Appendix H
Noise Analysis

Cedar Ridge Wind
Acoustic Assessment

Prepared for

Cedar Ridge Wind LLC

prepared by

Superna Energy L.L.C

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Superna Energy was not directly involved in the collection of the sound pressure level data used as the basis for the analysis in this report and therefore can not be held responsible for the accuracy of this data which was developed by the turbine manufacturer.

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1. INTRODUCTION

This report has been prepared for Midwest Wind Energy and outlines the methods used to prepare the expected acoustic noise contours resulting from the development of the proposed Cedar Ridge Wind Project in Eden, Wisconsin, comprised of forty (40) 2 MW Gamesa G87 wind turbines, the turbine model with the highest sound pressure levels of those turbines under consideration. Appendix C provides the noise data for this machine as supplied by for Midwest Wind Energy. The layout used in the analysis has the turbine locations provided in Appendix B.

2. SOUND LEVELS AROUND THE WIND PROJECT

2.1 WIND TURBINE NOISE

The total noise generated by a wind turbine is made up of several different components. However, the primary sources of noise can be broadly grouped as:

- Mechanical and electrical noise.
- Aerodynamic noise.

Wind turbines only produce significant noise when they are generating power. When the wind speed is less than 7 to 9 mph (3 to 4 m/s), wind turbines do not generate power and are stationary or slowly turning. Above this "cut-in" wind speed the wind turbine will rotate at a higher speed and start generating electrical power, together with some noise. The amount of noise increases with increasing wind speed to a maximum as shown in Table 1 of Appendix C. However the background sound levels increase at a higher rate as a function of the wind speed. Because of this, the noise from the wind turbine will be most noticeable at low wind speeds (and above the cut-in wind speed).

2.1.1 MECHANICAL AND ELECTRICAL NOISE

Mechanical noise originates from sources such as the gearbox, cooling fans, electrical generator(s) and transformers. Occasional low levels of mechanical noise also arise from motors that control the pitch of the blades and the orientation of the wind turbine nacelle.

All mechanical noise sources are contained within the wind turbine nacelle. There are several standard techniques that are used to reduce these noise sources. These include use of special gears, the mounting of vibrating components on vibration isolating mounts and the use of acoustic insulation to dampen noise.

Modern wind turbines are designed to reduce mechanical noise sources to levels such that the dominant noise from the wind turbine is the aerodynamic noise (i.e. that produced by the movement of the blades through the air).

Electrical noise can be emitted by the electrical generator(s), transformers and power electronics. These sounds are usually tonal. Modern turbine designs have minimized these emissions so that they are inaudible.

2.1.2 AERODYNAMIC NOISE

Aerodynamic noise is produced by the movement of air past the blades. For modern wind turbines the majority of the noise emitted by a wind turbine is caused by the blades 'cutting' through the air.

Aerodynamic noise is made up of a wide range of frequencies and as such it has characteristics similar to, for example, the noise of wind rushing through trees. This noise increases with the speed of the blades passing through the air, i.e. with speed of rotation. In the US two types of Utility Scale turbines are used; (i) fixed speed machines for which the rotor speed varies very little over the total generation range, and (ii) variable speed machines for which the maximum rotor speed is at full load and can be as much as 50% slower at low loads (hence reducing the sound pressure level generated at low power output). The proposed Gamesa turbine is of the second type.

Close to the turbine, the loudness of the aerodynamic noise component (as heard by an observer on the ground) varies with rotor speed (if applicable) and with each blade passing the tower. At a distance any noise that would be heard would have less variation due to propagation effects. By placing a number of wind turbines in a wind farm, sound pressure level at a fixed location is the sum of effect from each turbine thus the variations due to blade passing would be less noticeable and the noise characteristics would blend in much more with the local background noise.

2.2 NOISE ATTENUATION

Sound levels decrease (attenuate) with increased distance from the source. The simplest approximation is that sound levels attenuate by 6 dB(A) (i.e. reduce to a quarter of the energy) for each doubling of distance from the source. This is due to the hemispherical spreading of the sound from a point source. However, there are refinements to be made because of the way sound travels through the atmosphere and over the ground.

Having a barrier between the sound source and the observer reduces sound levels. The measure of attenuation, due for example to topography (hills etc.) or shielding from structures (buildings) or trees, is difficult to define because it is dependant on frequency. Typical figures for broadband noise are 8 - 12 dB(A) attenuation for locations not in the line of sight of the noise source, and a further 10 dB(A) attenuation inside a typical residence, with open windows. If windows are closed the attenuation is 20 dB(A) or more, depending on the standard of glazing. (Ref. ISO 1996).

Wind speed gradients (wind shear[1]) and temperature gradients alter the way the sound travels. The normal temperature gradient, i.e. decreasing with height, causes sound to 'bend' away from the ground surface thus reducing noise at ground level. The reverse is true with an inverted temperature gradient i.e. temperature increasing with height, which can occur in calm cold conditions. However, this condition of inverted temperature gradients normally only occurs in still conditions in which wind turbines will not be operating. Of more significance is the refraction of the sound due to the wind shear. This can cause a noise shadow (quiet area) upwind of the wind turbines, though may increase noise levels in a downwind direction.

Sound is absorbed by the air itself, and this varies according to the frequency of the sound and the temperature, pressure and humidity. Low frequencies are absorbed very little but high frequencies are absorbed very quickly. Sound is also absorbed over rough surfaces such as grass, shrubs and trees as it passes through these and obstacles that lie between the source and the receiver/observer. Turbulence in the wind further distorts and attenuates the sound waves.

For this report, the levels of sound at a distance from the source have been calculated using formulae established by the International Standards Organization in ISO 9613-2, which is generally conservative since it ignores attenuation by vegetation, barriers, etc., assumes the sound propagates in a hemispherical fashion from the source and no allowance is made for the reduction associated with locations out of the line of sight.

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[1] Wind shear is a difference in wind speed relative to a change in height above ground level.

$L_p = L_w - 10 \log (2\pi R^2) - L_a$

Where:

L_p = The free field sound pressure level at the receiver.

L_w = The sound power level of the source (wind turbine). (Measured according to IEA International Energy Agency procedures)

R = The distance between the source and the receiver.

L_a = a.R

a = Attenuation of sound due to air absorption (varies with frequency).

In the analysis done for this report, a value of 1.9 dB/km has been used for air absorption {calculated for frequency of 500Hz at a temperature of 10°C (38°F), and 70% humidity}, '**a**' in the above equation.

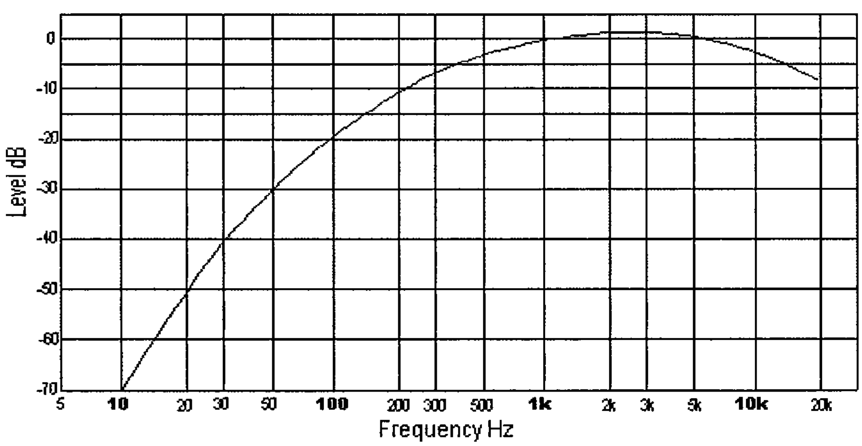
The above equation gives a prediction of the sound level at a distance from the source (the wind turbines) assuming that the wind turbine is in line of sight from the observation position.

If the turbine is hidden from view, a further attenuation of 8 to 12 dB(A) is expected. For turbines in partial view, attenuation will be between 0 dB(A) and 10 dB(A). However, no line of site attenuation is applied for this report.

3. HUMAN PERCEPTION OF SOUND

The human ear is sensitive to sound (air pressure fluctuations) over a wide range of frequencies and an extremely wide range of energy levels. The ratio of energy levels between the quietest audible sound and the loudest tolerable is more than 1 to 1 trillion (10^{12}). In order to cope with this large range when expressing a sound level, and to give a scale that matches the perception of sound levels by the human ear, the decibel scale is used. This is a logarithmic scale, where the quietest audible sound is defined as 0 dB (decibels) and the loudest tolerable is about 120 to 130 dB. Using this scale, a doubling of the sound energy (for instance by adding a second sound source) increases the sound decibel level by just 3 dB. An apparent doubling of loudness requires an increase in the sound level of approximately 10 dB, which is 10 times the sound energy.

In addition, the apparent loudness of a sound is affected by its frequency as the human ear is not sensitive to high and low frequencies. The audible range covers about 20 Hz to 20,000 Hz, and audibility rapidly decreases below about 1,000 Hz. When sound levels are being considered in relation to human audibility, the measured sound levels are adjusted to indicate how loud they are perceived to be. This is done by using the ‘A’ weighting scale. The resulting sound levels are described with the units dB(A) (or dBA), to indicate that they have been adjusted according to the ‘A’ weighting audibility scale. The following figure shows the human ear’s ability to process sound pressures at various frequencies over the audible range. The figure is scaled based on the ear’s performance compared to its best range (ie 1000 to 5000Hz ie 1k to 5k). Note that this scale is in negative dB thus the ear’s performance at 200Hz is 10dB less than at 1000Hz, ie the sound energy would need to be greater at 200Hz to be perceived the same as 1 times the sound energy at 1kHz.



The A-Weighting Curve

Figure 3.1 shows, in graphic form, typical sound levels from common sources. Table 3.1 shows further sound sources and their typical levels at various distances from the sources on the “A” weighted decibel (dBA) scale.

Relative noise levels

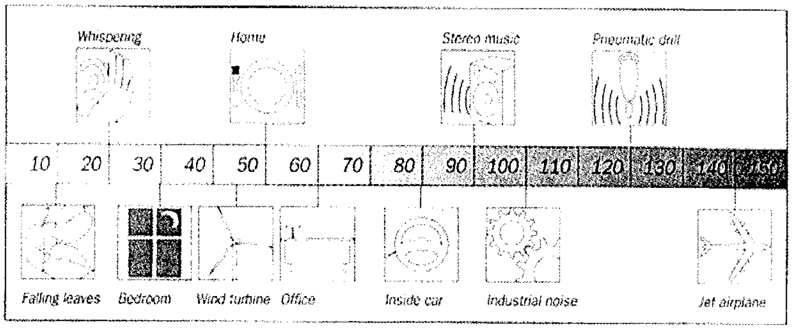


Figure 3.1 Range of typical sound levels from common sources.

Perceived Loudness Relative to Normal Speech	Sound level [dB(A)]	Description
x 256	140	Jet aircraft taking off (at 75 meters)
x 128	130	Threshold of pain
x 64	120	Pneumatic drill (at 1 meter)
x 32	110	Loud car horn (at 1 meter)
x 16	100	Pop group (at 20 meters)
x 8	90	Noisy vacuum cleaner, Lawn mower
x 4	80	Inside bus, Electric drill (at 1 meter)
x 2	70	Loud television, Curbside of busy street
Normal Speech	60	Inside a busy office
x ½	50	Suburban living room
x ¼	40	Approximate daytime noise limit
x 1/8	30	Quiet bedroom at night (no wind)
x 1/32	10	Falling leaves
x 1/64	0	Threshold of hearing

Table 3.1 Range of typical sound levels from common sources.

The character of the sound is also significant. For example, sounds consisting of only one frequency (tonal) are perceived to be more noticeable than their dB(A) value would suggest. Similarly impulsive (suddenly starting and stopping) sounds are perceived to be more noticeable. However, sounds containing frequencies over a wide range (broad band sounds) are perceived to be less intrusive. Trees blowing (rustling) in the wind or waves breaking on the shore are two everyday examples of broad band noise. On the other hand a dog barking or the sound of a siren is impulsive or tonal in character.

A significant factor for assessing human reaction to a particular sound is its loudness relative to other sounds occurring at the same time, i.e. the 'background' noise. If the background noise from a source such as traffic, farm machinery or wind is relatively high, then the noise from a new source is said to be masked. The new sound is not thought to be intrusive. However, if the background sound level is low, relative to the new source, then the new sound can be more intrusive. For example the sound of a dog barking is likely to be less intrusive on a stormy night that on a quiet and windless evening. Background (masking) noise levels tend to be lower at night, which is when a new noise is most likely to intrude. Typically, masking is such that a new noise can have a level several decibels higher than the background before it becomes intrusive. The degree of masking, however, is highly dependent on:

- The nature of the noise. For example, it's tonal or broad band content and its impulsive nature.
- The individual's perception of the noise.
- The individual's activity.
- The individual's tolerance of the source of the noise.

From Table 2 of Appendix B it is shown that the human ear perceives the sound generated by the wind turbine less and less as the frequency decreases and from the discussion above it is seen that adult people seldom hear sounds below 20Hz.

4. PREDICTED SOUND LEVELS AND LIMITS AND CONCLUSION

Wind turbine manufacturers supply sound levels produced by their wind turbines at a "standard wind condition" of 8 m/s (18mph) at 10 m (33ft) AGL (above ground level). Using these figures it is possible to calculate sound levels in the vicinity of the proposed wind farm. The wind speed condition used for the wind turbine sound levels is in the area that the wind turbines are expected to be most noticeable above the background noise, so the predicted level gives a good indication of the impact the actual wind farm will have.

The predicted sound levels at individual 30m x 30m grid points have been calculated based on sound power levels of 105.3 dB(A) – measured at a wind speed of 8 m/s (18mph) at 10m (33ft) AGL using the methods documented in ISO 9613-2. The results are shown as a dB(A) contour plot in the Appendix A.

The Joint Development Agreement (JDA) between Cedar Ridge Wind LLC and the towns of Eden and Empire requires that sound level due to wind turbine operation shall not exceed fifty (50) dBA when measured from non-participating occupied dwellings adjacent the turbines, or if it does the land owner provides a written noise waiver.

Such dwellings would only exist inside the red contours (50dBA) shown on the map in Appendix A (which consist of the calculated noise contours overlaid on the project layout). There are two residences that are within the 50dBA contours: (i) the house Southeast of WTG 6 (which satisfies the JDA in that it belongs to a participating land owner) and (ii) the house East of WTG 9 (which satisfies the JDA via a noise waiver from the land owner).

It should however be noted that these results are expected to be generally conservative (over-estimates), as they do not include the effect of sound absorption due to trees, grass and other vegetation. They do however include a factor for the absorption of sound by the atmosphere {calculated for a temperature of 10°C (38°F), and 70% humidity}, which varies with frequency.

Background noise effects usually masks the wind turbine noise, i.e. the noise from the turbine is less noticeable than indicated by the above calculations. It should also be noted that this analysis has not taken into account the following factors, likely to be present at the residences in and around the project site that would further reduce the sound levels:

- Sound levels will be lower inside the residences; a further 10 dB(A) attenuation can be expected inside a typical residence, with open windows and if the windows are closed the attenuation is 20 dB(A) or more, depending on the standard of glazing. (Ref. ISO 1996)

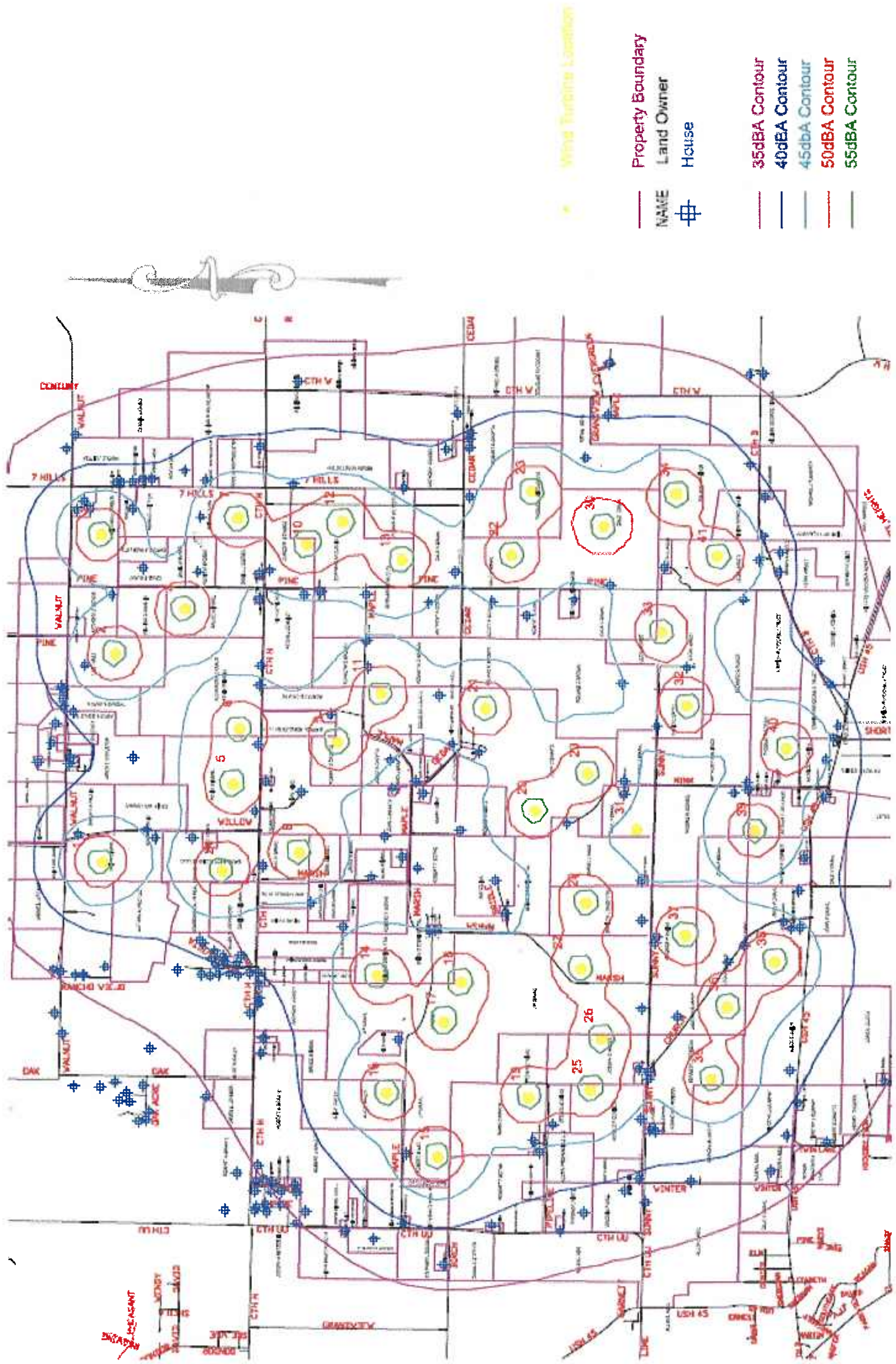
- Tall plantings around the residences - this will further increase noise attenuation and also increase wind-induced background noise which will mask the effect of the turbines. Many of the residences in the area have trees planted around the houses to provide privacy and a barrier from the prevailing winds

- Many of the residences are surrounded by farm buildings which will have an attenuation effect on the noise produced by the turbines and will also increase the wind-induced background noise further masking the effect of the turbines.

4.1 CONCLUSION

The analysis described above produces the sound level contours shown in Appendix A.

APPENDIX A: ACOUSTIC NOISE CONTOUR MAP



APPENDIX B: WTG LOCATIONS

Turbine ID	Easting (m)	Northing (m)
1	393795	4844058
2	395491	4843951
3	396460	4844062
4	395853	4843373
5	394431	4842984
6	394880	4842927
7	396593	4842937
8	393875	4842441
9	394774	4842135
10	396380	4842378
11	395169	4841776
12	396565	4842087
13	396253	4841606
14	392871	4841807
15	391398	4841327
16	391918	4841740
17	392493	4841273
18	392823	4841129
19	391882	4840576
20	394210	4840519
21	395045	4840925
22	396290	4840705
23	396810	4840535
24	393724	4843076
25	391942	4840069
26	392359	4839975
27	392929	4840147
28	393460	4840100
29	394515	4840087
30	396523	4839955
32	395065	4839275
33	395665	4839482
34	396788	4839354
35	392029	4839075
36	392614	4838950
37	393197	4839288
38	392983	4838561
39	394048	4838725
40	394718	4838461
41	396283	4839020

Table 1. Wind Turbine Locations in UTM NAD27 zone 16

APPENDIX C: GAMESA G87 NOISE DATA

Vwind[m/s]	dB(A) H= 60m	dB(A) H= 67m	dB(A) H= 78m
3	91.78	91.78	91.78
4	94.46	94.79	95.25
5	99.30	99.64	100.1
6	103.3	103.6	104.1
7	105.3	105.3	105.3
8	105.3	105.3	105.3
9	105.3	105.3	105.3
10	105.3	105.3	105.3
11	105.3	105.3	105.3
12	105.3	105.3	105.3
13	105.3	105.3	105.3
14	105.3	105.3	105.3
15	105.3	105.3	105.3
16	105.3	105.3	105.3
17	105.3	105.3	105.3
18	105.3	105.3	105.3
19	105.3	105.3	105.3
20	105.3	105.3	105.3
21	105.3	105.3	105.3
22	105.3	105.3	105.3
23	105.3	105.3	105.3
24	105.3	105.3	105.3
25	105.3	105.3	105.3

Table 1. Noise level of G87 – 2MW wind turbine for different wind velocities and tower heights

Frequency (Hz)	Sound Power Level (dBA)
31.5	79.4
63	85.6
125	91.6
250	96.6
500	99.8
1000	100.8
2000	97.0
4000	89.6
8000	77.2

Table2. Noise spectra in octave bands for G87.