Second International Meeting
on
Wind Turbine Noise
Lyon France September 20 – 21 2007

A proposal for evaluating the potential health effects of wind turbine noise for projects under the Canadian Environmental Assessment Act

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Abstract

The *Canadian Environmental Assessment Act* (CEAA) requires certain projects with federal government triggers to undergo an environmental assessment (EA) before receiving federal government approval. The intent is to ensure that actions are taken to promote sustainable development and to ensure that projects do not cause significant adverse environmental effects. Environmental effects may include health effects from project related noise. To help the responsible authorities for an EA make this determination, they may request specialist information and knowledge from Health Canada or other specialists, as prescribed under CEAA. For wind turbine projects, Health Canada has provided advice based on the evaluated project-related changes in high annoyance, per ISO 1996-1 and U.S. Federal Transit Administration (FTA) noise impact criteria. In the U.S document, a 6.5% increase in high annoyance can be considered a severe noise impact. Extension of the U.S. FTA document to wind turbine noise in quiet rural settings implied that a severe noise impact for wind turbines could correspond to sound levels as low as 45 dBA. This takes into account the finding that in quiet rural areas there may be a greater expectation for and value placed on “peace and quiet” equivalent to up to 10 dB. A constant sound level less than 45dBA measured outdoors also corresponds to the WHO threshold level for sleep disturbance when windows are partially opened. Furthermore, if sound levels at the receptor are kept below 45dBA, the ANSI S12.2 rattle criterion will not be exceeded in the 63 Hz octave band. Turbine noise has been evaluated at the wind speed that produces the highest noise from the turbine, and background noise has been evaluated in calm winds. This allows for sheltering

by obstructions or wind speed gradients related to stable atmospheric conditions. Wind turbine construction noise has been assessed in terms of whether widespread complaints may be expected from its normalized day-night sound level, based on the EPA "Levels" document.

Introduction

The *Canadian Environmental Assessment Act* (CEAA) requires certain projects with federal government triggers to undergo an environmental assessment (EA) before receiving federal government approval. The intent is to ensure that actions are taken to promote sustainable development and to ensure that projects do not cause significant adverse environmental effects. Environmental effects may include health effects from project related noise. To help the responsible authorities for an EA make this determination, they may request specialist information and knowledge from Health Canada or other specialists, as prescribed under CEAA [1;2]. Noise has been an issue in a number of projects of major social, economic and military importance and wind turbine projects have become more common in the recent past.

As of 2006, Canada became one of 13 countries to exceed 1000 megawatts of wind capacity [3]. This was owing in large part to a doubling of wind energy capacity in 2006 in Canada to 1459MW and it has been projected that Canada will increase this capacity to at least 10,000MW by 2015. The increase in projects falling under CEAA can be explained by the fact that the development of wind energy in Canada is partially related to financial support through Federal government programs such as the now completed Wind Power Production Incentive (WPPI) program and the current EcoEnergy for Renewable Power program. EcoEnergy for renewable power is coordinated by Natural Resources Canada with a Federal commitment of $1.48 billion to increase Canada's supply of clean electricity from renewable sources such as wind, biomass, low-impact hydro, geothermal, solar photovoltaic and ocean energy. The EcoEnergy initiative is intended to increase the production of energy to 14.3 terrawatt hours from renewable energy sources [4].

As a starting point for the potential development of Health Canada guidelines, this paper provides proposals for criteria for evaluating the potential

health effects of wind turbine noise for environmental assessments. The reasoning behind the proposals is summarized.

Proposed Criteria for predicted sound levels

On the assumption that the wind turbines produce constant noise, it is proposed that a 45 dBA Leq for the sound level not be exceeded at the most exposed façade of a noise sensitive receptor during wind turbine operation in quiet rural settings[1]. In the rare cases where turbines have been erected in more urbanized areas, higher levels are proposed for the criterion value of the assumed continuous sound level (i.e. from 55 to 69 dBA Leq). In these latter cases, the proposed criterion value is the wind turbine sound level that leads to a 6.5% increase in the percentage highly annoyed.

The Leq value is the predicted sound level determined for the highest wind turbine sound power level found as a function of wind speed, evaluated as if all noise sensitive receptors are sited under favourable, propagation conditions.

The proposed sound level criteria are based on project-related changes in high annoyance, evaluated in terms of changes in the percentage highly annoyed (%HA) from the noise environment without the wind turbine(s) to the noise environment with the wind turbines, as per ISO 1996-1 [6]. The second factor determining the proposed criterion value, is the U.S. Federal Transit Administration's (FTA) [7] consideration that a 6.5% increase in the %HA corresponds to a severe noise impact. Furthermore, if sound levels at the receptor are kept below 45dBA, the ANSI S12.2 [8] rattle criterion will not be exceeded in the 63 Hz[2] octave band. A 45 dBA Leq for constant noise is also consistent with the World Health Organization's (WHO) recommendation that the equivalent sound level indoors should not exceed 30 dBA for continuous background noise for a good night's sleep[9]. With windows partially opened, this

[1] The characterization of an area as a "quiet rural" is ultimately left up to the project proponent to determine through community consultation. However, until the proponent makes this determination, Health Canada assumes an area to be a quiet rural area when the background sound levels are below 45dBA during the day and 35dBA during the night. In such areas, population density is typically less than 8 dwellings per square kilometre [5].

[2] In ANSI S12.2 [8] recommendations are given for the 16, 32 and 63 Hz octave bands, but 63 Hz is the lowest measured band in the normative section of IEC 61400-11.

translates into an outdoor continuous sound level of 45 dBA. A 40-45 dBA limit is also similar to the most stringent values used for industrial noise sources in quiet areas in some of the provinces in Canada (e.g. Alberta, Quebec, Ontario and Manitoba -- a more detailed discussion of Provincial guidelines is given below).

Dose response for annoyance

Preferably, the proposed criteria would be based on a dose response relationship that was specific to wind turbines. Independently verified dose response relationships are available for transportation sources [10], but there has only been a small number of published dose response relationships available that are specific to wind turbines [11;12].

One study of older wind turbines from Sweden [12] suggested that the percentage "very annoyed" by wind turbine noise was around 8% at a predicted value of 36 dBA Leq, rising steeply to around 36% as a predicted sound level of 40 dBA was approached. However, these authors did not reproduce this observation in a follow up to this study [11] where there was no statistically significant relationship between wind turbine sound level and the percentage of surveyed respondents who indicated that they were either rather or very annoyed by wind turbine noise.

Adjustments compared to other industrial sources

Quiet areas

The lack of a specific dose response relationship for wind turbines and health effects requires that effects be evaluated by applying the relationships for other sources. It is common to apply adjustments to other sources, but it is not immediately obvious what, if any, should be applied to wind turbines.

In quiet rural areas where wind turbines are typically sited, it is proposed that a 10 dB adjustment be applied to project noise compared to industrial sources in urbanized settings. This is a precautionary adjustment based on the statement in ISO1996-1:2003 [6] indicating that research has shown that there is

a greater expectation for and value placed on “peace and quiet” in quiet rural settings, which may be equivalent to up to 10 dB.

Tonal noise

It is not common for modern wind turbine designs to be associated with tonal noise, however, it needs to be verified whether the project gives rise to tonal sound. This sound level information should be available if the manufacturer’s specifications conform to the requirements of International Electrotechnical Commission (IEC) standard IEC 61400-11 (2002) on Wind turbine generator systems - Part 11: Acoustic noise measurement techniques [13]. In accordance with the ISO 1996-1 standard, audible tonal sound is adjusted by +5dB in the determination of noise annoyance. To the extent that tonal noise is present, the proposed criterion level of 45 dBA will need to be reduced.

Low frequencies

Even though research shows that annoyance is greater when low frequency noise is present [6;14], modern turbine designs are not normally associated with audible levels of low frequency or infrasound [15]. Natural levels of wind induced noise make wind turbine noise below the 50 Hz 1/3rd octave band difficult to measure and this information is not required by standard IEC 61400-11 [13]; although it is considered optional information. Therefore, the proposed criterion sound levels are based on a comparison of sound levels from the project in the 63 Hz octave band[3] to the ANSI S12.2 [8] rattle criterion to indicate the effect that these low frequency sounds may have on the noticeability of noise-induced vibrations in light-weight ceilings and duct work and rattling in light fixtures, doors and windows. In the 63 Hz octave band, moderately noticeable vibrations are associated with a sound level of 70 dBZ, or 43 dBA (conservatively assuming that all the sound energy is in the 63 Hz octave band)

[3] In ANSI S12.2 [8] recommendations are given for the 16, 32 and 63 Hz octave bands, but the 50 Hz 1/3rd octave band is the lowest measured band in the normative section of IEC 61400-11.

[16]. Above 43 dBA, rattles due to low frequency noise may become a possibility for wind turbine noise impacts. If this level is exceeded, then a comparison should be made to 80 dBZ for the 63 Hz band. At 80dBZ, clearly noticeable vibrations may occur and they could be ongoing [8]. Therefore, it is reasonable to conclude that there could be an increase in annoyance from these vibrations.

Other Potential Sound Level Adjustments

Other sound level adjustments that would help predict community reaction/annoyance towards wind turbines were also considered in the development of the proposed criterion. These other adjustments have not been applied due to lack of supporting data. In ISO1996-1 source specific adjustments are applied to aircraft and electric rail, which reflect human response to these, but no similar adjustments have been proposed for wind turbines.

Wind turbines create a characteristic “swooshing” sound [13]. In the province of Ontario, in land use guidelines [17;18] a +5 dB adjustment is specified for a project that contains a cyclic variation in sound level. This adjustment is applied when the project noise has an audible “beating” or other amplitude modulations, but not applied to wind turbines, nor has it been used in other jurisdictions. For these reasons, this adjustment was not applied to the proposed wind turbine criterion.

Although it has not been adopted in the proposed criterion, another plausible adjustment for consideration stemmed from an analysis of the similarities between some aspects of aircraft noise and wind turbine noise under certain conditions. When large turbines are built close to homes (e.g. less than 5 times the turbine hub height), the source may be more similar to an overhead source than a typical ground-level industrial source. When turbines are located close to homes, the noise can enter through the roof of the house, which has comparatively less sound insulation than the walls. Noise barriers have little effect, and unlike ground based sources, there is no acoustic shadow due to wind direction and temperature gradients. ISO1996-1 2003 suggests a +3 to +6 dB adjustment on aircraft noise. It has been hypothesized that one of the reasons for the demonstrated adjustment for aircraft noise is the fact that it is an overhead

source, suggesting that the potential for a +3 to +6 dB adjustment for wind turbine noise may need to be investigated if large turbines are built close to homes where they may begin to take on the characteristics of an overhead source. More research would be needed to assess this potential adjustment. Also, at this time, it does not appear to be an issue in Canada because most large turbines are installed at set-back distances further than about 5 times the turbine hub height; however, no guidelines exist on how far a turbine should be from a noise sensitive receptor.

Justification for use of the predicted worst case

The proposed criterion sound level is the predicted sound level determined for a worst case condition for the highest wind turbine sound power level found as a function of wind speed, evaluated as if all noise sensitive receptors are sited under favourable, propagation conditions.

Frequently the wind speed at the receptors is assumed equal to the wind speed associated with the noise levels obtained using the IEC standard [13]. However, this can create a risk of unexpected annoyance from intruding wind turbine noise because the wind speed at the noise sensitive receptor may be significantly different than that at the turbine hub due to sheltering by obstructions or wind speed gradients related to stable atmospheric conditions.

The United Kingdom's Department of Trade and Industry [19] has suggested that, in some cases, receivers can be sheltered from the wind so that there is no masking of the turbine noise by ground level wind noise. In Canada, wind turbines are often sited on hilltops. On level ground sheltered areas due to treed wind breaks are common to avoid winter whiteout and snow drifting. These stands of trees can attenuate wind noise heard on the ground, yet may do little to attenuate wind turbine noise (i.e. turbine noise becomes more noticeable at the receptor).

Also, under conditions of atmospheric stability, (i.e., clear nights) wind speed at receptors may be significantly lower than wind speed at the turbine hub. Van den Berg [20] has shown that the wind speed at night is up to 2.6 times

higher at the turbine hub than on the ground (at 10m). Based on atmospheric stability data from the Netherlands [21], worst case conditions might be expected on clear nights when wind speed on the ground may be less than 5 m/s and speed at the turbine hub can exceed 10 m/s. Therefore the wind turbine noise can be well above the background sound level due to the wind at receptors since some turbine noise levels peak at wind speeds between 9 to 12 m/s [22].

The noise level criteria proposed here should not be considered as strictly applied limits. It is possible that the noise from the wind turbine could be masked by wind noise. This situation can be identified by historical data for wind speed as a function of height and documented wind noise at the noise sensitive receptor.

Prediction

In Canada, predicted noise levels are usually based on ISO 9613-2 1996, which has a standard uncertainty of +/- 3 dB [23]. As a result, it is proposed that a cautious approach in environmental assessments would be to prepare possible mitigation measures if uncertainties in predicted noise levels suggest that the proposed criterion levels may be measurably exceeded in operation.

Provincial guidelines

As noted above, the proposed criteria are not to be interpreted as strictly applied limits. First and foremost, in order to take into account regional variations in noise sensitivity to industrial installations, applicable provincial or territorial legislation, guidelines and policies need to be met. In the provinces and territories, wind turbines are evaluated under the category of stationary or industrial noise sources. For Zone I land use (i.e., isolated single family detached or semi-detached dwellings, schools, hospitals or other teaching, health or convalescent institutions) Quebec's night time limit is Leq 40 dBA. This limit increases to 45dBA for Zone II land use (i.e. multi-family dwellings, mobile home parks, institutions or camping grounds) [24].

Ontario and Alberta are the only provinces with guidance specific to wind turbines [24-26], and this limit increases with increasing wind speed. In quiet areas when wind speeds at 10 m height is below 6 m/s the noise limit is 40 dBA and at 11 m/s the noise limit rises to 53 dBA. For industrial sources in quiet areas in Ontario the regulated noise limit is 40 dBA at the property line of the nearest noise sensitive receptor [17]. In a rural area, application of Alberta's Energy Utilities Board Directive 038 [26] would yield a criterion with a night time Leq of 40 dBA for wind speeds between 6-9 m/s. Of note, in Alberta, existing noise due to wind turbines and other energy projects are not considered background noise but are considered to contribute to the noise produced by the new project.

Audibility

An increase in community reaction can occur if an intruding noise which was supposed to be inaudible or barely perceptible is readily heard by the community. Therefore, it is also proposed that environmental assessments avoid statements that suggest wind turbines are inaudible, or that changes of up to 5 dB are either not, or barely noticeable. Health Canada's knowledge of some community complaints and follow ups regarding wind farms suggests that it is difficult to predict whether wind turbine noise will be identifiable (i.e., audible/noticeable). The EPA "Levels" document [27] states that when the "normalized day-night sound level of an identifiable intruding noise is approximately 5 dB less than the day-night sound level" the community is expected to have "no reaction although noise is generally noticeable." In the "Levels" document, sporadic complaints would be expected for a 3dB increase in environmental noise level due to an identifiable intruding noise.

Construction noise

In Canada construction noise limits are typically governed by municipal noise by-laws. One exception is the province of Quebec, where, for isolated single family dwellings the daytime limit is 45 dBA and the night time limit is 40 dBA [24]. Due to typically large setback distances from residences, wind turbine

construction noise is not usually an issue at noise sensitive receptors. However, it is proposed that, if potential health effects from construction noise are to be assessed, then, for each representative noise sensitive receptor, the environmental assessment should provide the expected duration of construction (years, months or weeks or days) and an estimate of noise levels, or sound limits that will be met as well as any plans to monitor or mitigate construction noise or complaints arising from construction noise.

It is also proposed that short term construction noise be evaluated using the US EPA "Levels" document method of assessing qualitative complaint reactions [27]. If the resulting levels are predicted to result in widespread complaints or a stronger community reaction (according to [27]), noise mitigation is proposed. Health Canada has used the Alberta Energy Utilities Guide 38 [5] for guidance as to whether construction noise should be considered temporary. If it lasts for less than 60 days at a receptor, then it can be considered temporary[4] [26].

Based on an interpretation of the US EPA "Levels" document, for receptors in quiet rural areas, it is proposed that an Ldn of 57 dBA can be used as a typical criterion value. This measured value is based on a normalized value of 62dBA. The corrections needed to determine the measured value from the normalized value can be obtained by assuming (i) a quiet rural community (-10dB), (ii) the community is aware that the operation causing noise is very necessary and will not continue indefinitely (+10dB), and (iii) pure tone or impulsive character is present in the construction noise (-5dB).

[4] EUB Directive 038 Noise Control states that "Drilling and servicing rigs fall into the temporary facility category even if they are expected to be at a location more than 60 days. Temporary activities generally do not require an NIA. The licensee is responsible for noise control." p.13

Conclusions

To provide protection from high annoyance and sleep disturbance, the health effects, standards literature and published data on wind turbines provide support for a proposed criterion value of 45 dBA for wind turbine noise at residences, where the value refers to the Leq predicted for the maximum sound power level found as a function of wind speed. Complaint reactions and their follow ups for wind turbines and other noise sources indicate that it is advisable for environmental assessments to not refer to inaudibility or lack of noticeability of wind turbines. The criteria proposed in this paper appear to be a useful starting point for comparison to applicable provincial guidelines and the potential development of Health Canada guidelines for provision of advice on wind turbine noise to Natural Resources Canada under CEAA.

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