Guidelines for Selecting Wind Turbine Sites

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This article reviews a number of wind turbine sites with known health problems and sound studies conducted by consultants for governments, the wind turbine owner, or the local residents. The purpose is determine if a set of simple guidelines using dBA and dBC sound levels can serve as "safe" siting guidelines. Findings of the review and recommendations for sound limits are presented, followed by a discussion of how the proposed limits would have affected existing sites where people have demonstrated pathologies apparently related to wind turbine sound.

A relatively new source of community noise is spreading rapidly across the rural U.S. countryside. Industrial-grade wind turbines, a common sight in many European countries, are now being promoted by federal and state governments as the way to minimize coal-powered electrical energy and its effects on global warming. But initial developments using the newer 1.5- to 3-megawatt wind turbines here in the U.S. has also led to numerous complaints from residents who find themselves no longer in the quiet rural communities they once knew before the wind turbine developments came to town. Questions have arisen as to whether the current siting guidelines being used in the U.S. are sufficiently protective for the people living closest to the developments. Research being conducted into the health issues using data from established wind turbine developments is beginning to appear that leaves open the possibility that there is a basis for the health concerns. Other research into the computer modeling and other methods used for determining the layout of industrial wind turbine developments and the distances from residents in adjacent communities are showing that the output of the models should not be considered accurate enough to be used as the sole basis for making site decisions.

The authors have reviewed a number of noise studies conducted in response to community complaints for wind energy systems sited in Europe, Canada, and the U.S. to determine if additional criteria are needed for establishing safe limits for industrial wind turbine sound emissions in rural communities. In several cases, the residents who filed the complaints have been included in studies by medical researchers who are investigating the potential health risks associated with living near industrial-grade wind turbines 365 days a year. These studies were also reviewed by the authors to help in identifying what factors need to be considered in setting criteria for "safe" sound limits at receiving properties. Due to concerns about medical privacy, details of these studies are not discussed here. Current standards used in the U.S. and in most other parts of the world rely on not-to-exceed dBA sound levels, such as 50 dBA, or on not-to-exceed limits based on the preconstruction background sound level plus an adder (e.g. L_{90A} + 5 dBA).

Our review covered the community noise studies performed in response to complaints, research on health issues related to wind turbine noise, critiques of noise studies performed by consultants working for the turbine developer, and research/technical papers on wind turbine sound emissions and related topics. The papers are listed in Table 1.

Discussion

After reviewing the materials in the table, we arrived at our current understanding of wind turbine noise and its impact on the host community and its residents. The review showed that some residents living as far as 3 km (2 miles) from a wind farm complain of sleep disturbance from the noise. Many of residents living one-tenth this distance (300 m or 1000 feet) from a wind farm are experiencing major sleep disruption and other serious medical problems from nighttime turbine noise. The peculiar acoustic characteristics of turbine noise emissions cause the sounds heard at the receiving properties to be more annoying and troublesome than the more familiar noise from traffic and industrial factories.

Limits used for these other community noise sources do not appear to be appropriate for siting industrial wind turbines. The residents who are annoyed by wind turbine noise complain of the approximately 1-second repetitive "swoosh-boom-swoosh-boom" sound of the turbine blades and "low-frequency" noise. It is not apparent to these authors whether the complaints that refer to "low-frequency" noise are about the audible low-frequency part of the swoosh-boom sound, the 1-Hertz amplitude modulation of the swoosh-boom sound, or some combination of both acoustic phenomena.

To assist in understanding the issues at hand, we developed the "conceptual" graph for industrial wind turbine sound shown in Figure 1. This graph illustrates the data from one of the complaint sites plotted against the sound emission spectra for a modern 2.5-MW wind turbine; Young's threshold of perception for the 10% most sensitive population (ISO 0266); and a spectrum obtained for a rural community during a 3-hour, 20-minute test from 11:45 p.m. until 3:05 a.m. on a still June evening in eastern Michigan. It is worth noting that this rural community demonstrates how quiet a rural community can be when located a distance from industry, highways, and airport-related noise emitters.

During our review we posed a number of questions to ourselves related to what we were learning.

Q. Do national, international or local community noise standards for siting wind turbines near dwellings address the low-frequency portion of the wind turbine's sound emissions?

A. No! State and local governments are in the process of establishing wind farm noise limits or wind turbine set-backs from nearby residents, but the standards incorrectly presume that limits based on dBA levels are sufficient to protect the residents

Do wind farm developers have noise limit criteria or wind turbine set-back criteria that apply to nearby residents?

Yes! But the wind turbine industry recommended residential wind turbine noise levels (typically 50-55 dBA) are too high for the rural nature of the communities and may be unsafe for the nearest residents. An additional concern is that some of the methods for implementing preconstruction computer models may predict sound levels that are too low. These two factors together can lead to post-construction complaints and health risks.

Are all residents living near wind farms equally affected by wind turbine noise?

No, children, people with pre-existing medical conditions, especially sleep disorders, and the elderly are generally the most susceptible. Some people are unaffected, while some nearby neighbors develop serious health effects caused by exposure to the same wind turbine noise.

How does wind turbine noise impact nearby residents?

Initially, the most common problem is chronic sleep deprivation during nighttime. According to the medical research documents, this may develop into far more serious physical and psychological problems.

What are the technical options for reducing wind turbine noise emission at residences?

There are only two options: 1) increase the distance between source and receiver; 2) reduce the source sound power emission. Either solution is incompatible with the objective of the wind farm developer to maximize the wind power electrical generation

Based on a paper presented at NOISE-CON 08, Institute of Noise Control Engineering, Dearborn, MI, July 2008.

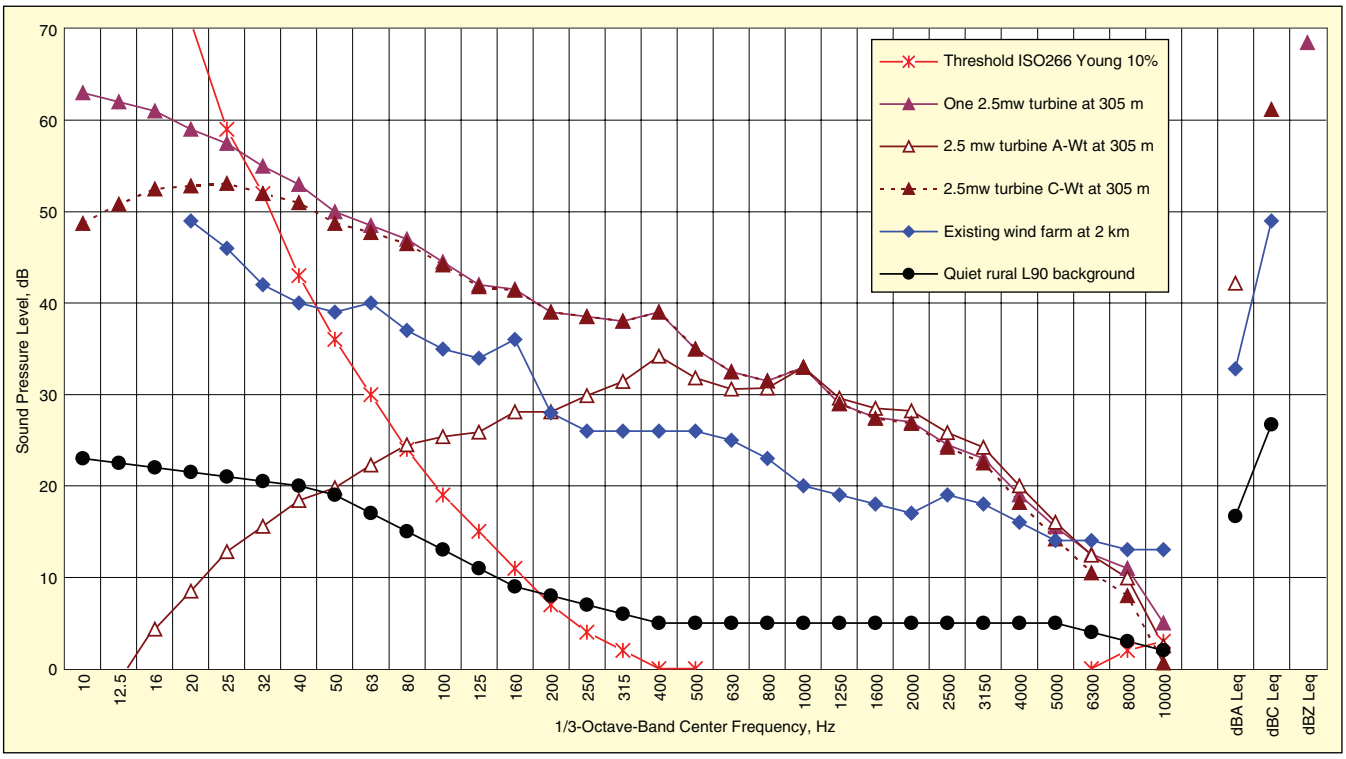

Figure 1. Generalized sound spectra vs. perception and rural community L_{90A} background, one-third-octave SPL.

within the land available.

Is wind turbine noise at a residence much more annoying than traffic noise?

Yes, researchers have found that "wind turbine noise was perceived by about 85% of the respondents even when the calculated A-weighted SPLs were as low as 35.0-37.5 dB. This could be due to the presence of amplitude modulation in the noise, making it easy to detect and difficult to mask by ambient noise." [JASA 116(6), December 2004, pp. 3460-3470, "Perception and Annoyance due to Wind Turbine Noise – A Dose-Relationship," Eja Pedersen and Kerstin Persson Waye, Dept. of Environmental Medicine, Goteborg University, Sweden.]

Why does wind turbine noise emissions of only 35 dBA disturb sleep at night?

This issue is now being studied by the medical profession. The affected residents complain of the middle- to high-frequency swooshing sounds of the rotating turbine blades at a constant repetitive rate of about 1 Hz plus low frequency noise. The amplitude modulation of the swooshing sound changes continuously. The short interval between the 1 Hz swooshing sound is described by residents as sometimes having a thump or low frequency banging sound that varies in amplitude up to 10 dBA as phase changes occur between turbines. The assumptions about wall and window attenuation being 15 dB or more may not be correct for a wind turbine's emission spectra.

What are typical wind farm noise emission criteria or standards?

Limits are not consistent and may vary even within a particular country. Example criteria include: Australia – the lower of 35 dBA or L_{90} + 5 dBA; Denmark – 40 dBA; France – L_{90} + 3 (night) and L_{90} + 5 (day); Germany – 40 dBA; Holland – 40 dBA; United Kingdom – 40 dBA (day) and 43 dBA (night) or L_{90} + 5 dBA; Illinois – 55 dBA (day) and 51 dBA (night); Wisconsin – 50 dBA; and Michigan – 55 dBA. Note: Illinois statewide limits are expressed only in nine contiguous octave frequency bands and no mention of A-weighting for the hourly L_{eq} limits. Typically, wind turbine noise just meeting the octave band limits would read 5 dB below the energy sum of the nine octave bands after applying A-weighting. So the Illinois limits are approximately 50 dBA (daytime 7 a.m. to 10 p.m.) and 46 dBA at night assuming the wind farm is a Class C property line noise source.

What is a reasonable wind farm sound emission limit to protect the health of residences?

We are proposing an emission limit of 35 dBA or L_{90A} + 5 dBA, whichever is lower, and also a C-weighted criteria to address the impacted resident's complaints of turbine low-frequency noise. For the proposed criteria, the dBC sound level at a receiving property shall not exceed L_{90A} + 20 dB. In other words, the dBC operating emission limit shall not be more than 20 dB above the measured dBA (L_{90A}) preconstruction nighttime background sound level. A maximum not-to-exceed limit of 50 dBC is also proposed.

Why should the dBC emission limit not be permitted to be more than 20 dB above the background measured L_{90A}?

The World Health Organization and others have determined a noise with dBC – dBA value greater than 20 dB to be an annoying low-frequency issue.

Is not L_{90A} the minimum dBA background noise level?

This is correct, but it is very important to establish the statistical average background noise environment outside a potentially impacted residence during the quietest (10 p.m. to 4 a.m.) sleeping hours of the night. This nighttime sleep disturbance has generated the majority of complaints about wind farms throughout the world. The basis for a community's wind turbine sound emission limits would be the minimum 10-minute nighttime L_{90A} plus 5 dB from 10 p.m. to 7 a.m. This would become the nighttime emission limits for the proposed wind farm. This can be accomplished with one or several 10-minute measurements during any night when the atmosphere is classified as stable. The daytime limits (7 a.m. to 7 p.m.) could be set 10 dB above the minimum nighttime L_{90A} measured noise, but the nighttime criteria will always be the limiting sound levels.

A nearby wind farm meeting these noise emission criteria will be clearly audible to the residents occasionally during nighttime and daytime. Compliance with this noise standard would be determined by repeating the initial minimum nighttime L_{90A} tests and adding the dBC (L_{eqC}) noise measurement with the turbines on and off. If the nighttime background noise level (turbines off) was slightly higher then the measured background prior to the installation, then the results with the turbines on must be corrected to determine compliance with the pre-turbine established sound limits.

The common method used for establishing the background sound level at a proposed wind turbine farm used in many of the studies in Table 1 was to use unattended noise monitors to record hundreds of 10-minute measurements to obtain a statistically sig-

Table 1. Lists of wind-turbine studies.

Community Noise Studies Related to Complaints

1. Resource Systems Engineering, Sound Level Study – Ambient and Operations Sound Level Monitoring, Maine Department of Environmental Protection Order No. L-21635-26-A-N, June 2007.
2. ESS Group, Inc., Draft Environmental Impact Statement For the Dutch Hill Wind Power Project – Town of Cohocton, NY, November 2006.
3. David M. Hessler, Environmental Sound Survey and Noise Impact Assessment – Noble Wethersfield Wind Park – Towns of Wethersfield and Eagle, NY; for Noble Environmental Power, LLC, January 2007.
4. George Hessler, "Report Number 101006-1, Noise Assessment Jordanville Wind Power Project," October 2006.
5. HGC Engineering, "Environmental Noise Assessment Pubnico Point Wind Farm, Nova Scotia, Natural Resources Canada Contract NRCAN-06-0046," August 23, 2006.
6. John I. Walker, Sound Quality Monitoring, East Point, Prince Edward Island" by Jacques Whitford, Consultants for Prince Edward Island Energy Corporation, May 28, 2007.

Studies Related to Health

1. Nina Pierpont, "Wind Turbine Syndrome – Abstract" from draft article and personal conversations. www.ninapierpont.com.
2. Nina Pierpont, "Letter from Dr. Pierpont to a resident of Ontario, Canada, Re: Wind Turbine Syndrome," Autumn 2007.
3. Amanda Harry, "Wind Turbine Noise and Health," 2007.
4. Barbara J. Frey and Peter J. Hadden, "Noise Radiation from Wind Turbines Installed Near Homes, Effects on Health," 2007.
5. Eja Pedersen, "Human Response to Wind Turbine Noise – Perception, Annoyance and Moderating Factors, Occupational and Environmental Medicine," The Sahlgrenska Academy, Gotenborg 2007.
6. Robin Phipps, "In the Matter of Moturimu Wind Farm Application, Palmerston North, Australia," March 2007.
7. WHO European Centre for Environment and Health, Bonn Office, "Report on the third meeting on night noise guidelines," April 2005.

Studies Reviewing Siting Impact Statements

1. Richard H. Bolton, "Evaluation of Environmental Noise Analysis for Jordanville Wind Power Project," December 14, 2006, Rev 3.
2. Clifford P. Schneider, "Accuracy of Model Predictions and the Effects of Atmospheric Stability on Wind Turbine Noise at the Maple Ridge Wind Power Facility," Lowville, NY, 2007.

Research and Papers Included in Review Process

1. Anthony L. Rogers, James F. Manwell, Sally Wright, "Wind Turbine Acoustic Noise," Renewable Energy Research Laboratory, Dept. of ME and IE, U of Mass, Amherst, amended June 2006.
2. ISO. 1996. Acoustics – Attenuation of sound during propagation outdoors, Part 2: General method of calculation, International Organization of Standardization, ISO 9613-2. p. 18.
3. G. P. van den Berg, "The Sounds of High Winds – the effect of atmospheric stability on wind turbine sound and microphone noise," Ph.D. thesis, 2006.
4. Fritz van den Berg, "Wind Profiles over Complex Terrain," *Proceedings of Second International Meeting on Wind Turbine Noise*, Lyons, France, Sept. 2007.
5. William K. G. Palmer, "Uncloaking the Nature of Wind Turbines Using the Science of Meteorology," *Proceedings of Second International Meeting on Wind Turbine Noise*, Lyons, France, Sept. 2007.
6. Soren Vase Legarth, "Auralization and Assessment of Annoyance from Wind Turbines," *Proceedings of Second International Meeting on Wind Turbine Noise*, Lyons, France, Sept. 2007.
7. Julian T. and Jane Davis, "Living with aerodynamic modulation, low-frequency vibration and sleep deprivation – how wind turbines inappropriately placed can act collectively and destroy rural quietitude," *Proceedings of Second International Meeting on Wind Turbine Noise*, Lyons, France, Sept. 2007.
8. James D. Barnes, "A Variety of Wind Turbine Noise Regulations in the United States – 2007," *Proceedings of Second International Meeting on Wind Turbine Noise*, Lyons, France, Sept. 2007.
9. M. Schwartz and D. Elliott, Wind Shear Characteristics at Central Plains Tall Towers, NREL 2006
10. IEC 61400 "Wind turbine generator systems, Part 11: Acoustic noise measurement techniques," Rev: 2002.

nificant sample over varying wind conditions or a period of weeks. The measured results for daytime and nighttime are combined to determine the statistically average wind noise as a function of wind velocity measured at a height of 10 meters. This provides an enormous amount of data, but the results have little relationship to the wind turbine sound emission or turbine noise impact with nearby residents. The purpose of this exhaustive exercise often only demonstrates how much noise is generated by the wind. In some cases it appears that the data are used to "prove" that the wind noise masks the turbine's sound emissions.

The most glaring fault with this argument is shown during the frequent nighttime conditions with a stable atmosphere when the wind turbines generate maximum electricity and noise, while the wind at ground level is calm and the background noise level is low. This is the condition of maximum turbine noise impact on nearby residents. It is the condition that most directly causes chronic sleep disruption. Furthermore, this methodology is usually faulty, since much of the wind noise measured by unattended sound monitors is the wind noise generated at the microphone windscreen and gives totally erroneous results (see studies in Table 1).

Are there additional noise data to be recorded for a pre-construction wind turbine noise survey near selected dwellings?

Proposed Sound Limits for Wind Turbine Sites

1. Audible Sound Limit

a. No wind turbine or group of turbines shall be located so as to cause an exceedance of the pre-construction/operation background sound levels by more than 5 dBA. The background sound levels shall be the L_{90A} sound descriptor measured during a pre-construction noise study during the quietest time of evening or night. All data recording shall be a series of contiguous 10-minute measurements. L_{90A} results are valid when L_{10A} results are no more than 15 dBA above L_{90A} for the same time. Noise-sensitive sites are to be selected based on wind development's predicted worst-case sound emissions (in L_{eqA} and L_{eqC}), which are to be provided by developer.

b. Test sites are to be located along the property line(s) of the receiving nonparticipating property(s).

c. A 5-dB penalty is applied for tones or when the sound emissions fluctuate in amplitude or frequency over time in reasonable synchronicity with the blade revolution.

2. Low-Frequency Sound Limit

a. The L_{eqC} sound levels from the wind turbine at the receiving property shall not exceed the lower of either:

1) $L_{eqC} - L_{90A}$ greater than 20 dB outside any occupied structure, or

2) A maximum not-to-exceed sound level of 50 dBC.

These limits shall be assessed using the same nighttime and wind/weather conditions required in 1.a. Turbine operating sound emissions (L_{eqA} and L_{eqC}) shall represent worst-case sound emissions for stable nighttime conditions with low winds at ground level and winds sufficient for full operating capacity at the hub.

3. General Clause

a. Not to exceed 35 dBA within 30 m. (approx. 100 feet) of any occupied structure.

4. Requirements

a. All instruments must meet ANSI or IEC precision sound level meter performance specifications.

b. Procedures must meet ANSI S12.9 and other applicable ANSI standards.

c. Measurements must be made when ground level winds are 2 m/s (4.5 mph) or less. Wind shear in the evening and night often result in low ground level wind speed and nominal operating wind speeds at wind turbine hub heights.

d. IEC 61400 procedures are not suitable for enforcement of these requirements. ANSI standards shall be followed for testing procedures.

Yes, the measuring sound level meter(s) need to be programmed to also include measurement of L_{eqA} and L_{10A}. These results will be used to help validate the L_{90A} data. On a quiet night, for example, one might expect L_{10A} less L_{90A} or L_{eqA} to be less than 10 dB. On a windy night or day, the difference may be more than 20 dB. There is a requirement for measuring wind velocity near the sound measurement microphone continuously throughout each 10-minute recorded noise sample. The 10-minute average of the wind speed near the microphone shall not exceed 2 m/s (4.5 mph), and the maximum wind speed for operational tests shall not exceed 4 m/s (9 mph). It is strongly recommended that observed samples be used for these tests.

Is there a need to record weather data during the background noise recording survey?

One weather monitor is required at the proposed wind farm on the side nearest the residents. The weather station sensors are a standard 10 meters above ground. It is critical the weather be recorded every 10 minutes and synchronized with the clocks in the sound level recorders with no ambiguity in the start and end of each 10-minute period. The weather station should record wind speed and direction, temperature, humidity and rain.

Why do Canada and some other countries base the permitted wind turbine noise emission limits on the operational wind velocity at the 10-meter height wind speed instead of a maximum dBA or L_{90} + 5 dBA emission level?

First, it appears that the wind turbine industry will take advantage of every opportunity to elevate the maximum permitted noise immission level to reduce the setback distance from the nearby dwellings. Including wind as a masking source in the criteria is one method for elevating the permissible limits. Indeed the background noise level does increase with surface wind speed. When it does occur, it can be argued that the increased wind noise provides some masking of turbine noise emission. But in the middle of the night when the atmosphere is defined as stable (no vertical flow from surface heat radiation), the layers of the lower atmosphere can separate and permit wind velocities at the turbine hubs to be 2 to 2.5 times the wind velocity at the 10-meter-high wind monitor but remain near calm at ground level. The result is the wind turbines can be operating at or close to full capacity while it is very quiet outside nearby dwellings. This is the heart of the wind turbine noise problem for residents within 3 km (about 2 miles) of a wind farm. When the turbines are producing operating noise, it is quietest outside the surrounding homes. The Ph.D. thesis of P.G. van den Berg "The Sounds of High Winds," is very enlightening on this issue. Also the letter by John Harrison in Ontario "On Wind Turbine Guidelines."

What sound monitor measurements would be needed for enforcing a wind turbine sound ordinance?

A similar sound and wind 10-minute series of measurements would be repeated at the pre-wind farm location nearest the resident registering the wind turbine noise complaint with and without the operation of the wind turbines. An independent acoustics expert should be retained to report to the county board or other responsible governing body. This independent acoustics expert shall be responsible for all the acoustic measurements including instrumentation setup, calibration and interpretation of recorded results. An independent acoustical consultant shall also perform all pre-construction background noise measurements and interpretation or results to establish the nighttime (and daytime, if applicable) industrial wind turbine sound emission limits. At present, acoustical consultants are retained by and work directly for the wind farm developer.

This presents a serious problem with conflict of interest on the part of the consultant. The wind farm developer would like to show the significant amount of wind noise that is present to mask the sounds of the wind turbine emissions. The community impacted by the wind farm would like to know that wind turbine noise will be only barely perceptible and then only occasionally during night or day.

Is frequency analysis required either during pre-wind farm background survey or for compliance measurements?

Normally one-third octave or narrower band analysis would only be required if there is a complaint of tones being emitted from the wind farm.

Proposed Sound Limits

The simple fact that so many residents complain of low-frequency noise from wind turbines is clear evidence the single A-weighted (dBA) noise descriptor used in most jurisdictions for siting turbines is not adequate. The only other simple audio frequency weighting that is standardized and available on all sound level meters is the C-weighting or dBC. A standard sound level meter set to measure dBA is increasingly less sensitive to low frequencies below 500 Hz (one octave above middle C). The same sound level meter set to measure dBC is equally sensitive to all frequencies above 32 Hz (lowest note on a grand piano).

We are proposing to use the commonly accepted dBA criteria that is based on the pre-existing background sound levels plus a 5-dB allowance for the wind turbine's emissions (e.g. L_{90A} +5) for the audible sounds from wind turbines. But to address the lower frequencies that are not considered in A-weighted measurements, we are proposing to add limits based on dBC. The proposed criteria are presented in the "Proposed Sound Limits for Wind Turbine Sites" sidebar.

For current industrial-grade wind turbines in the 1.5- to 3-MWatt range, adding the dBC requirement will result in an increased distance between wind turbines and nearby residents. For the generalized graphs shown in Figure 1, the distances would need to be approximately double current distances. This will result in setbacks in the range of 1 km or greater for the current generation of wind turbines if they are to be located in rural areas where the L_{90A} background sound levels are 30 dBA or lower. In areas with higher background sound levels, turbines could be located somewhat closer but still at a distance greater than the 305 m (1000 ft) or less setbacks commonly seen in U.S.-based wind turbine developments. SV

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