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Health Canada's Wind Turbine Noise and Health Study—A Review Exploring Research Challenges, Methods, Limitations and Uncertainties of Some of the Findings

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Abstract

Background: Risk of harm associated with wind turbines is debated globally. Some people living or working in proximity to wind turbines report adverse health effects such as sleep disturbance, noise annoyance, and diminished quality of life. Due to public concern, Health Canada announced its wind turbine noise and health study which included subjective and objective measurements. Findings were published between 2014 and 2016. In 2018, Health Canada published clarifications regarding the design and interpretation of study conclusions. **Methods:** Methods and subjective/objective findings were

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reviewed. Peer reviewed publications, conference presentations, judicial proceedings, government documents, and other sources were evaluated and considered in context with advanced methods for investigating reports of adverse health effects. **Objectives:** To review and explore some of the research challenges, methods, strengths and limitations of findings and conclusions. To participate in scientific dialogue and contribute towards an understanding of reported health risks associated with wind turbine noise. **Results:** Wind turbine human health research is challenged by numerous variables. Knowledge gaps and individual human and wind turbine variables are identified. Strengths and advisories of limitations are considered and acknowledged. Health Canada's advisories that its study design does not permit any conclusions about causality and results may not be generalized beyond the sample taken in Canada are supported. Enhanced methods for investigating health outcomes are proposed including establishing referral resources within medical facilities for physicians. It is proposed staffing of the resource center includes multidisciplinary teams of physicians, epidemiologists, acousticians and other specialists to investigate suspected wind turbine adverse health effects. **Discussion:** A review and the appraisal of some of the research challenges associated with wind turbine human health research are presented. Given the identified methods, research/knowledge gaps, and limitations and cautionary advisories, Health Canada's results should be carefully considered when predicting or protecting from health risks of wind turbine noise.

Subject Areas

Public Health

Keywords

Wind Turbines, Research Challenges, Research Gaps, Risk of Harm, Adverse Health Effects

1. Introduction

The risk of harm to humans associated with exposure to wind energy facilities is controversial and debated globally [1] [2] [3] [4]. Industrial wind turbine (WT) health research is challenged by a number of variables such as: WT noise and power output; proximity and sitting array; terrain; and seasonal and atmospheric conditions. Additional research challenges are more likely to occur when the WT variables are combined with human variables such as individual response to noise; social and economic issues; risks to vulnerable population groups associated with age (fetus, children and elderly) including those with special needs and who have pre-existing medical conditions.

Some people exposed to WT report adverse health effects such as sensations, sleep disturbance, noise annoyance, cognitive disorders, lowered general health and reduced quality of life [3] [5]-[10]. In some cases, Canadian and other families residing in proximity to WT have effectively vacated their homes [11] [12], been billeted by WT project developers [13] or successfully negotiated financial agreements [11].

There are limited studies related to occupational workers. A scoping review by Freiberg *et al.* 2018 found "no specific overall health effects of working in the wind sector" but found associations with accident rates which resulted in injuries or fatalities [5]. Other occupational worker research has reported WT noise annoyance and other adverse health effects which are consistent with reports by residents who live near WT [14]-[20].

Audible and inaudible noise, noise annoyance, visual impacts, stray voltage, and social impacts have been identified as potential/plausible causes of adverse health effects [3] [8] [11] [12] [15] [21].

Health Canada observed there is "public concern for potential health impacts, which include disrupted sleep from exposure to wind turbine sound" [22]. In 2012, the design of Health Canada's *Wind Turbine Noise and Health Study* (Health Canada Study) was announced and the public advised the approach will:

> … support decision makers by strengthening the evidence base of peer reviewed scientific research that ultimately supports decisions, advice and policies regarding wind power development proposals, installations and operations in Canada [23].

While the Health Canada Study is known as the "Wind Turbine Noise and Health study", it is also referred to as the CNHS (Community Noise and Health Study [24]. During 2013, in collaboration with Statistics Canada [25], Health Canada conducted its cross-sectional study and published results during 2014, 2015 and 2016 [24]-[32]. Subsequently in response to comments expressed by some, Health Canada clarified the Health Canada Study design and interpretation of conclusions [33].

For the interest of readers, publications by Michaud *et al.* 2016 [24] [28] [30] have provided corrections related to the following Health Canada Study results [34] [35] [36]. Corrections include regarding reference [28], an advisory that the data file used to analyse the objective sleep endpoints included data processing errors and the steps taken to conduct a reanalysis [34]; for reference [24] correction of a citation and an endnote description [35]; and for reference [30] corrections of a citation, plus advisories to reduce the values in one of the figures and to shift a WT noise curve by approximately 0.8 dB [36].

Health Canada conducted pilot interviews to test the questionnaire and participants' overall comprehensiveness and willingness to participate in both subjective and objective measurements. Results obtained from the pilot were not included in the published findings [22]. Data were collected between May and September 2013 [24]. The study design included self-reported and objectively measured health indicators such as blood pressure and heart rate, hair cortisol (as a biomarker of stress), sleep actigraphy data to assess sleep quality and a computer assisted face-to-face personal interview administered in the participant's home [22].

In 2013 and 2014 Health Canada cautioned that regarding the Health Canada Study design:

- results will not provide a definitive answer on their own [37];

And that:

- results may not be generalized to areas beyond the sample as the wind turbine locations in this study were not randomly selected from all possible sites operating in Canada;
- results do not permit any conclusions about causality; and,
- results should be considered in the context of all published peer-reviewed literature on the subject [25].

The Health Canada Study findings have been referenced in support of various procedures such as: an Ontario Ministry of Environment and Climate Change regulatory framework [38] and during various legal and other proceedings [39]-[46].

Indications are in some cases, the Health Canada Study findings appear to have been interpreted beyond Health Canada's advisories of the above limitations and/or failed to differentiate these.

This article considers WT related research challenges and knowledge gaps. In addition, it reviews Health Canada's subjective/objective methodologies and explores some of the limitations and uncertainties related to published findings and conclusions. Approaches for augmenting methods are proposed with the goal of participating in scientific dialogue and contributing towards future investigations of WT and human health.

2. Method

The Health Canada Study methods were reviewed and assessed. Some of the research challenges associated with this topic were explored and a number of factors and methods which could influence research findings identified. These include methods such as: use of WT calculated noise models; sampling and analytical methods of hair cortisol; consideration of acute verses chronic exposure; and outcomes of objective and subjective measurements. Research and knowledge gaps were considered and evolving research methods identified. Enhanced WT methods for investigating health outcomes associated with living or working in proximity to WT are proposed.

Reference sources include:

- peer reviewed publications and conference papers associated with WT acoustical noise research, adverse health effects, research challenges and knowledge gaps;
- expert testimony during judicial and other proceedings;
- rulings of judicial proceedings;
- authoritative documents such as those from government and other jurisdictions; and
- other sources.

3. Results

3.1. Calculated Wind Turbine Noise Models

It is common practice to rely on calculated WT noise models. The Health Canada Study followed this approach for both A- and C-weighed noise [47] [48]. There is evidence that divergence between WT calculated and actual full spectrum noise measurements could influence findings. For example, Barlas *et al.* indicate that to the authors' knowledge "none of the noise mapping tools take into account the increased source levels due to ambient or wake induced turbulence. Neither the standards demand turbulence dependent noise curves" which can be one of the reasons for "inaccurate far field noise predictions" [49].

A study by Iannace observed that "People complain about a greater noise due to particular wind speed conditions" and that depending on placement of WT and wind direction "the contribution to the sound level due to wind speed increase is considerable, which is about 10 dB" [50]. In a systematic review, Schmidt and Klokker suggested "It might be relevant to include another type of sound weighting rather than just the A-weighting in future studies" [51].

Determining WT compliance has methodological issues as well. For example, the use of calculated models which typically predict A-weighed noise levels outside a home do not necessarily correspond to the actual noise level inside a home environment during the time an adverse effect occurred. A study by Gortsas *et al.* 2017 comments:

> The most important conclusions here are 1) the microseismicity creates higher levels of noise inside a house than that of the airborne noise radiated by a WT and 2) bedrock being in low depths underneath the soil has an additional contribution to the generated acoustic noise by the induced microseismicity [52].

The Administrative Appeals Tribunal (AAT), appointed by the Attorney General of Australia, provides an independent review of decisions made by the Australian Government. A judicial Decision accepted that regarding the Health Canada Study "measurements based on estimates or averages may not accurately reflect the sound which was present when the particular level of annoyance was experienced or recorded" [53] and that:

> A major limitation is that the conclusions of the study were based on calculated, rather than actual, noise measurements (although some of the calculated noise levels were based on measurements). [[53] pg 146] [para. 478]
> All of the evidence before us is to the effect that WTN cannot be accurately captured in dB(A), or even dB(C) (although dB(C) is preferable) [[53] pg 146] [para. 479].

The lack of actual noise measurements could have influenced the analysis of self-reported findings obtained during the computer assisted face-to-face personal interview and the objectively measured health indicators such as stress, blood pressure and heart rate. Full spectrum noise measurements sensitive to the fluctuations in amplitude from dynamic pressure pulses, including infra and low frequency sound could have enhanced the overall study design. In addition, the application of actual noise measurements combined with technology such as remote monitoring or the SCADA (Supervisory Control and Data Acquisition) [54] for real time supervisory control and monitoring of each WT to determine the operational status of the WT during the correlation and interpretation of the objective and subjective measurements could have contributed towards an understanding of the health outcomes.

Subsequent to the publication of the Health Canada results related to sleep [28], attendees of a WT noise conference session were advised that a more refined analysis was being conducted "to assess wrist actigraphy measured sleep patterns in relation to nightly variations in wind turbine operations" [55]. Health Canada's slide presentation disclosed WT sound power level was calculated using SCADA for the 3 nearest WT. The recalculation was restricted to a subset: *i.e.*, 275 (116 males, 159 females) living between 0.25 and 1 km from wind turbines [56] resulting in 35.2% of the 781 participants' data being reassessed.

Michaud *et al.* [28] concluded that the study results do not "support an association between exposure to outdoor WTN up to 46 dB(A) and an increase in the prevalence of disturbed sleep". These conclusions are based on WT noise averaged over one year. Michaud *et al.* [28] also suggested that in some cases, results may be "strengthened with an analysis that examines sleep quality in relation to WTN levels calculated during the precise sleep period time". While the reanalysis indicated there is "no impact on any of the self-reported outcomes and the overall conclusion of the original paper does not change." [33 of reference 28], consideration of sleep quality and precise sleep time could potentially clarify potential WT related sleep issues.

Except for the above subset of participants, it appears the operational status of the WT was unknown *i.e.*, whether the WT were turned off or on, operating at partial or full capacity or ramping up or down during the interviews and the measurements of heart rate and blood pressure.

While several studies have conducted actual noise measurements during the times the WT were turned off and on [7] [50], cooperation of the WT developer would support a full spectrum actual noise measurement methodology including the WT operational status. This would give the ability to compare actual noise measurements with calculated/predictive noise models.

It is recommended that during the investigation of reported adverse health effects, actual full spectrum noise measurements be taken inside and outside a sample of family homes and interpretation of subjective and objective measurements be correlated with WT operational status, *i.e.*, turned off, operating at partial or full capacity or ramping up or down. Actual full spectrum noise measurements should be evaluated and compared to calculated noise models when considering human health findings.

3.2. Cortisol and Low Frequency Noise (LFN)

Although there is convincing evidence in the literature that cortisol levels can be an indicator of exposure to stress, variables such as inaudible infra and low frequency noise (LFN) may have the potential to influence results. While the Health Canada Study relied on calculated noise models for both A- and C-weighed noise [47] [48], actual field noise measurements indicate the occurrence of LFN/infrasound [52] [57] [58]. Four firms which cooperatively conducted actual WT noise measurements commented they were of "the opinion that enough evidence and hypotheses have been given herein to classify LFN and infrasound as a serious issue, possibly affecting the future of the industry" [59].

Persson Waye *et al.* [60] examined and compared the effects of LFN and night-time traffic noise on the cortisol awakening response and subjective sleep quality. The data indicated that responses during exposure to the two types of noise differed. The cortisol awakening response was altered following nocturnal exposure to LFN in that cortisol levels had not peaked by thirty minutes after awakening. The attenuated levels of salivary cortisol were related to tiredness and negative mood. This was not the case with exposure to night-time traffic noise or reference nights. While the authors advised to interpret the results with caution it was concluded that the study showed "night time exposure to LFN may affect the cortisol response upon wake up and that lower cortisol levels after awakening were associated with subjective reports of lower sleep quality and mood".

Relying on calculated models risks "inaccurate far field noise predictions" [49] and when combined with the potential for LFN to reduce cortisol levels, these factors could have influenced the results of the objective measurements of hair cortisol.

Rather than relying on calculated LFN/infrasound (C-weighted sound pressure levels), conducting actual noise measurements in a representative sample of participants may have clarified the potential for inaccuracies in the interpretation of study results. It is proposed that these factors be considered and controlled in future WT investigations.

3.3. Hair Cortisol: Excluded Samples

Michaud *et al.* [29] report that of the 917 samples collected during the Health Canada Study, over 26% (n-242) were excluded or discarded:

- 214—too little hair was taken;
- 9—levels were too high;
- 19—high levels of which 14 used chemical treatment in the last 3 months.

The validity of excluding 28 (9 + 19) samples due to high levels which included the use of chemical treatment in the last 3 months is unclear and has not been justified. Research indicates hair cortisol levels are not affected by hair color or by dyeing hair samples after they were obtained [61]. The high values may indicate an unidentified problem with the specificity of the assay or that the research subjects were highly stressed.

If chemical treatment were considered an issue, samples from those who had chemically treated their hair during the past 3 months should have also been excluded. This would have ensured consistency of the remaining 675 (917 – 242) individuals. It is unclear whether this was considered.

It is recommended that chemical and color/dyeing treatment be consistently considered during hair cortisol sampling.

3.4. Hair Cortisol Values

Michaud *et al.* 2018 [33] observe that "higher perceived stress scores were related to higher hair cortisol concentrations". The study by Michaud *et al.* [29], *Table I* states that hair cortisol values ranged from 18 to 7139 ng/g (pg/mg) with *Table* 3 indicating many samples were over 200 ng/g. The stated values are substantially higher than those typically reported in the literature: Sauvé *et al.* [62] indicate a reference range for hair cortisol of 17.7 - 153.2 pg/mg of hair (median 46.1 pg/mg) and Karlan *et al.* [61] report levels of up to 212 pg/mg (mean levels 17 - 20 pg/mg) while a study across countries which also compared measurement kits indicate only a 2.3-fold difference [63].

No reason was given for the Health Canada Study values being above those published in the literature. A possible explanation is that cortisol levels were elevated in some patients of all WT noise groups. This could have been due to an exposure other than audible noise such as WT LFN/infrasound as compared to those with no WT exposure. If some subjects were sensitive to inaudible infrasound, effects of WT could potentially extend beyond Health Canada's study area of 10 km. An alternate explanation is sample or assay error. For levels to be so much higher and more variability than other published studies requires some justification.

The advice of the Health Canada SAB (Science Advisory Board) provides some guidance: in 2012 the SAB recommended that Health Canada investigators consider supplementing hair cortisol with a group that provides saliva cortisol for diurnal patterns [64].

In order to support future WT investigations related to stress, it is proposed that consideration be given to the SAB recommendation.

3.5. Hair Cortisol Sampling

Hair cortisol measurements have been used when it is impractical or inconvenient to collect saliva or a 24-hour urine sample or blood.

Based on the approximate rate of hair growth, one centimetre of hair typically indicates the average cortisol level over a month. The Health Canada Study methodology indicates that "subjects from whom a length of 3 cm or more of hair was collected" was used to measure cortisol values [29]. A 3 cm sample provides cortisol values averaged approximately over a 3 month period. Due to averaging the cortisol values, the results may indicate chronic levels but are less likely to reflect acute situational or individual stresses. Measuring segmented hair over about a 1 month period would provide a more specific indication of stress, but even that would average out dips and spikes in cortisol values, thereby masking acute releases of cortisol.

Based on the Health Canada Study's methodology for measuring hair cortisol, there is no indication segmented hair was assessed.

Another consideration is if some residents were sensitive to noise, and/or infrasound/LFN, and/or WT were exceeding the approved operational range, the data relating to an increase of cortisol would be lost or un-interpretable due to averaging this objective measurement. Since Health Canada Study relied on predictive noise calculations [47] [48], actual noise levels are unknown. Applying measures of cortisol release over short periods of time, such as those collected by salivary or urine, with correlation of subjective/objective measurements to actual noise levels as well as WT operational status could have provided comparative information.

To assist with measuring peak stress, it is recommended that future WT investigations consider including either a study or sampling group and to correlate subjective and objective measurements while conducting full spectrum actual audible and inaudible noise measurements inside and outside family homes as well as capturing WT operational status including hub rpm, wind speed and direction at the hub for each WT within 10 km of a family home.

3.6. The Enzyme-Linked Immunosorbent Assay (ELISA) Methodology

Stress-induced cortisol changes have been measured using blood and saliva or a 24-hour urine sample which can be elusive to interpret. Serum and salivary cortisol levels at a point in time reveal acute changes. However, it is difficult to evaluate chronic systemic cortisol [65], is subject to "variations due to acute stress, the diurnal rhythm and pulsatile secretion" [66] and "challenging due to the need to take multiple urine, saliva or serum samples" [62]. As a result, the use of hair cortisol measurements has been increasingly recognized [65] [66] [67] [68]. Sauvé *et al.* [62] compared hair cortisol with cortisol levels of other commonly used methods and found that "saliva and serum levels both reflect acute levels, urine represents cortisol secretion during one day, whereas hair cortisol levels represent levels during 1 - 2 months" and commented that regarding hair cortisol, "the levels are not affected by acute stress" [62].

The Health Canada Study methods for hair sample collection and cortisol analysis are described in section 2*. Hair treatment and enzyme-linked immunosorbent assay (ELISA)* [29]. The ELISA methodology was used in accordance with a previously established protocol described by Pereg *et al.* [69]. Due to the potential for false positives, indications are that in some circumstances results of the ELISA test are presumptive, requiring confirmation using a method with a higher degree of specificity, such as gas chromatography–mass spectrometry (GC-MS) or liquid chromatography-tandem mass spectrometry (LC-MS/MS [70] [71] [72] [73].

For the interest of readers and researchers, the ELISA methodology was examined by the Honourable Justice Susan Lang as the result of child protection and criminal proceedings by child protection agencies seeking to determine if a parent or caregiver had used drugs or alcohol [73]. A statement of claim for a lab class action has been issued [74]. In addition, since a fetus is considered at risk from exposure to the Zika virus, physicians were alerted of some false positive results from the Zika MAC-ELISA [71]. The CDC (Centers for Disease Control and Prevention) provided a fact sheet for healthcare providers which included an advisory that confirmation of "positive or equivocal results requires additional testing by CDC or by qualified laboratories designated by CDC and in consultation with CDC ..." [72].

ELISA has been compared to other assay methods. For example, a study in children indicates that when compared to liquid chromatography-mass spectrometry (LCMS), ELISA-based assays "showed greater sensitivity for measuring hair cortisol levels" [75]. However, regarding consistency of extraction methods, the study found:

> A lack of consistency in hair cortisol data from different laboratories using single extraction methods contributes to greater variability and inconsistency in the reported reference ranges, an inability to perform quantitative meta-analyses, or to examine age-related changes [75].

Slominski *et al.* [75] indicate further refinements in hair cortisol analysis may be required "before the data reported in the clinical literature can be considered precise enough for clinical decision-making, or for establishing reference ranges for different age groups" and propose enhanced analytical methods.

Based on the methods described in Michaud *et al.* [29] it appears confirmation testing was not performed. If confirmation testing were indicated but not performed on positive hair cortisol results, there could be perceived uncertainty of hair cortisol results.

While these discussions relate to factors such as forensic and legal requirements, the challenges associated with capturing acute or chronic cortisol values, and the potential for lack of consistency during analysis, there is an opportunity to enhance future WT investigations related to stress outcomes. These opportunities include comparing ELISA with other analytical methods, to consider measurements that contribute towards eliciting chronic and acute values, and sampling some subjects using a method with a higher degree of specificity than ELISA and comparing results.

3.7. Availability of Raw Data

The Health Canada Study announcement of 2012 advised:

> Specific details related to the study locations, timing and survey components will be made available on the Health Canada website upon completion of the research in order to protect the integrity of the study [23].

In addition, the summary of results publicly advised that the raw data originating from the study were available to Canadians, other jurisdictions and interested parties through a number of sources such as the Health Canada website (noise data), open access to publications in scientific journals and conference presentations, and the Federal Resource Data Center (RDC) [25].

Regarding the RDC process, the complete file of un-interpreted, *i.e.*, raw data, appears unavailable to researchers. For example, in 2016, an Ontario research team entered into a contractual agreement with Statistics Canada to research the Health Canada Study findings [76]. The project team members were subject to all the conditions and penalties of Statistics Canada employees including fines and/or imprisonment for breach of confidentiality. Research requirements included access to the complete and unaltered raw data file. While some of the raw data were available, other data were the property of Health Canada and were not available through the RDC. In an effort to obtain the required raw data elements, federal public record requests were submitted to the Health Canada ATIP (Access to Information and Privacy) system. In response, Health Canada stated these were "totally exempted from disclosure pursuant to the following provisions of the *Act*... third party financial, commercial, scientific or technical information given in confidence to the government" [77] [78].

It appears another research team which assessed Health Canada's findings experienced a similar limitation. The researchers comment:

> Our analysis has limitations. Raw sound data were not available to us with the Community Noise and Health dataset. Only background-level noises and the modelled wind turbine sound were. Therefore, it was not possible to model sound using alternative methods, such as using G-weighted modelled sound, which would better account for low frequency sound waves … [79].

Justice Sébastien Grammond, a Canadian Federal Court Judge [80] ruled on a case involving a researcher's request for clinical trial data in order to conduct a systematic review of a pharmaceutical product. When Health Canada considered it "confidential business information" and would not provide these data without a confidentiality agreement, the researcher took the case to Canada's Federal Court. Justice Grammond indicated Health Canada's stance "unreasonable" and issued "an order of *mandamus* requiring Health Canada to grant Dr. Doshi's request and to communicate the information sought" [80].

While the Federal Court case relates to clinical trial data, it appears in principle there is a potential to apply its ruling to the Health Canada Study raw data file.

Michaud *et al.* encourage "constructive criticism of scientific research" and acknowledges this "often stimulates improvements in future studies" [33]. In addition, it appears a revised data file is publically available through the Statistics Canada Research Data Centres [34]. However, at this time it is unknown whether the revised data file will include access to the complete and unaltered raw data file or whether it would be limited in its content.

While researchers can comment on Health Canada Study's interpreted and published papers, the lack of a centralized custodian of the complete raw data file hinders the ability to "independently reproduce the Health Canada findings and to explore opportunities to confirm and/or provide additional contributions and insights regarding this complex topic" [76].

For the interest of readers, a status update is available through the link provided at Krogh and Aramini [76].

3.8. Research/Knowledge Gaps and Evolving Research Methods

WT related research and knowledge gaps have been acknowledged by researchers and others [1] [9] [12] [37] [81] [82] [83] [84]. Health Canada identified one of the challenges related to "competition for resources for research and assessment" which leaves "many health concerns and potential risks unaddressed" [83]. In response to knowledge and research gaps, the World Health Organization (WHO) announced the development of environmental noise guidelines for the European Region which includes WT: "… the guidelines highlight critical data and research gaps to be addressed in future studies" [84].

Differences in study design, the absence of longitudinal studies and inter-subject variability contribute towards WT research challenges. Sensitivities to audible and inaudible noise (infrasound), age related vulnerabilities (elderly and fetus to youth), disease states and pre-existing medical conditions, variability of exposure (chronic verses acute), lack of sufficient statistical power due to low population densities to detect small changes in risk factors, and social issues also contribute to research challenges. Additional factors include potential effects of WT related LFN/infrasound emissions and electromagnetic energy, operational variables, use of calculated noise models and a variety of local or state noise guidelines. Combined, these factors can make it difficult to compare research results and health outcomes.

Since the Health Canada Study design of 2012, methods have evolved. Objective measurements have included the use of advanced methods and technologies such as: a time stratified, case-crossover design [85]; MRI technology to document changes of brain activity when exposed to infrasound from WT [86]; verification of the physiological impact by ECG (electrocardiogram) [20] and brain waves by electroencephalogram (EEG) associated with low frequency/infrasound [87]; and a double blind provocation case control pilot [88].

These methods should be considered during future investigations of WT.

4. Discussion: What Is the Way Forward—More Research, Prevention, Precaution?

Internationally, governments, authorities, WT energy developers and many of those including occupational workers and families who are currently exposed, or in the future expect to be exposed to WT facilities, have an interest in the Health Canada Study findings.

Some people living in proximity to WT report a variety of adverse health effects such as sleep disturbance, body sensations, anxiety, tinnitus, noise annoyance, altered quality of life and health, excessive tiredness, headaches, migraines, hearing problems, heart palpitations, anxiety, stress, depression and social issues. The authors of Colby *et al.* conducted an Expert Panel review for the American Wind Energy Association and Canadian Wind Energy Association and determined that the symptoms of "wind turbine syndrome" described by Pierpont 2009 are not new, have been published previously in the context of "annoyance" and are the "well-known stress effects of exposure to noise" [4].

Fredianelli *et al.* observe with the increasing installation of WT there is an increase towards WT noise and as a result the "scientific community has promptly responded, increasing the studies and the social surveys in order to better understand the cause of disturbance and the indicators that relate to it" [89]. WHO indicates that reliance on wind energy in Europe has increased which has "resulted in higher public annoyance in the EU" and announced the development of new environmental noise guidelines including:

> … consideration of new evidence associating environmental noise exposure with health outcomes, such as annoyance, cardiovascular effects, obesity and metabolic effects (such as diabetes), cognitive impairment, sleep disturbance, hearing impairment and tinnitus, adverse birth outcomes, quality of life, mental health, and wellbeing … [84]

The release of WHO noise guidelines indicate there "are serious issues with noise exposure assessment related to wind turbines" and that further work is needed to "assess fully the benefits and harms of exposure to environmental noise from wind turbines and to clarify whether the potential benefits associated with reducing exposure to environmental noise for individuals living in the vicinity of wind turbines outweigh the impact on the development of renewable energy policies in the WHO European Region" [[90] Table 42].

In Ontario Canada, numerous WT related complaints have been filed by neighbors who live in proximity to WT. For example, WCO (Wind Concerns Ontario) obtained government records provided through requests under the province of Ontario's Freedom of Information legislation. The records revealed that between 2006 to the end of 2016, Ontario families who live near operating WT projects submitted 4562 Incident Reports of WT noise complaints. Thirty-five percent of these reports contained explicit references by government staff to reported adverse health effects which were related to WT noise emissions [91]. Despite unresolved knowledge gaps and official records of complaints, WT projects continue to operate and others continue to be proposed near family homes [40] [92].

Some of the citations in this paper encourage the need for additional WT studies [9] including proposals for what should be studied. Suggestions include: to consider quantification of amplitude modulation and tonality [1] [32]; to study occupational "work-related injury and accident rates, and health outcomes in later life cycle phases" [5]; to conduct epidemiological and laboratory research by health professionals and acousticians [14]; to research occupational worker exposure [15] and confirm occupational exposure results [18]; to focus on alternative exposures other than noise [79]; to intentionally explore the factors regarding differences in community responses to WT noise [55]; to conduct experimental and observational studies regarding wind turbine noise and health [2]; to determine the distances that risks become negligible [21]; to replicate findings [85]; to assess health status before and after WT development [79] [81]; to conduct longitudinal studies [64] and require further (especially longitudinal) studies to substantialize findings [87].

In response to comments made by some, Health Canada summarized the strengths and limitations of the Health Canada Study, identified issues associated with third party re-evaluation and reinforced the limits for applying results:

> … one must avoid potential "apples to oranges" comparisons as the sample population in the CNHS is not generalizable. This has been identified by the CNHS authors as one of the limitations (*i.e.*, caution on extrapolation beyond the study sample because the communities in the study may have important differences when compared to others in Canada, or elsewhere) [33].

Health Canada has also acknowledged that the Health Canada Study will "not permit any conclusions to be made with respect to causality" [37]. In the province of Ontario, Canada legislation requires community members who wish to appeal an approval of a WT project must prove the project "will cause serious harm to human health" prior to the start up of WT operations [93]. Small rural communities with a low population density face financial and scientific burdens. Proof of causality is rare in human health and ranks:

> … at about 95% to 99% certainty and is rarely possible for biological systems; the Precautionary Principle ranks at the about the 50% medium level, consistent with civil and some administrative law; and environmental protection has a low level of certainty (10% to 30%) [94].

During a 2005 conference presentation, Health Canada commented that releases from products and technologies (which included renewables) can alter environmental quality which could result in unexpected risks to health. The presentation concluded:

> We cannot afford to wait until the health of Canadians is affected before we act. We have the means, tools and knowledge to become proactive in protecting the health of our citizens, in particular those most at risk [95].

Health Canada advised during a presentation to the Health Canada SAB that it would:

Place hold on Guideline finalization: HC will explore research options and release guidelines only when knowledge gaps are filled [96].

If the intention is to prove causality, as with other complex research this would take many years. In the meantime, more people are at risk of harm.

WHO 1999 [97] provides "environmental management principles on which government policies, including noise management policies, can be based":

1) The precautionary principle. In all cases, noise should be reduced to the lowest level achievable in a particular situation. Where there is a reasonable possibility that public health will be damaged, action should be taken to protect public health without awaiting full scientific proof.

2) The polluter pays principle. The full costs associated with noise pollution (including monitoring, management, lowering levels and supervision) should be met by those responsible for the source of noise.

3) The prevention principle. Action should be taken where possible to reduce noise at the source. Land-use planning should be guided by an environmental health impact assessment that considers noise as well as other pollutants.

Formal adoption and application of these principals by authorities and regulators would contribute towards protecting families and occupational workers from risk factors while living or working near WT.

A critical question is "*Why are some people vulnerable to WT noise while others are not?*" Endeavouring to determine whether or not people exposed to WT noise are affected, and determining the degree of an adverse effect is complex. As is the case with any potentially pathogenic stimulus, people are not equally affected. When adverse effects do occur they may be acute and transient, recurrently episodic and/or chronic. It is therefore essential to utilize sensitive measurements which can not only detect a subset of disturbed people but also consider the pattern of responses. Time sensitive measurements would assist with determining whether the reported adverse effects occur at night during sleep, during waking hours, or during both, and while seeking potential correlations with the nature of the noise exposure.

WT health related investigations could be conducted by multidisciplinary teams centered in medical facilities and staffed by physicians, clinicians, acousticians and other specialists. Full spectrum noise measurements and EMF emissions could be taken in homes and occupational settings of those reporting adverse health effects. Subjects could be monitored over time through long term surveillance. Family physicians could refer patients suspected of being affected by WT to a centralized facility. The WT investigative protocols by McMurtry *et al.* [98] and the Austrian Medical Association [99] could provide assistance during these investigations.

5. Conclusions

To conclude, this paper presents a contemporary example of the research challenges associated with WT with the goal of participating in scientific dialogue and contributing towards enhanced methods for future investigations. While exploring some of the limitations/uncertainties and commenting on some of the methodologies employed by Health Canada, this paper acknowledges the Health Canada Study design had a number of strengths as noted by Michaud *et al.* 2018 [33]. This paper also concurs with Health Canada's advisories that the Health Canada Study results will not be "definitive on their own"; the design will not permit conclusions regarding "causality"; and results may not be generalized beyond the sample studied in Ontario and Prince Edward Island, Canada.

Given Health Canada's advisories, the unresolved research and knowledge gaps, the limitations and uncertainties presented in this paper, reliance of Health Canada Study results to support the safety of WT in literature and during judicial processes should be considered with caution in predicting or understanding the health risks of WT noise.

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Conflicts of Interest

There are no conflicts of interest.

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