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# Health Impacts and Exposure to Wind Turbine Noise: Research Design and Noise Exposure Assessment[1]

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The last decade has seen a sharp increase in wind turbine generated electricity in Canada. As of May 2012, Canada's installed capacity was 5.4 Gigawatts, representing almost a 7-fold increase since 2005 and 2.3 percent of Canada's current electricity demands. The wind energy industry has set a vision that by 2025 wind energy will supply 20% of Canada's electricity demands. Development has been challenged by public resistance to wind farms based on various concerns, including the potential health impacts of wind turbine noise. The health effects reported by individuals living in communities in close proximity to wind turbine installations are poorly understood due to limited scientific research in this area. This is coupled with the many challenges faced in measuring and modeling wind turbine noise, in particular low frequency noise, which continue to be knowledge gaps in this area. The continued success and viability of wind turbine energy in Canada, and around the world, will rely upon a thorough understanding of the potential health impacts and community concerns that underscore public resistance.

Health Canada, in collaboration with Statistics Canada, will undertake a cross-sectional field study to evaluate these self-reported health impacts and symptoms of illness against objective biomarkers of stress and the sound levels generated by wind turbines, including low frequency noise. This data will be correlated with calculated wind turbine noise so that any potential relationship to reported health symptoms can be reliably determined. The research design includes a computer-assisted personal interview using a questionnaire consisting of modules that probe endpoints such as noise annoyance, quality of life, sleep quality, stress, chronic illnesses and perceived impacts on health. Following the 25-minute interview, the subject will be invited to participate in the health measures collection part of the study. This will include an automated blood pressure measurement and the collection of a small hair sample that will provide a 90-day retroactive average cortisol level. An objective evaluation of sleep will be undertaken using actigraphy for a period of 7 consecutive days, which will be synchronised with wind turbine operational data. Environmental sound level measurements, including low frequency noise, will be conducted inside and outside a sub-sample of homes in order to validate parameters ensuring accurate sound level modeling. The sample will consist of 2000 dwellings at setback distances ranging from less than 500 metres to greater than 5 kilometres from 8-12 wind turbine power plants. The results of the research study will contribute to the body of peer-reviewed scientific research examining the health impacts of wind turbine noise.

## 1. Introduction

Wind turbines (WTs) are becoming an increasingly common power generation option across North America and in many parts of the world. This source of energy is viewed as a viable and environmentally friendly alternative to fossil fuels. Since the announcement of the Government of Canada's renewable energy initiatives, there has been a steady rise in the number of WT installations across Canada. Wind capacity is currently surpassing 5.4 Gigawatts (GW) - enough to power over 1.2 million homes. By 2015, wind capacity is expected to reach 10 GW, which is a 20-fold increase over 2000 levels. By 2025, it is envisioned that 20% of Canada's electricity will be wind power generated (Canadian Wind Energy Association, 2005).

There has been considerable attention generated internationally and nationally by advocacy groups, concerned citizens and media on the potential heath impacts from exposure to noise from WTs. Some groups have expressed concern that the presence of WTs within the vicinity of residential dwellings may not only have a negative impact on property values, but also pose a public health risk to nearby residents. WTs are often situated in rural communities where background sound levels are typically low. Therefore, wind turbine noise (WTN) may be particularly problematic for rural residents as it may be more noticeable and they may experience large changes in sound levels with unpredictable operating times and variable wind conditions.

Health Canada acknowledges the World Health Organization's (WHO) definition of "health" as "*a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity*" and, "*the extent to which an individual or a group is able, on the one hand, to realize aspirations and to satisfy needs, and on the other, to change or cope with the environment*" (WHO, 1999). The WHO's *Night Noise Guidelines for Europe* (2009) cites sleep disturbance as a potential indirect health impact of environmental noise for yearly averaged night time outdoor sound levels at the residence higher than 40 A-weighted decibels (dBA). There are studies which report that this sound level may be exceeded at some residences, suggesting the potential for WTN to disturb sleep among sensitive individuals (Pedersen and Waye, 2004; Pedersen et al., 2009; Krogh, 2011; Harry, 2007; Shepherd, 2011; Pierpont, 2009). Some studies have been criticized for having poor methodology and some did not find impacts on sleep (Pedersen and Waye, 2007; Knopper and Ollson, 2011).

Health Canada's ability to provide advice on noise impacts from WTs has been challenged by limited peer-reviewed scientific research related to both the character of WTN, in particular low frequency noise, and a lack of Canadian prevalence data on community complaints and self-reported health impacts from studies with rigorous methodological designs. WTN includes the production of low frequency sound (Møller and Pedersen, 2011). Beyond the auditory threshold, low frequency sound is more annoying than that at higher frequencies. It also travels further than higher frequency sound, and can penetrate structures such as homes without much reduction in energy. Low frequency noise can create indoor noise problems such as perceptible vibration and rattle.

Prevalence data on community reaction and self-reported health concerns would allow a better understanding of the relative magnitude of the public's concern about WTN. This could then be compared to the prevalence of other community health concerns and also to the prevalence of similar health concerns in communities that are not situated near WT installations.

## 1.1 Health impacts of wind turbine noise

Assessment of health outcomes, potentially related to noise exposure from WTs, has so far been limited. Among the various health outcomes assessed, the only reproducible findings linked to WTN have been based on measures of well-being or quality of life and the extent to which they disturb various human activities (i.e. sleep disturbance). WTs, and the noise they produce, continue to receive attention as the numbers of wind-power projects increase in line with national and provincial clean-energy targets. Concerns of individuals regarding WT installations include, but are not limited to, nausea, vertigo, tinnitus, heart palpitations, stress, blood pressure spikes, sleep disturbance and annoyance resulting from the noise that WTs produce (Harry, 2007; Pierpont, 2009; Krogh, 2011). To date, there have been no field studies that have included objective health measures in their study design which could lend support to some of the self-reported claims derived from questionnaires.

Environmental noise, which includes WTN, is a frequent complaint. Noise concerns are typically observed in urban or residential settings that may be impacted by highways, railways, and airports. However, more recently, wind power projects have been introduced in rural environments, where man-made noise sources tend to be relatively quiet. Regardless of the community type, exposure to prolonged or excessive noise may directly or indirectly affect the health of individuals. Directly, exposure to sound pressure levels in excess of 75 A-weighted decibels (dBA) could result in hearing loss, depending on the duration of exposure and the sensitivity of the individual. Because of the health impacts that have been associated with sleep disturbance (for any reason), long-term sleep disruption may also be considered an indicator of a possible health impact. Although no study to date has objectively assessed sleep disturbance in populations living in the vicinity of WTs, self-reported impacts on sleep have been associated with exposure to WTN in some but not all field studies (see review by Knopper and Ollson, 2011).

Considering the scientific evidence on the lowest observed adverse effect level for sleep disturbance, the WHO identified an average annual outdoor nighttime sound level of 40 dBA as a recommended limit to protect public health from night noise, including that of the most vulnerable groups such as children, the chronically ill, and the elderly. Although the limits in the WHO's *Night Noise Guidelines* are based on transportation noise sources, current science shows that the same levels are applicable to noise emitted from WTs. There has also been criticism directed at the use of an A-weighted base limit for a source that contains low frequencies such as the large scale WTs.

Indirectly, noise annoyance has been found to be positively correlated with WTN (Pedersen and Waye, 2004 and 2007; Pedersen et al., 2009), which is suggestive of a direct causal relationship. This relationship has intuitive appeal, but attribution of this correlation is complicated as it has been found to be moderated by economic and visual effects (Pedersen et al., 2009; Pedersen and Larsman, 2008). For example, it is not clear if those receiving economic benefit experience lower WTN annoyance because they gain financially, or if they began with a lower annoyance and, therefore, were more likely to become participating receptors in the first place. Similarly, the interaction between visual annoyance and noise annoyance is equally difficult to disentangle. In both cases, it is difficult to make causal statements about the relationship between exposure to WTN and community annoyance and, therefore, to set science-based sound level limits.

## 1.2 Wind turbine noise

Noise associated with an operational wind-power project can originate from the WT itself, the transformer station (where applicable), vehicle traffic between the WTs and maintenance activity. WTs produce noise from two major sources:

1. Mechanical noise, which is produced by the motor or gearbox of the WT's nacelle; if functioning correctly, mechanical noise from modern WTs should not be an issue.
2. Aerodynamic noise, which is produced by wind passing over the blade of the WT and passage of the blades in front of the tower.

WTs produce broadband noise similar to that produced in buildings by heating, ventilation, and air-conditioning systems. This broadband noise can be modulated by the blade passage frequency resulting in a characteristic "whooshing" sound. As distance from a WT increases, the highest frequencies are reduced, and the sound shifts toward lower frequencies. Early WTs were designed with blades placed downwind of the tower, forcing wind to travel past the tower before striking the blades. This design resulted in a sound output that generated a strong low-frequency pulse and had significant levels of energy in the infrasound range (1-20 Hz). Although modern WTs have overcome many of the noise problems associated with their predecessors (modern turbines have blades placed upwind of the tower to minimize the generation of low-frequency noise and infrasound), today's turbines are much larger and continue to generate noise complaints from nearby residents.

The level of noise at the receptor is dependent on several factors including the type of WT, distance from the WT, intervening structures, the existing background sound levels, wind speed and direction, topography, and meteorological conditions.

# 2.0 Proposed Cross-Sectional Field Study

## 2.1 Research objectives

*To investigate the prevalence of health effects or health indicators among a sample of Canadians exposed to WTN using both self-reported and objective health measures.*

*To apply statistical modeling in order to derive exposure response relationships for WTN levels as well as self-reported and objective health measures.*

*To address the uncertainty that currently exists with respect to low frequency noise from WTs as a potential contributing factor to adverse community reaction.*

## 2.2 Research outcomes and limitations

The proposed research would provide decision makers with new scientific evidence that could be combined with existing research to inform decisions and policies on practices regarding WT proposals, installations and operations in Canada. It is important at the outset to clearly acknowledge that this research is being conducted to provide additional insight into an emerging issue; however, the results will not provide a definitive answer on their own.

## 2.3 Research design

The study will be conducted on a sample of 2000 dwellings randomly selected from those located near 8 to 12 WT installations in Canada. Sampling will be conducted on volunteers that are at least 18 years of age. Each participant will be asked to complete a 25-minute computer-assisted personal interview. The questionnaire will be read to the subject and it includes modules that assess demographics and validated scales that provide information on well-being, sleep quality and noise annoyance. The prevalence of chronic illness and symptoms collectively referred to as "WTN syndrome" are also included in the questionnaire.

To ensure that the validity of the study is not compromised in any way, the questionnaire and sampling locations will only be revealed when the study is completed. Self-selection bias is something that needs to be carefully addressed in this study because it is unreasonable to assume that subjects will not be aware of the purpose of this study. This can be partially accounted for with a participation rate of between 70 and 75% and with a characterization of non-respondents that includes demographics and dwelling location relative to the turbines.

In addition to the questionnaire, subjects' blood pressure will be taken following a standardized protocol. A small hair sample will be collected for the purpose of quantifying average cortisol levels over the 3 months preceding the collection period. A wrist-worn actimeter will be used to provide an objective measure of total sleep time and sleep efficiency for a period of 7 consecutive days. A small pilot study utilizing 15 volunteers will be conducted to evaluate different actimeter models, and to assess anticipated issues associated with non-compliance. The value of adding a complementary sleep diary will also be part of this pilot study.

### 2.4 Wind turbine noise measurements and modeling

Outdoor noise levels will be predicted using CadnaA with ISO 9613 and Harmonoise software, and the modelling will include terrain features. For comparison with other studies, outdoor noise predictions will also be made using a simple Swedish national method (Ljud från vindkraftverk, 2001). Indoor levels will be estimated assuming a generic transmission loss for rural Canadian homes when windows are partially open. To complement the indoor estimates, details of the construction of each house and the participant's bedroom dimensions will also be obtained during the in-person interview.

The basis for the sound level predictions is the WT sound power levels, which will conform to the requirements of IEC 61400-11. Sound power levels supplied by the manufacturer will be verified and extended into the infrasound range using a Bruel & Kjaer PULSE system with Bruel & Kjaer ground plane boundary layer microphones (with a large secondary windshield). During these measurements, wind and temperature will be monitored at ground level and a height of 10 m. This system will also be used to validate the predictions from CadnaA at distances up to 5 km from the WTs.

The transmission loss for rural Canadian homes at low frequencies is of primary interest. These measurements will be made based on ISO 140-5 and the low frequency transmission loss measurements made in Denmark (Hoffmeyer and Sondergaard, 2008). At high frequencies, the household transmission loss will be based on typical estimates with windows partially open. These estimates will be validated using reciprocal measurements of transmission loss using high-powered sound sources inside the home and microphones located outdoors (Sharp and Martin, 1996). The noise sources will be located indoors to avoid disturbing neighbours.

During actigraphy measurements, the WTN will be logged at a single position near the WTs using a Bruel and Kjaer 2250 sound level meter. This measurement will be synchronised with the actimeters to enable an estimate of the times when the turbines are operating intermittently or continuously. Due to the large number of individuals wearing actimeters at any given time, simultaneous indoor sound level measurement is not a feasible option.

## 3 Conclusions

The research study to be undertaken by Health Canada will support the Government and other stakeholders by strengthening the evidence base that supports decisions, advice and policies regarding WT development proposals, installations and operations in Canada. The research is a critical element of the Department's multi-dimensional approach which also includes a comprehensive review of existing knowledge by an independent panel of international experts.

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Due to space restrictions, the references used in this paper are not an exhaustive list

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