

**Review of Studies and Literature Relating to
Wind Turbines and Human Health**

Prepared by Public Service Commission Staff for the Wisconsin State Legislature in Response to
2015 Wisconsin Act 55

December 2015

Introduction

The Public Service Commission of Wisconsin (Commission) was directed by 2015 Wisconsin Act 55 (Act 55) to “conduct a review of studies conducted to ascertain the health effects of industrial wind turbines on persons residing near the turbine installations.” This requirement is similar to the work recently done by the Wind Siting Council¹ (WSC) in an earlier report to the Legislature (2014 WSC report).

Wisconsin Stat. § 196.378(4g)(e) directs the WSC to “survey the peer-reviewed scientific research regarding the health impacts of wind energy systems and study state and national regulatory developments regarding the siting of wind energy systems.” This section also requires the production of a report for the Wisconsin State Legislature every five years, putting a recurring obligation upon the members of the WSC to review current scientific literature on the topic of health impacts of wind energy systems and regulatory trends. The WSC’s 2014 report, the first such required report, was delivered to the Wisconsin State Legislature at the end of October 2014. Commission staff was closely involved with identifying source materials and assisting with the writing of this document. The WSC is tasked with producing another such report by October 2019. This task also requires that the WSC determine whether recommendations on any legislation should be suggested, based on information in the research or regulatory developments.

Commission staff recognizes the work done by the WSC and has not used sources that were evaluated and either used or dismissed by the WSC’s work during the production of the 2014 WSC report. Rather, Commission staff has sought any directly relevant studies or literature that were made available from the time when the WSC stopped taking in new literature, August 2013, until October 2015, when Commission staff began the task of summarizing findings and writing this current document. The 2014 WSC report, which included two minority reports, was the product of almost two years of research, discussion, and writing. This process will likely begin again in late 2017.

Based on the few additional studies in the current review, the research literature on this subject continues to show trends similar to those identified in the 2014 WSC report. There is an association between exposure to wind turbine noise (WTN) and annoyance for some residents near wind energy systems. Some researchers show this as a causal relationship. There is more limited and conflicting evidence that shows association or a causal relationship between wind turbines and sleep disturbance. There is a lack of evidence to support other hypotheses regarding human health effects caused by wind energy systems.

Commission staff identified a number of documents that address the topic of “human health effects of wind energy systems” from a number of sources. As indicated above, Commission staff did not revisit documents that were included in the 2014 WSC report, or more recently published review articles by authors of documents included in the 2014 WSC report where the study methods and results were the same and there was no significant new analysis done. The goal

¹ A Wind Siting Council of Public Service Commission-appointed members was established in the Public Service Commission by Wis. Stat. § 15.797.

was to identify any new direct research or new analysis that might provide additional insight into this topic. Articles that did not directly examine health effects, but rather explored hypotheses that could lead to health effects or discussed ways to model or measure sound produced by turbines were not included. A link to the 2014 WSC report is attached as an appendix to this report to provide the reader with the previous review and analysis done on this subject.

Health Canada Study

Health Canada is the Canadian federal agency responsible for national public health. In response to public concern regarding potential health impacts from wind turbines, Health Canada, in partnership with Statistics Canada, undertook a \$2.1 million Canadian Dollar epidemiological study to evaluate the health of people living up to 10 kilometers (km) (6.2 miles) from wind turbine installations. The study took place in communities in southern Ontario and Prince Edward Island. Preliminary results were published in November 2014, and the study's authors state that these are considered preliminary until published in the peer-reviewed scientific literature.² Only results published in the peer-reviewed literature are provided in this report. It is anticipated that more results will be made available in the peer-reviewed literature by the time of the next WSC report.

The Health Canada study went through a lengthy and open development process prior to the study taking place. A panel of experts that included epidemiologists, acoustic engineers, academics, neurologists, statisticians, and wind energy engineers developed the study design. The members of the expert panel were screened for activities or affiliations that would present bias or conflict with their mandate, and were required to sign confidentiality statements. The study methods and details of the research design committee were put out for a 60-day comment period.³ After the comment period ended, Health Canada provided a summary of the comments received, along with responses from the research committee. This openness allowed for a clear showing of the methods and reasons for the study design, where evaluations and changes were made after comments, and how certain comments were understood but why no changes were made. The study design was also evaluated by the Health Canada Science Advisory Board and the World Health Organization Noise Committee.

Health Canada Study Methods

The study consisted of three main parts:

1. An in-person questionnaire, given to randomly selected adult participants living at various distances from the wind turbines. The study found 1,570 eligible households in the study areas, of which 1,238 households participated (78.9 percent).

² Such publications are starting to be seen at the time of this report. Feder *et al.* 2015, later in this section, describes the quality of life analysis. An article was also published in SLEEP, October 2015 (abstract with results reviewed, full text not yet available), describing specifically the results of the sleep and wind turbine noise (WTN) exposure part of the study.

³ The specific planned locations and timing of the survey were not made available to prevent bias.

2. A collection of physical health measures that assessed stress levels using hair cortisol, blood pressure, sleep actimetry⁴ (over seven days) and resting heart rate. This goal of obtaining objective measures of health sets the Health Canada study apart from many other studies on this subject, which rely only on self-reported health effects.
3. More than 4,000 hours of WTN measurements were conducted to support the modeled calculations of WTN levels at homes in the study.

The study aimed to test all households located within 600 meters of a wind turbine in the study area, with others between 600 meters and 10 km randomly selected. One randomly selected adult in each household was selected to participate in the study. Details of house construction, including the dimensions of the participants' bedrooms were obtained during the survey to assist with sound level modeling.

Although the Health Canada study represents one of the larger and more comprehensive studies regarding health effects of wind turbines, it does not allow for making causal inferences. It does allow conclusions to be made with respect to associations between endpoints. As stated in the preliminary findings:

The current cross-sectional study is an observation study at one point in time among a sample of subjects living various distances from wind turbines. The temporality of the relationship renders it difficult to establish if exposure to wind turbine sound precedes the investigated health endpoints or if the health endpoints are already present before being exposed. Therefore this design does not permit any conclusions to be made with respect to causality.

Health Canada clearly includes a disclaimer that the results produced by the study do not provide definitive answers on their own and should be considered in conjunction with other research available on the topic.

Health Canada Study Results

Calculated outdoor A-weighted WTN levels for the homes participating in the study reached 46 A-weighted decibels (dBA) for wind speeds of 8 meters/second. Use of A-weighted scales in evaluating noise is a common method of measuring environmental noise and assessing potential noise health effects. It is meant to represent the noise filtering process of the human ear, putting less importance on frequencies to which human ears are less sensitive. Other ways of assessing noise could use different weighted scales, and some argue that using A-weighted scales underrepresents low frequency sounds. The Health Canada study also calculated C-weighted sound levels to attempt to better assess the low frequency levels, but found A and C weighted levels were so close as to provide the same information.⁵ The calculated WTN levels are likely to be representative of yearly averages with an uncertainty of about ± 5 dB.

⁴ Small watch-like devices were worn by participants to provide an objective measurement of sleep over a 7-day period.

⁵ Feder *et al.* 2015

An article⁶ published by the panel of the study described in greater detail the World Health Organization Quality of Life⁷ questionnaire (WHOQOL-BREF) used in the Health Canada study, as well as the results seen using univariate analyses and multiple linear regression models. It found that lower scores (less indication of satisfaction with quality of life) on the physical and environment domains of the questionnaire were observed among participants that reported high visual annoyance towards wind turbines. Higher scores (more indication of satisfaction with quality of life) on the physical domain of the questionnaire were seen in participants that received a personal benefit from wind turbines (such as rental payments). Overall, the analysis of the study results do not support an association between exposure to WTN up to 46 dBA (modeled) and quality of life assessed. The article does agree with some other researchers that some quantification of amplitude modulation⁸ and tonality produced from WTN would provide further information into how WTN may influence quality of life. The Health Canada study results do not support an association between exposure to WTN up to 46 dBA and sleep disruption as measured through actimetry.⁹

Additional Published Empirical Research

In addition to the large study conducted by Health Canada, Commission staff identified two additional cross-sectional studies that were published after the cutoff date for those evaluated in the 2014 WSC report. Brief summaries of their methods and results are provided below. Both of these have been incorporated into the critical reviews done by other organizations as described later in this document.

New York (Magari *et al.* 2014)

This was a study in western New York State, where a 126 megawatt wind energy system consisting of 84 turbines covered an area of 19 square miles. Fifty-six homes in the area were randomly selected (out of 256 possible), and the researchers were able to conduct surveys at 52 of these. Sixty-two individuals were interviewed with a survey that was adapted from that previously used by researchers in the Netherlands.¹⁰ This study also collected short-term sound measurements inside and outside of respondents' homes. Average wind speeds that were below the wind speeds typically present in the wind energy system and the short-term nature of the measurements makes comparisons with other studies' findings that use modeled sound levels difficult. Supplementing these short-term measurements with modeled sound levels would improve the ability of the study to compare self-reported health and quality of life data with

⁶ Feder *et al.* 2015.

⁷ The World Health Organization defines Quality of Life (QOL) as a broad multidimensional concept that includes subjective evaluations of both positive and negative aspects of life. Physical domains of health are joined with social, psychological, and environmental domains to create a complex series of measurements. Evaluated items are ranked from a low of 1 to a high of 5.

⁸ Amplitude modulation is used in this context to refer to increased variation of sound levels produced by the aerodynamic noise of the blades of the turbines as they pass the tower. Several articles explore how this effect can occur, how levels could be "enhanced" and how it could be incorporated into noise modeling for projects. See Larsson and Öhlund (2013), and Kaliski (2014) as two examples of this topic of discussion.

⁹ Michaud *et al.* 2015.

¹⁰ Pedersen and Wayne (2007), reviewed in the 2014 WSC report.

average sound levels at each residence. The survey results did not support an exposure-response relationship between short-term indoor or outdoor noise exposure and self-reported annoyance.

Looking instead at the survey responses, they found that there was a correlation between an individual's concern regarding health effects and the prevalence of sleep disturbance or stress among the study population. Ninety percent of the survey participants stated they were either very satisfied or satisfied with their living environment. Thirty-four percent had a negative or very negative view of wind turbines, while 44 percent had a positive or very positive opinion of turbines. The subjective sound descriptor of "swishing" when describing WTN was significantly negatively correlated with an individual's level of satisfaction with their living environment. This study did not include the type of sound monitoring that would be needed to characterize amplitude modulation, which is commonly seen as one cause of this sound characteristic in relation to WTN.

The study found that general annoyance from WTN was statistically correlated with an individual's: (1) general opinion on wind turbines; (2) opinions on altered landscapes; (3) concern over health effects associated with wind turbines; and (4) their sensitivity to noise in general. There was a statistically significant association between an individual's satisfaction with their living environment and if they had some type of relationship with the energy company, such as rental agreements.

Poland (Pawlaczyk-Luszczynska *et al.* 2014)

This study analyzed the relationships between distance and levels of WTN at residences and the percentage of people annoyed by the noise, as well as the individual factors affecting the perceived annoyance. Questionnaires were given to 361 subjects living in the vicinity of 8 wind energy systems in central and northwest Poland. Sound levels were modeled following the sound propagation model used by previous studies such as Pederson and Waye (2004). Noise levels were measured outside some of the respondents' houses to verify the calculated sound levels.

Preliminary analyses of this study found exposure-response relationships between A-weighted sound levels and annoyance. Where sound levels were calculated at 31-50 dBA, almost one-third of participants found outdoor WTN annoying. Although the study found there were no significant difference in subjects noticing WTN compared to other sources of environmental noise, where WTN was noticed, it was more frequently assessed as annoying compared to other environmental noise. Strong correlations were observed between subjective factors such as attitude to wind turbines in general and their visual impact on landscape and levels of annoyance. Generally, the results of this study are similar to those in earlier Swedish and Dutch cross-sectional studies reviewed in the 2014 WSC report.

Additional Literature Reviews

There were four new reviews found published in peer-reviewed journals in the time period of this report. The same caveats as were expressed in the 2014 WSC report¹¹ apply with regard to the quantity and quality of the research available for such review articles to consider. Three of these

¹¹ At pp. 7-8.

review articles¹² restricted the reviews to peer-reviewed scientific literature, while the fourth¹³ imposed no such restriction on the quality of the literature, but specified the topic suitable and identified bias where it was likely to exist.

McCunney *et al.* 2014

The Canadian Wind Energy Association (CanWEA) funded a critical review of peer-reviewed literature regarding evaluations of potential health effects among people living in the vicinity of wind turbines by academic staff at the Massachusetts Institute of Technology (MIT). The coauthors of the paper have backgrounds in occupational and environmental medicine, acoustics, epidemiology, otolaryngology, psychology and public health.¹⁴ This review assessed many of the same studies reviewed by the WSC in its 2014 report. Some additional papers were reviewed that had not been published by the time of the 2014 WSC report literature deadline.¹⁵

The review found four results:

1. Infrasound near wind turbines does not exceed audibility thresholds;
2. Epidemiological studies have shown associations between living near wind turbines and annoyance;
3. Infrasound and low-frequency sound do not present unique health risks; and
4. Annoyance seems more strongly related to individual characteristics than noise from turbines.

Onakpoya *et al.* 2014

This was a review and analysis of the eight studies¹⁶ that met their selection criteria, which the authors describe as “moderate” in quality. The authors are academic researchers with no stated interests with regards to wind energy systems. The results show that living in areas with wind energy systems appears to result in annoyance and may be associated with sleep disturbances and decreased quality of life. The review suggests that visual perception of turbines is correlated with increased episodes of annoyance and that reported adverse effects are more prominent in quiet areas compared with noisy ones. Individual attitudes could influence the type of response to noise from wind turbines. The review does state that as the response variables measured in the studies are subjective, causality between the variables cannot be established.

¹² McCunney *et al.* 2014; Onakpoya *et al.* 2014; and Knopper *et al.* 2014.

¹³ Schmidt and Klokke. 2014.

¹⁴ A statement accompanying the article reads: “Although the funding for this project came from CanWEA through a grant to the Department of Biological Engineering of MIT, members of CanWEA did not take part in editorial decisions or reviews of the manuscript. MIT conducted an independent review of the final manuscript to ensure academic independence of the commentary and eliminate any bias in the interpretation of the literature.”

¹⁵ Both McCunney *et al.* 2014 and Onakpoya *et al.* 2014 review Magari *et al.* 2014 and Pawlaczyk-Luszczryska *et al.* 2014, which are research studies published after the 2014 WSC report was being written.

¹⁶ Six of these had been included in those articles reviewed by the WSC for its 2014 report.

Schmidt and Klokke (2014)

The authors are clinical researchers with no stated interests with regards to wind energy systems. They conducted a systematic review of literature from both peer-reviewed and non-peer-reviewed internet sources.¹⁷ To be included, studies must have investigated any relationship between WTN exposure and health-effect outcomes. No limiting criteria regarding the quality of the research was used in the initial selection process, but risk of bias identified in any of the studies was assessed after review and reported as part of a quality assessment of the studies.

This review clearly states that while case series studies (four of which were reviewed) can generate hypotheses, due to the general likelihood of bias, they contribute weak evidence towards evidence of causation. The rest of the 26 publications were cross-sectional studies. Selection bias¹⁸ and observational bias¹⁹ are still recognized as likely to occur within these studies, and therefore, they also cannot be used to determine specific causal relationships. Even with the more relaxed criteria for literature, the review found similar results to other articles.

This review found that evidence of a dose-response relationship between wind turbine noise linked to noise annoyance, sleep disturbance and possibly psychological distress²⁰ was evident in the studies reviewed. Currently there is no further existing statistically-significant evidence indicating any association between wind turbine noise exposure and tinnitus, hearing loss, vertigo or headache.

The authors suggest that future studies should focus on investigations aimed at objectively demonstrating whether measurable health-related outcomes can be proven to fluctuate depending on exposure to wind turbines.

Knopper et al. 2014

This revisited a previous review²¹ of the literature relating to wind turbines and health effects, looking specifically for new evidence in the studies that had been published since the previous review. The authors are made up of environmental health scientists that do work with wind power companies. For their updated review, they searched the literature and restricted their review to peer-reviewed articles, but did not restrict their review to articles or studies of direct evidence.

This review is bibliographic in nature and provides brief summaries of the articles reviewed, under topic headlines such as “low-frequency noise and infrasound.” Many of these articles were also reviewed in the 2014 WSC report. They find that there is a lack of evidence that suggests that

¹⁷ Referenced specifically in this study was that three websites highly critical of wind energy systems were checked for articles that did not come up in Google Scholar or other searches and suitable literature reviewed.

¹⁸ Selection bias occurs where proper randomization of subjects is not achieved either through selecting specific subjects or allowing subjects to self-select. This can lead to the distortion of statistical analysis and inaccuracies.

¹⁹ Observational bias, also known as information bias, can occur in several ways and are errors in measurement or misclassifications that can affect results. Self-recall of symptoms or effects are a common source of such bias.

²⁰ Sleep disturbance and psychological distress were only reported in self-reported questionnaires which increase the risk of introducing information bias into the study.

²¹ Knopper and Ollson, 2011 (reviewed in the 2014 WSC report).

factors such as electromagnetic fields, shadow flicker, low-frequency noise and infrasound affect human health. They find annoyance may be associated with WTN, and that this annoyance may be associated with self-reported health effects, particularly where exposure to sound levels by non-participants is regularly greater than 40 dBA. They recommend incorporating sound measurements into setback distances and conducting post construction monitoring to ensure modeled sound levels are within limits. This review also discusses the influence psychogenic or subjective factors have on annoyance and other health complaints and identifies these as potentially resulting in levels of annoyance even when noise exposures are below sound level limits.

Conclusion

Concern over whether wind energy systems impact human health continues to prompt new research. For the purposes of this report, Commission staff restricted the acceptance of literature to new peer-reviewed direct studies or critical reviews of such literature published in peer-reviewed journals. There are numerous articles and papers that explore the hypotheses relating to infrasound, low frequency noise, amplitude modulation, and how WTN should be measured or modeled.²² Other articles explore the hypotheses regarding whether some of the impacts associated with wind turbines could be explained through psychogenic factors²³ or effects to the vestibular system.²⁴ These may prove useful for future research on health effects or experts working on sound measurement protocols.

Commission staff regularly searches for new articles and research done on this subject and reviews materials for new information. With more analysis of the results of the Health Canada study expected, as well as potentially new research from Australia and Denmark, it is likely that the WSC will have new studies and reviews to use in its next report to the Legislature. The WSC may choose to review sources cited within this document as part of the already scheduled analysis of literature relating to the health impacts of wind turbines leading up to the October 2019 WSC report. Commission staff does not intend for the current report to be the only consideration of the documents reviewed if WSC members also choose to review the documents as part of their statutorily required report.

Presently, the recent literature on this subject continues to reach conclusions similar to those identified in the 2014 WSC report. The studies have found an association between exposure to wind turbine noise and annoyance for some residents near wind energy systems. Some studies show this as a causal relationship between wind turbines and annoyance. There is more limited and conflicting evidence demonstrating an association or a causal relationship between wind turbines and sleep disturbance. There is a lack of evidence to support other hypotheses regarding human health effects caused by wind energy systems. Overall, the research in this area is limited and insufficient to determine causal relationships between variables.

²² Berger *et al.* 2015; Maffei *et al.* 2015.

²³ Crichton *et al.* 2014.

²⁴ Harrison 2014; Salt and Lichtenhan 2014.

Acronyms

§	Section
CanWEA	Canadian Wind Energy Association
dB	Decibel
dBA	A-weighted decibel
Commission	Public Service Commission of Wisconsin
km	Kilometers
MIT	Massachusetts Institute of Technology
QOL	Quality of life
WHOQOL-BREF	World Health Organization Quality of Life questionnaire
Wis. Stat.	Wisconsin Statute
WSC	Wind Siting Council
WTN	Wind turbine noise

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Appendix A

A copy of the 2014 WSC report to the Wisconsin Legislature can be found on the Public Service Commission website at: <http://psc.wi.gov/renewables/documents/windSitingReport2014.pdf>.

It includes both minority reports as well as appendices.