level, L_{Aeq} noise contours at 5 dB intervals were generated and overlaid on a Google Earth image of the wind farm.

The resulting noise contours represent worst case L_{Aeq} at any receiver located 360 degrees in the horizontal plane around the noise sources. This includes the effects of winds blowing from noise source(s) to receiver notwithstanding the actual prevailing conditions in the area. Specifically, the diagram containing the noise contours does not represent a typical seasonal condition.

4 NOISE SOURCES AND FACTORS INFLUENCING NOISE AT A RECEPTOR

Various factors may, either individually or collectively, influence the level ("loudness") and nature of noise emitted by a wind turbine that is perceived at a receiver location.

4.1 WIND TURBINE NOISE

The two main sources of wind turbine noise are mechanical noise generated by machinery such as generator and gearboxe in the nacelle and aerodynamic noise emanating from movement of air around the turbine blades and tower.

Noise from the electrical generator and gearbox can be radiated through the nacelle into the atmosphere. Mechanical vibrations from generator and gearbox can also be transmitted into the tower wall that radiates the vibration energy as sound into the atmosphere.

The aerodynamic noise may include continuous broadband noise, noise with a noticeable tone, as well as impulsive noise. Human hearing is particularly sensitive to tonal and impulsive sounds. Although these were emitted by some of the first wind turbines thereby eliciting community complaints, extensive improvements in design have resulted in the virtual elimination of both tonality and impulsivity in the latest generation of wind turbines.

The noise emitted by a wind turbine extends over most of the audio frequency range. The level of noise varies over the operating wind speeds ranging from the cut-in wind speed of approximately 5 m/s (18 km/hr) to a maximum wind generating speed of approximately 12 m/s (43 km/hr). The noise emission level is lowest at the cut-in speed but it is not linearly related to wind speed with the maximum emission level generally occurring between 7 m/s and 8 m/s; thus not at the maximum wind speed. It is noteworthy that, for most modern wind turbines, the maximum change in overall noise emission level (L_{Aeq}) rarely exceeds 3 dB over the entire operating wind speed range. This difference is considered insignificant in terms of human response to sound/noise. Most humans would barely notice a difference in "loudness" for a 3 dB change in noise level. Refer to Appendix A.

The sound power emission levels provided by the wind turbine manufacturer considered for this project were determined in accordance with International Standard IEC 61400-11, *Wind turbine generator systems – Part 11 Acoustic noise measurements techniques*. Further data provided indicated that adjustments for tonal and impulsive character in both cases were 0 dB. The calculated $L_{Aeq,T}$ at a receiver location thus equalled the $L_{Req,T}$. Refer to the Glossary.

Figure 4.1 displays a graph of the A-weighted sound power emission levels in each 1/3rd octave frequency band (sound power spectrum) for a 2 MW wind turbine with hub height of 80 m being considered by the client and used in this investigation at a wind speed of 7 m/s (referenced to 10 m height) associated with the highest overall A-weighted sound power level, L_{WA}, emitted. The overall L_{WA} of 104.2 dBA is recorded in the legend.

The frequency range shown on the graph extends over most of the human audio frequency range. For information, the average frequency range of speech is shown extending from a low baritone voice to the high frequency sounds produce by uttering the letters "s" and "f".

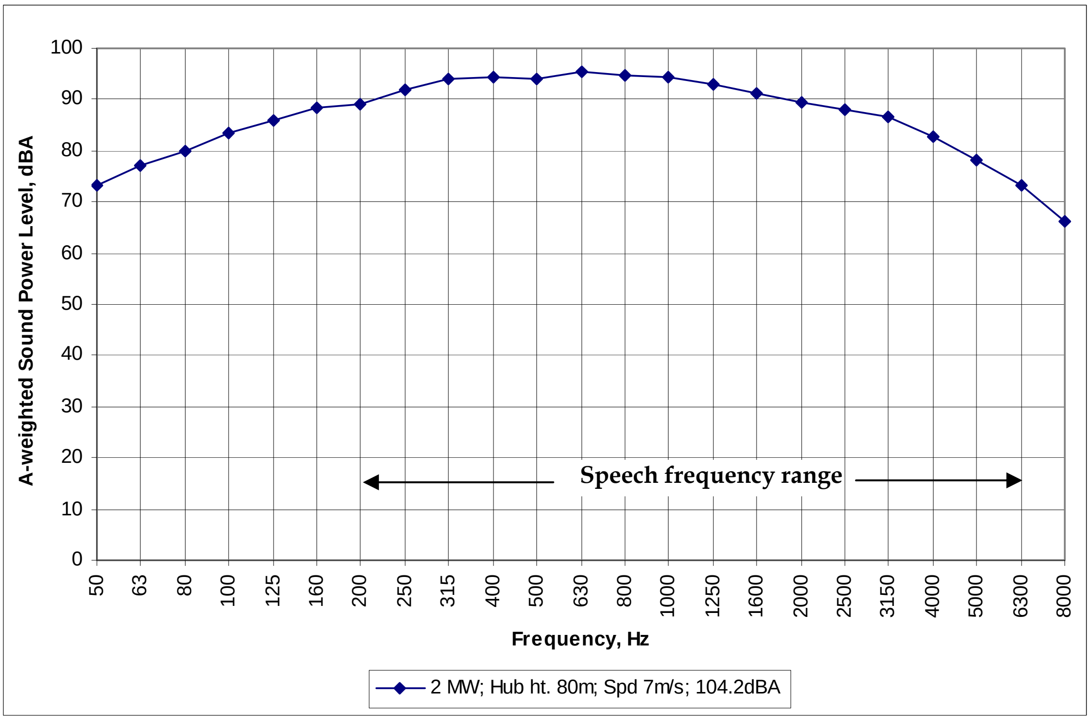


Figure 4.1 **A-weighted sound power level spectra of 2 MW wind energy turbine with hub height of 80 m used in this study operating in a wind speed of 7 m/s.**

4.2 *PROPAGATION OF SOUND*

A brief outline is provided of various physical factors that influence sound as it propagates outdoors from a sound source to a receiver location. All of these factors are incorporated in national and international standard calculation procedures and that were used in this study.

4.2.1 *Geometrical spreading*

Sound power radiating into air from a sound source propagates equally in all directions. At a particular separation distance, r, the intensity level (sensation of "loudness") is the power radiated divided by the surface area of a sphere of radius r. With increasing distance the same power is spread over a spherical surface of increasing area. The intensity level of all sound frequencies reduce by the same amount due to this "geometric spreading". This is similar to the sensation of "warmth" felt from the thermal power radiated from a household "heater". The power radiated stays constant but with increasing distance the sensation of warmth decreases.

4.2.2 Sound absorption

In addition to spherical spreading, the process of absorption of sound by the air through which it propagates starts to become significant at separation distances beyond approximately 50 m. The additional reduction, or attenuation, in intensity level due to absorption is not the same for each frequency but increases for increasing frequencies, particularly above 1000 Hz. For example, at a distance of 400 m the additional attenuation due to absorption is less than 1 dB for all frequencies below 1000 Hz but is almost 7 dB at 4000 Hz. Thus, although broadband noise throughout the audio frequency range is emitted by wind turbines (refer to Figure 4.1), only the frequency content below 1000 Hz is dominant at large distances.

4.2.3 Meteorological conditions

Vertical wind speed and temperature gradients almost always exist over the surface of the earth. Wind speed gradients are associated with the interaction between moving air and the ground with wind velocity increasing with height above the ground. If the general wind direction is from sound source to receiver the higher portion of the sound wave-front travel slightly faster than the wave-front closer to the ground. This results in a "bending" of the wave downwards towards the ground. When the wind is in the opposite direction the sound wave bends away from the ground.

Temperature gradients are due to heat exchange between the ground and atmosphere. The speed of sound increases with increasing air temperature. Around sunrise and sunset the ground is often cooler than the air above. The slight increase in sound speed with increasing height similarly causes a "bending" of sound downwards towards the ground.

The "bending" downwards of sound by appropriate wind and/or temperature gradients can result in sound from a source being heard over significantly greater distances than when these meteorological conditions are absent.

High wind speeds, frequently occurring during daylight hours, cause air turbulence that disrupts both wind and temperature gradients thereby eliminating the "bending" of sound towards or away from the ground.

The procedures contained in SANS 10357, T*he calculation of sound propagation by the Concawe method*, enables the influence of all wind and temperature gradients as well as wind direction to be considered. However, in line with international standards, this study has included only meteorological conditions most suitable for the propagation of sound from sound source towards receiver location, irrespective of the actual climatic conditions prevailing in the study area. This represents a worst case scenario in the calculation of the sound level at each receiver location.

4.3 *WIND GRADIENTS AND SOUND MEASUREMENTS.*

Close to the earth's surface the wind speed increases with height above the ground. This is due to friction of the ground and vegetation slowing the air movement close to the ground. The change in wind speed (wind gradient) is greatest close to the ground, becoming less with increasing height. Wind speed as a function of height can be calculated for different ground/vegetation conditions (IEC 61400-11). This is illustrated by the wind speed profile in Figure 4.2. Figure 4.2.a extends to a height of 100 m while Figure 4.2.b is an expanded portion extending up to 10 m height.

The Sound power emission levels of wind energy turbines are recorded for different wind speeds. The measured wind speeds are converted to corresponding wind speeds at a reference height of 10 m above the ground. The graph in Figure 4.2 displays a wind speed of 8 m/s at 10 m reference height. This would be the recorded wind speed for the associated sound power emission level of a turbine. The actual wind speed at a typical wind turbine hub height of 100 m would be slightly higher, namely, 11,5 m/s.

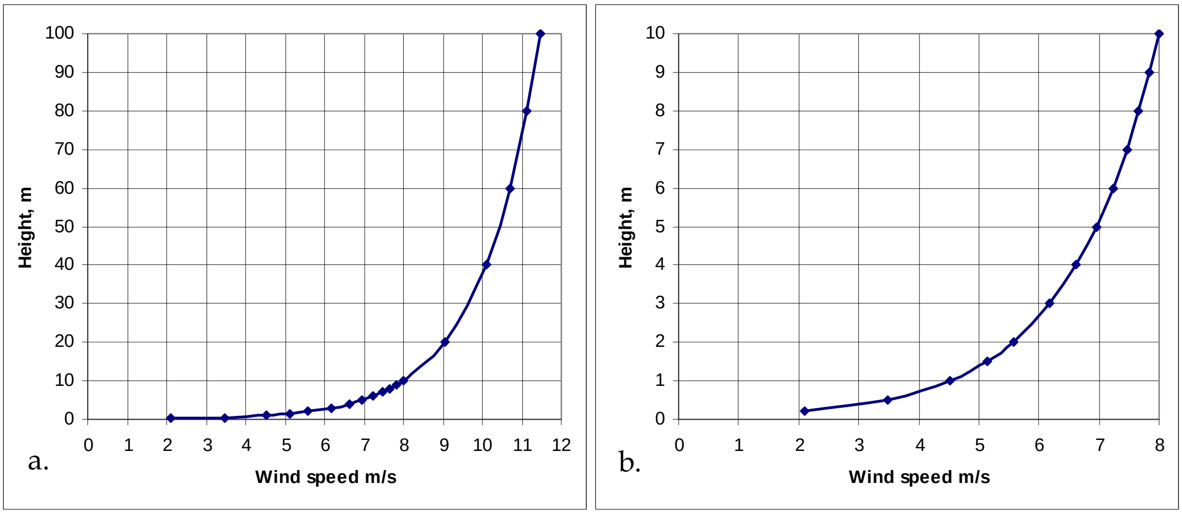


FIGURE 4.2 Wind speed profile: a. up to 100 m above ground; b. up to 10 m above ground

The measurement of environmental noise is generally conducted with the microphone of the sound level meter located between 1,2 and 1,5 m above the ground; these being the average height of the ears of a person seated and standing, respectively. Figure 4.2.b indicates that for an 8 m/s wind speed at the reference height of 10 m, the speed at 1,5 m is 5,1 m/s.

It is standard procedure to cover the microphone of a sound level meter with a windshield that significantly reduces the noise that would otherwise be generated by airflow over an unprotected microphone for wind speeds up to 5 m/s.

This means that the noise emanating from wind turbines can be measured at a measurement height of 1,5 m during wind speeds up to 5 m/s at the microphone of the sound level meter without contamination by airflow induced noise. This corresponds to wind speeds of up to 8 m/s at the reference height of 10 m and thus includes the speeds at which most turbines emit the highest level of noise.

4.4 *MASKING INFLUENCE OF RESIDUAL NOISE*

The influence of noise from one source on masking (reducing the audibility) of noise from another source is complex. This is dependent on the level (loudness) and frequency content of the noise from the two sources. In the present context, noise from one source (residual noise) could mask that of another (wind turbine noise) containing the same and higher frequencies. However, if the frequency content of the two sources differ significantly, little or no masking occurs unless the residual noise levels are significantly higher than the turbine noise levels (Rossing, 1990).

The following sub-section considers typical residual noise to be expected on land near towns and busy roads where man-made noise predominates. This is followed by that to be expected on land far removed from towns, roads and man-made noise where the predominant sources of noise are birds, insects and wind. Wind generated residual noise and the frequency content of the noise produced is dependent on the interaction of the air movement with structures (including foliage) and the physical composition of such structures. It is illustrated that the type of foliage has a significant influence on whether and to what extent wind generated residual noise at a location could mask noise emanating from wind energy turbines at the same location.

4.4.1 Proximity to towns and roads

Where land is located near to towns or busy roads the residual noise contains low and medium frequency sound energy emanating from road traffic noise that is similar to that emanating from wind turbines. Because of similar frequency spectra the road traffic noise may partially or wholly mask the turbine noise during daytime. However, reduced traffic during night-time would be accompanied by lower levels of road traffic noise and reduced effects of masking

4.4.2 Karoo landscape

Many of the proposed WEF sites are located in a typical dry Karoo landscape which in its natural state is covered all year round by predominantly scattered small bushes with fairly rigid branches and very small leaves. Large shrubs and trees are absent except where these are planted by humans near some of the residential dwellings. The sites are far removed from towns and busy roads. Because of the absence of man-made noise these areas are typically described as being "very quiet".

The $L_{Aeq,}$ and equivalent A-weighted 1/3rd octave frequency band sound levels (sound level spectrum) were recorded during daytime at seven typical Karoo sites in the Western and Northern Cape Provinces under different wind speed conditions ranging from 0 m/s to 5.2 m/s (18.7 km/hr) measured at 1,5 m above the ground. With reference to Section 4.3 the corresponding wind speed at 10 m reference height would be 8,1 m/s. The L_{Aeq} ranged from a minimum of 32.7 dBA at two of the sites during wind-still conditions to a maximum of 35.0 dBA at the site where the maximum wind speed was recorded. The average $L_{Aeq,}$ for the seven sites was 33 dBA. Of note was the very small variation of 2.3 dBA between the seven sites located hundreds of kilometers apart even for different wind speeds. With regard to humans' subjective response to sound a level difference of 2.3 dB is insignificant (refer to 4.1 and Appendix A). The only discernable sound at any of the sites was that due to the occasional chirping of a bird and occasionally small insects. Despite listening intently, no wind generated noise was audible at any of the sites.

During the measurements special care was taken to provide adequate screening of the microphone of the sound level meter to avoid noise generated by wind turbulence around the microphone.

All seven sound level spectra were very similar. The average of the seven measured sound level spectra is recorded in the bottom graph in Figure 4.2 labeled "Karoo". The spectrum is characterized by very low sound levels at low frequencies. With increasing frequency the levels increase until a "plateau" is reached at 1 000 Hz above which the spectrum levels remain constant at approximately 20 dBA. Occasional bird song contributed to higher sound levels at frequencies centered on 4 000 Hz.

The results of the seven sound measurements provide sufficient confidence to suggest that on land found in the Karoo throughout the year the typical daytime rating level of residual noise $L_{Req,d}$ is 33 dBA with an associated sound level spectrum shown in Figure 4.3 for wind speeds ranging between 0 m/s and at least 5 m/s measured 1,5 m above the ground. It is noted that the measured $L_{Req,d}$ of 33 dBA is more than 10 dB lower than the typical daytime rating level $L_{Req,d}$ and lower than the typical night-time rating level, $L_{Req,n}$ for a "rural district" contained in Table 2 of SANS 10103.

For wind speeds up to at least 5 m/s the residual sound level spectrum in the Karoo contains very low levels of sound below 1 000 Hz. In the Sections that follow the calculated sound level spectra of wind turbine noise at specific receptors are shown to contain maximum sound levels below 1 000 Hz and decreasing sound levels with increasing frequency above 1 000 Hz. With reference to Section 4.4 the above results indicate that for residences in the Karoo the residual sound level would provide little if any masking of noise emanating from wind energy turbines operating at wind speeds up to 8 m/s referenced to 10 m height.

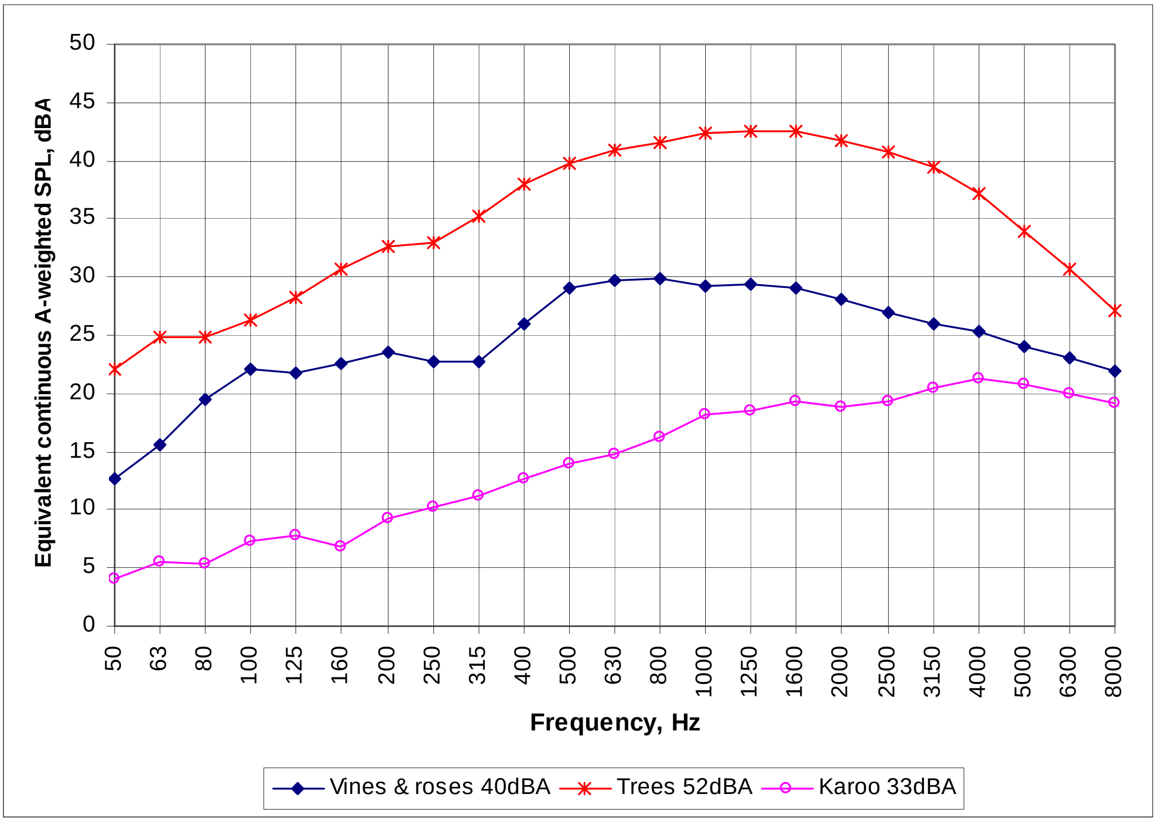


FIGURE 4.3 Measured sound level spectra on land covered by different types of foliage

4.4.3 *Wine lands*

Sound measurements were conducted amidst rose bushes and vines on a Western Cape wine farm far removed from trees or other structures during an average wind speed of approximately 6 m/s measured at 1,5 m above the ground.

Rose bushes and vines contain medium sized leaves on flexible stems that produce the characteristic rustling sound when the wind blows. The measured sound level spectrum is displayed by the middle graph in Figure 4.3. The spectrum is characterized by broad frequency band noise with maximum levels between 400 Hz and 2 500 Hz (mid-audio frequency band). The overall L_{Aeq} was 40 dBA. It was suspected that insufficient wind screening resulted in the generation of some turbulent noise around the microphone at frequencies below 315 Hz and thus not originating from the foliage.

4.4.4 *Trees and forests*

Sound measurements were conducted in close proximity (approximately 10 m) to a grove of trees during an average wind speed of approximately 6 m/s measured 1,5 m above the ground. The grove consisted of tall oaks, plane and cedar trees containing a mixture of large leaves and needles. This presented a large noise source spread over a large volume of rustling leaves and wind turbulent noise through the many branches close to the sound level meter. This produced the significantly higher broadband noise level spectrum with a maximum centered on 1 250 Hz displayed by the upper graph in Figure 4.3 and an overall L_{Aeq} of 52 dBA.

The wind generated noise in the vineyard and trees both contain relatively more noise within a frequency band coincident with that produced by wind turbines and would therefore result in the wind generated noise partially or wholly masking wind turbine noise depending on the overlapping spectrum levels.

It should be recognized that, contrary to foliage on Karoo land, the foliage on a wine farm is not constant throughout all seasons and that vines, for example, are without leaves for part of the year. So also, deciduous trees stand without leaves for part of the year. During those periods the level of wind generated noise, for the same wind speed, could be expected to be significantly lower and possibly with a different distribution of sound energy throughout the spectrum. The upper two graphs in Figure 4.2 can therefore not be considered to be representative of wind generated noise on land covered by such foliage throughout the year even for the same wind speed.

5 DESCRIPTION OF THE AFFECTED ENVIRONMENT

The proposed Roggeveld wind energy facility (WEF) site comprises several farms located along the R354 between Matjiesfontein in the south and Sutherland in the north. Figure 6.1 displays the WEF site boundaries containing the farms in red. The locations of the proposed 232 2MW wind turbines with 80 m high hub height are at the centre of the orange circles.

The land is rural with several farm dwellings located within the site boundaries. Six of these residences, demarcated by blue circles, were identified as being located within the predicted wind turbine noise contour footprint. The names of the farm residences are displayed to the left of Figure 6.1 in line with the respective blue circles. All, excepting Swartland, are located far from sources of man-made noise.

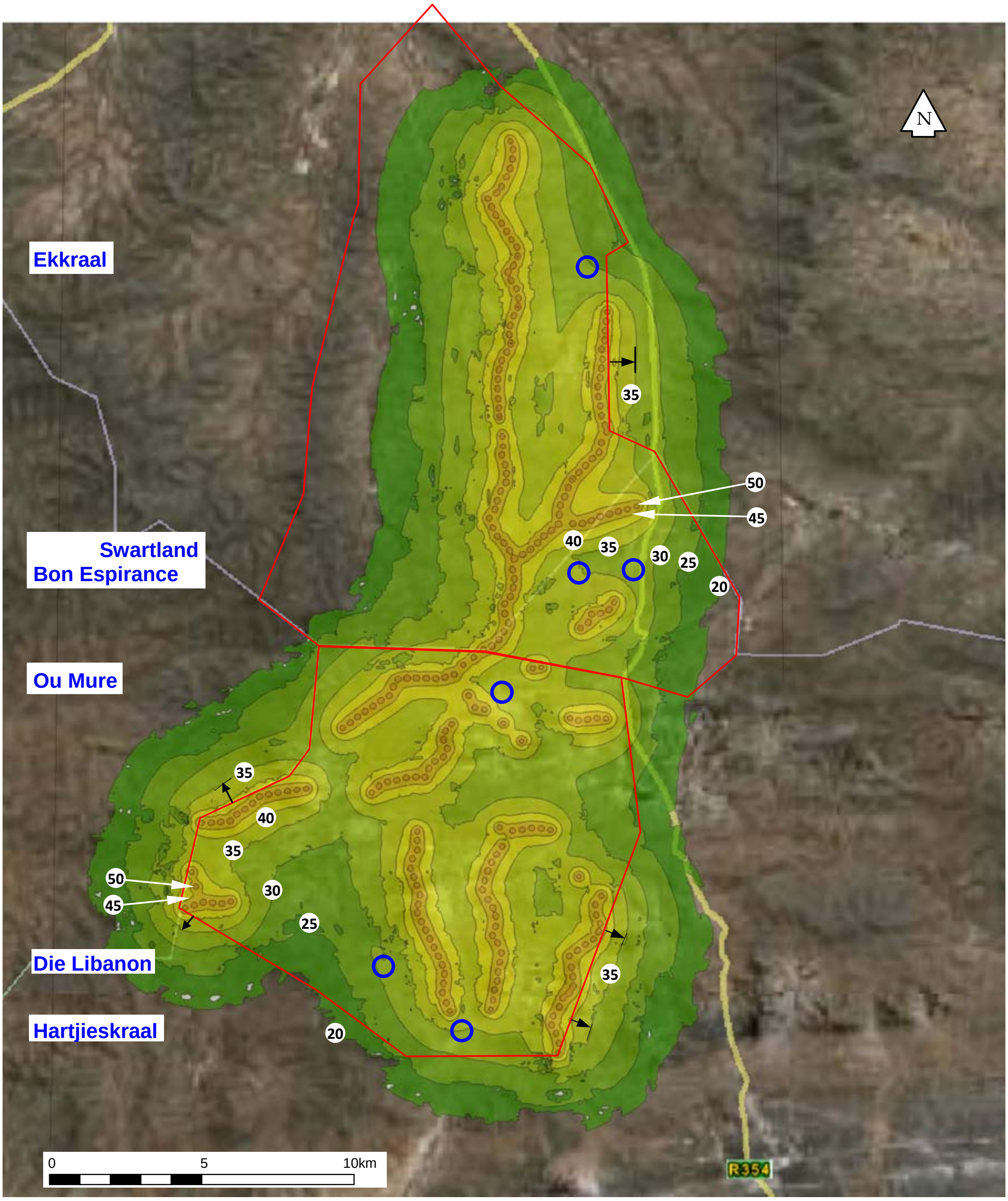


FIGURE 5.1 Roggeveld proposed wind farm with site boundaries demarcated by red lines;; farm dwellings demarcated by blue circles; and calculated L_{Aeq} contours due to noise from wind turbines.

5.1 RESIDUAL SOUND LEVELS

An L_{Aeq} of 33 dBA was measured between 17h00 and 17h30 on a Saturday during a light wind with an average wind speed of approximately 2 m/s. The sound level spectrum is displayed by the bottom graph in Figure 6.2. No road traffic or other man made noise was audible. The only audible sound was that of the occasional chirping of a bird in the distance. The measured level would be representative of that on all land far removed from the R354.

The Swartland dwellings, located approximately 300 m west of the R354, are exposed to low levels of noise from sporadic road traffic. It was estimated that the daytime $L_{Req,d}$ was 35 dBA and the night-time $L_{Req,n}$ less than 30 dBA

6 RESULTS OF WIND TURBINE NOISE CALCULATIONS

The predicted L_{Aeq} contours at a height of 2 m above local ground level due to operation of the wind turbines during a wind speed of 7 m/s are displayed in Figure 5.1. The respective contour L_{Aeq} values have been denoted by numerals on a white background with a lowest value of 20 dBA. This is well below the L_{Aeq} value measured in the study area. Areas that would be exposed to levels less than 20 dBA contain no colour shading.

6.1 NOISE IMPACT ON SURROUNDING LAND

The land adjacent to the proposed wind farm site boundary is zoned for agricultural use upon which the owner(s) of the adjacent land is(are) entitled to erect a residence anywhere within and up to their boundary. In terms of Table 2 of SANS 10103 a "rural" district would apply with typical outdoor $L_{Req,d}$ of 45 dBA and $L_{Req,n}$ of 35 dBA.

Approximately 4 500 m long strips of land adjacent to the eastern site boundary in the north and in the south, as well as along the south western boundary would be exposed to L_{Aeq} in excess of 45 dBA. Many wind turbines are located in very close proximity to the boundary resulting in L_{Aeq} in excess of 50 dBA. On all of the above land the intensity of noise impact would be **High**. The L_{Aeq} would reduce to 40 dBA at approximately 400 m from the boundary with an associated **Medium** intensity of noise impact. Beyond 400 m the L_{Aeq} would reduce to 35 dBA at approximately 1 000 m from the boundary. This is indicated by black arrows and lines. The intensity of noise impact on this land would be **Low**.

In terms of the NCR the noise levels would exceed the residual level of 33 dBA measured during daytime by more than 6 dB on land extending 400 m beyond the boundary and would thus constitute a disturbing noise. Noise mitigation would thus be legally required to reduce the excess to no more than 6 dB.

6.2 NOISE IMPACT AT DWELLINGS WITHIN THE SITE BOUNDARIES

Table 6.1 summarises the calculated L_{Aeq} due to wind turbine noise at the identified dwellings, the excess over the night-time $L_{Req,n}$ of 35 dBA typical of a rural district and the predicted intensity of noise impact in terms of SANS 10328.

Table 6.1 Summary of predicted noise impact on dwellings within the Roggeveld wind farm site boundaries in terms of SANS 10328

Dwellings	Turbines L_{Aeq},dBA	Excess, dB	Noise impact
Ekkraal	24	-	Negligible
Swartland	31	-	Negligible
Bon Espirance	36	1	Low
Ou Mure	39	4	Low
Die Libanon	29	-	Negligible
Hartjieskraal	35	-	Negligible

The noise spectrum levels due to noise emanating from the wind turbines were calculated at each of the identified dwellings within the WEF site boundaries. The results are displayed in Figure 6.1 together with the average measured daytime residual sound level spectrum (refer 4.4.2). The overall L_{Aeq} appear in the legend. The Figure provides a comparison of the noise level spectrum of wind turbine noise at each dwelling location with that of the average daytime residual noise for wind speeds up to 5 m/s measured on "Karoo" land (refer to 4.3.2). This comparison was considered to represent a best estimate assuming that the wind speeds at the wind turbines, located on elevated land at least 200 m above that of the dwellings, would be higher than at the dwellings.

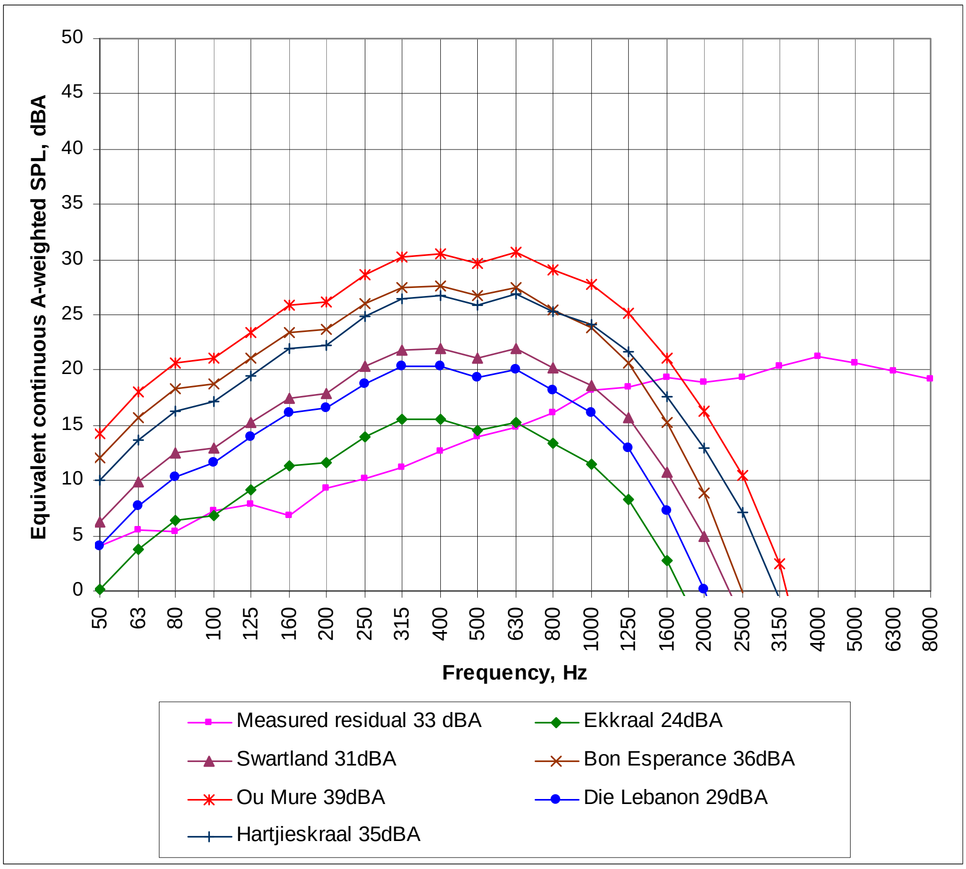


FIGURE 6.1 ***Calculated level spectra of wind turbine noise at each of six residential dwellings and average measured daytime level spectrum of residual noise.***

With the exception of Ekkraal, the level of noise from the wind turbines over a large range of frequencies would significantly exceed the residual noise by more than 10 dB. It is probable that the noise would be distinctly audible and might be construed to be intrusive.

7 NOISE MITIGATION

The mitigation of noise contains three fundamental components:

Noise source

In principle the most effective control measure is to reduce the noise at source.

Based on the information at hand the sound power emission levels of the wind energy turbines considered in this study were amongst the lowest of the latest generation of wind turbines available from different manufacturers. It was thus anticipated that a different choice of turbine manufacturer would not result in a significant reduction in levels of noise in the respective study areas. The principle of reducing the noise further at source would not be realizable.

Propagation path
Considerations include increasing the distance between noise source and receiver; the erection of enclosures around the source; the erection of noise barriers.

Enclosures around the wind turbines are not an option. Due to the height of the noise sources above the ground noise barriers, other than hills or mountain ridges, are not feasible. The only option is to increase the distance between noise source and receiver.

Receiver of the noise
In the present context this comprises the identified dwellings and their immediate surroundings.

Increasing the sound insulation of a dwelling structure would be technically feasible but would necessitate keeping all doors and windows closed air tight. This would require the costly installation and maintenance of a low-noise mechanical forced air ventilation and possibly cooling system in each dwelling. Dependent on the level of noise exposure, the adequacy of the existing structural elements (walls, ceilings, roofs, doors and windows) of each dwelling in reducing noise transmission would first need to be considered.

The implementation of actions described in the previous paragraph might well result in more comfortable indoor living conditions in the respective dwellings. In that instance it could be considered as a positive impact. However, the surrounding outdoors would still be exposed to wind turbine noise.

7.1 NOISE MITIGATION BEYOND WIND TURBINE SITE BOUNDARIES

The results of the noise calculations indicated that a separation distance of approximately 600 m between a row of wind turbines and the site boundaries would be required in order not to exceed the daytime residual sound level beyond the boundaries by 7 dB or more thereby ensuring that the noise would not be adjudicated to be a "disturbing noise" in terms of the NCR. Compliance with the legal requirement would also ensure that the intensity of noise impact on most of the land beyond the wind farm site boundaries would be **Low** in terms of SANS 10103.

In order to achieve this within the existing wind energy farm site boundaries numerous wind energy turbines would need to be relocated or removed. Alternatively, compliance with the NCR would be achieved by incorporating adjacent land into the proposed wind energy farm. There would then be **Negligible** impact of noise beyond the enlarged site boundaries.

7.2 NOISE MITIGATION AT DWELLINGS WITHIN THE SITE BOUNDARIES

In principle the airborne sound insulation of the dwellings could be increased. However, the prevailing climatic conditions would render this impractical. All apertures, such as windows and doors, would need to be kept closed necessitating the installation of forced air ventilation. The surrounding exterior noise levels would remain unaffected. Mitigation of noise at dwellings identified in this study would necessitate removal or relocation of several turbines to larger distances from the respective dwellings or relocation of the dwellings.

8 CONCLUSIONS

The results of the NIA indicated that where wind energy turbines were to be located closer than 600 m from the wind farm site boundaries the L_{Aeq} beyond the boundary would exceed the ambient (residual) sound level by 7 dB or more. In such instances this would be adjudicated to be a "disturbing noise" in terms of the NCR and noise mitigation procedures would be required to be implemented. In terms of SANS 10328 the associated intensity of noise impact would be **Medium**.

Compliance with the NCR would require the relocation or removal of numerous wind energy turbines or by incorporating adjacent land into the proposed wind energy farm.

At several dwelling locations within the Roggeveld site boundaries it was probable that the noise from the wind turbines would be audible and could be considered to be intrusive.

9 RECOMMENDATIONS

Based on the findings it is recommended that wind energy turbines are located no closer than 600 m from the wind energy farm site boundaries. With regard to the identified dwellings within the Roggeveld wind energy farm it is recommended that further, more detailed studies be conducted, to determine the most practical means of reducing the noise impact at each of the dwellings. Consideration should be given to relocation of wind turbines and/or improving the sound insulation of the dwellings.

10 REFERENCES

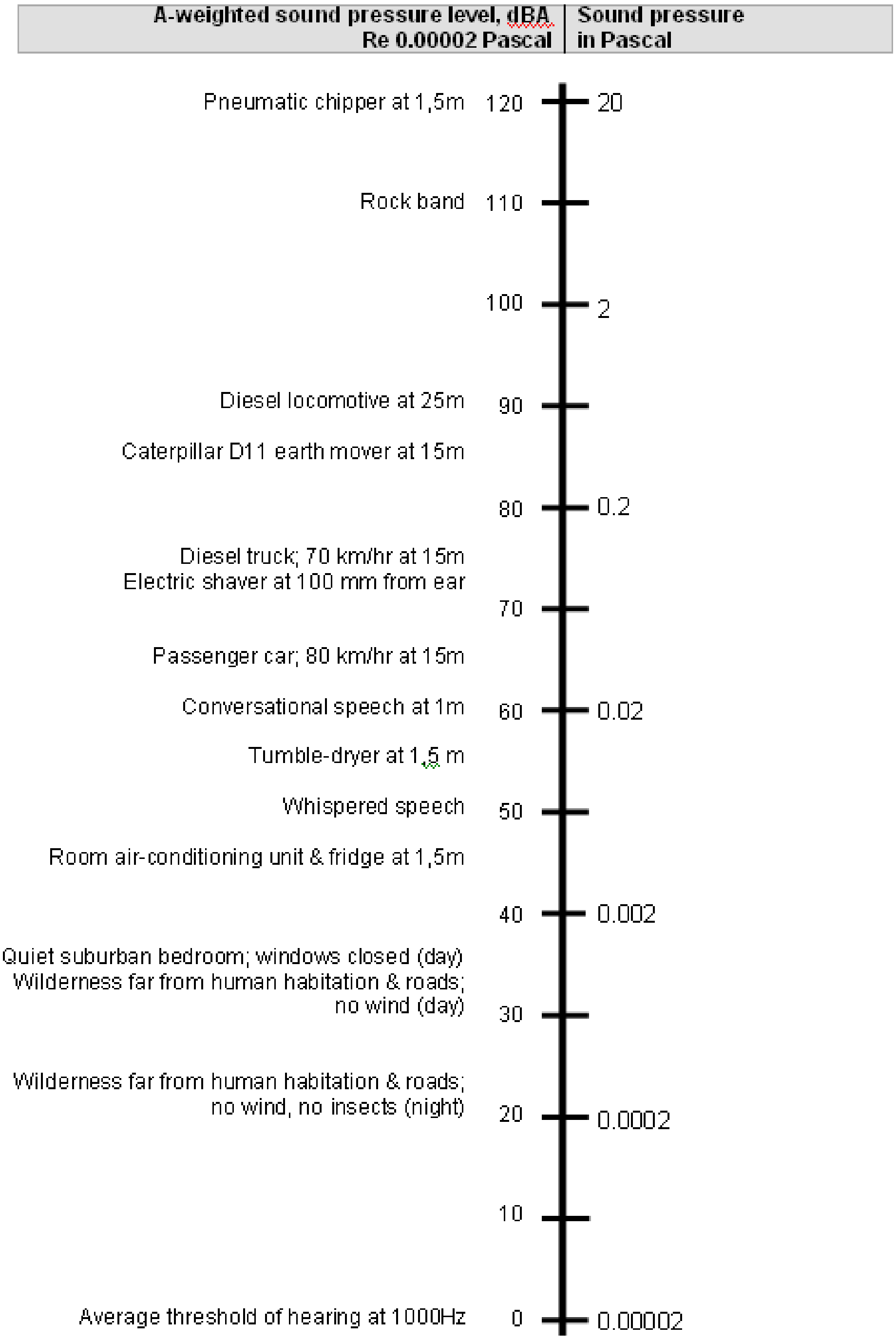
Rossing, T.D., 1990. The Science of Sound. 2nd Edition. Addison-Wesley

World Health Organisation. 2002. Protection of the Human Environment; Guidelines for community noise. Chapter 4, Guideline Values.

IEC 61400-11, Wind turbine generator systems – Part 11 Acoustic noise measurements techniques.

APPENDIX A

A-weighted sound pressure levels of typical noise sources



Humans' subjective response to changes in sound level ("loudness")

Level difference	Significance	Humans' subjective response
3 dB or less	Insignificant	No noticeable difference in "loudness"
6 dB	Significant	Noticeable difference in "loudness"
10 dB	Very significant	Doubling (or halving) of "loudness"; very noticeable