

Appendix U:  
PUBLIC HEALTH AND SAFETY REPORT  
(Exhibit A-10)

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# Riverbend Wind Energy Facility Public Health & Safety

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## Table of Contents

<b>1</b>	<b>Introduction.....</b>	<b>1</b>
<b>2</b>	<b>Michigan State-Level Siting Standards for Wind Turbines .....</b>	<b>2</b>
2.1	Wind Turbine Setbacks.....	2
2.2	Wind Turbine Sound Levels .....	2
2.3	Shadow Flicker .....	2
<b>3</b>	<b>Scientific and Engineering Justification of Michigan PA233 Wind Turbine Setback Standards.....</b>	<b>3</b>
3.1	Tower and Nacelle Collapse .....	3
3.2	Blade Failure .....	3
3.3	Ice Throw .....	4
<b>4</b>	<b>Health Research Supporting the Proper Siting of Wind Turbines - Sound... 8</b>	
4.1	Audible Sound.....	9
4.1.1	Sleep .....	9
4.2	Low Frequency Noise and Infrasound .....	14
4.3	Other Potential Health Concerns.....	18
4.3.1	Peer Reviewed Studies on Self-Reported and Objective Measures of Health....	18
4.4	Recent Systematic Review on Wind Turbines and Health .....	20
4.5	Michigan Sound Guidelines .....	22
<b>5</b>	<b>Shadow Flicker .....</b>	<b>23</b>
5.1	Shadow Flicker Health, Annoyance and Nuisance.....	24
5.2	Shadow Flicker Standards .....	25
<b>6</b>	<b>Riverbend Wind Project and Compliance With Michigan PA233 Requirements .....</b>	<b>27</b>
6.1	Setback Compliance .....	27
6.2	Sound Compliance .....	27
6.3	Shadow Flicker Compliance .....	28
<b>7</b>	<b>Conclusion on Michigan Wind Turbine Siting Standards and the Riverbend Wind Project .....</b>	<b>28</b>
<b>8</b>	<b>References.....</b>	<b>29</b>

**List of Figures**

Figure 1. Ice Pieces from the IceThrower Database shown to fall within tip height of the wind turbine. .... 6

Figure 2. Measurements of infrasound and low frequency noise 300 m from wind turbines compared to other sources. .... 17

**List of Table**

Table 1. Setback requirements of wind turbines to various features ..... 2

Table 2. Ice Throw Strike Probabilities (Garrad Hassan, 2007)..... 5

Table 3. Setback requirements of wind turbines to various features ..... 7

Table 4. Self-reported magnitude and contributing sources of sleep disturbance. .... 10

Table 5. Sound sources of sleep disturbance in rural and urban area types, only respondents who did not benefit economically from wind turbines (Bakker et al, 201)..... 11

Table 6. Sample profile of health conditions (Michaud et al., 2016a). .... 20

Table 7. State-level sound requirements ..... 22

Table 8. Setback requirements of wind turbines to various features ..... 27

## **1 Introduction**

The United States continues to see growth in the installation of wind turbines across the country. There are over 75,000 wind turbines installed across the United States, with more than 1,600 wind turbines producing over 3,800 MW of installed wind energy in Michigan.

With the growth of the industry has come the need to develop consistent and proper siting guidelines to ensure the protection public health and safety. There are no such federal guidelines or standards that govern the siting of wind turbines. However, the State of Michigan Public Act 233, effective November 29, 2024 (Michigan PA233) provides overarching state-wide standards for wind turbine setback distances to various features, sound levels and shadow flicker requirements to ensure the protection of public health and safety (MCL 460.1226 Subsection (8)(b)).

Dr. Christopher Ollson of Ollson Environmental Health Sciences (OEHM) was retained by MI Energy Developments, LLC to provide scientific rational support to the Michigan PA233 setback, sound and shadow flicker requirements for proper siting of wind turbines. He was also asked to review the Riverbend Wind Project siting against these requirements. Dr. Ollson has over 15 years of experience researching and working in the wind industry across North America to develop science-based wind turbine siting criteria that ensure the protection of public health and safety. Dr. Ollson's research has been presented at numerous international scientific conferences. He has been formally qualified to provide expert opinion evidence on wind turbines and potential health effects at a number of North American hearings, tribunals and legal cases. Dr. Ollson has appeared before numerous County Planning & Zoning and County Commissions and state Public Services Commissions across the country, including in Michigan.

There is no question that setting appropriate wind turbine siting guidelines is a complicated undertaking. As with any energy production project, one needs to balance community concerns with project needs, while still ensuring the protection of public health and safety of the local population.

Over the past twenty years, there has been extensive research evaluating public health, safety and welfare concerns of those living in proximity to wind turbines. This independent research by university professors, consultants and government agencies has taken place in many different countries on a variety of turbine models, many of which have been in communities for years. It is on the basis of this research that States, such as Michigan, have set appropriate wind turbine siting standards.

## 2 Michigan State-Level Siting Standards for Wind Turbines

In November, 2023 the Governor of Michigan approved Act No. 233 of Public Acts of 2023, that took effect on November 29, 2024 (Michigan PA233). This Act provides overarching state-wide standards for wind turbine setback distances to various features, sound levels and shadow flicker requirements to ensure the protection of public health and safety.

The following wind turbine siting requirements are found in MCL 460.1226 Subsection (8)(b):

### 2.1 Wind Turbine Setbacks

(i) *The following minimum setback distances, measured from the center of the base of the wind tower:*

**Table 1. Setback requirements of wind turbines to various features**

<u>Setback Description</u>	<u>Setback Distance</u>
Occupied community buildings and residences on nonparticipating properties	2.1 times the maximum blade tip height to the nearest point on the outside wall of the structure
Residences and other structures on participating properties	1.1 times the maximum blade tip height to the nearest point on the outside wall of the structure
Nonparticipating property lines	1.1 times the maximum blade tip height
Public road right-of-way	1.1 times the maximum blade tip height to the center line of the public road right-of-way
Overhead communication and electric transmission, not including utility service lines to individual houses or outbuildings	1.1 times the maximum blade tip height to the center line of the easement containing the overhead line

These setback distances have been put in place to primarily ensure the protection of public safety with respect to ice throw, blade failure, and tower collapse.

### 2.2 Wind Turbine Sound Levels

It is important to set appropriate sound limits to ensure protection against sleep disturbance and a potential cascade of adverse health impacts. Michigan PA233 requires:

*(iv) The wind energy facility does not generate a maximum sound in excess of 55 average hourly decibels as modeled at the nearest outer wall of the nearest dwelling located on an adjacent nonparticipating property. Decibel modeling shall use the A-weighted scale as designed by the American National Standards Institute.*

It is important to note that on October 10, 2024 the Michigan Public Services Commission (MPSC) issued Final Rules U-21547 (Order). The Order requires that during modeling of wind turbine sound at dwellings that a -6 dBA penalty is to be applied to account for potential façade pressure doubling at dwellings. This -6 dBA penalty effectively means that the modeled sound level standard at the exterior of non-participating dwellings is 49 dBA during pre-construction modeling. There is no sound restriction for participating dwellings.

### 2.3 Shadow Flicker

Although shadow flicker does not cause adverse health impacts (e.g., seizures or migraines), it does need to be limited to avoid excessive nuisance to nonparticipating property owners at their residences. Michigan PA233 requires:

*(ii) Each wind tower is sited such that any occupied community building or nonparticipating residence will not experience more than 30 hours per year of shadow flicker under planned operating conditions as indicated by industry standard computer modeling.*

### **3 Scientific and Engineering Justification of Michigan PA233 Wind Turbine Setback Standards**

Appropriate setback distances go hand in hand with sound and shadow flicker standards to ensure protection of public health and welfare. In addition, setbacks need to account for public safety concerns with respect to potential ice throw, blade failure, and tower collapse. Public safety setback distances are often set both to non-participating property lines and dwellings.

OEHM agrees that it is appropriate to distinguish setback distances for participating vs. non-participating residences/dwelling. It is also important to establish protective setback distances to non-participating property lines, road right-of-ways (ROWs). These setbacks all work together to ensure the protection of public health, safety and welfare of the residents. Each setback serves a specific purpose.

Table 3 provides a comparison of the Michigan wind turbine setbacks with other State-level setbacks that have been legislated across the US. They are setbacks that have been proven to ensure the protection of public health and safety and should be considered for adoption. In many jurisdictions, setbacks are a fixed distance to homes, whereas in others a multiplier on the total turbine height is used to establish the setback distances.

In all cases these jurisdictions have successfully hosted wind projects for one to two decades. In general, Michigan wind turbine setbacks are the same or similar to those in other States. It is true that there are some States that have greater setbacks, for specific features, than enacted in Michigan. However, these setback distances afford no greater health protection for public health.

Safety is of primary consideration for the design of any wind project. Safety is achieved primarily through engineering, design and construction standards being met. Although rare, wind turbines are mechanical structures and components can fail and become detached from the turbine. It is also true that wind turbines can catch fire.

#### **3.1 Tower and Nacelle Collapse**

Tower collapse is a very rare event, although it is acknowledged that it can occur. If a wind turbine experiences catastrophic failure of the tower it collapses on itself within an area equivalent to the total tip height of the turbine. Tower collapse is typically a result of a blade failure which strikes the tower itself or in some rare instances a structural failure of the tower.

The Michigan PA233 safety distance of 1.1 times turbine height from roads and nonparticipating property lines ensures that in the unlikely event of a tower collapse the wind turbine will impact only the participating parcel of land. It will not interfere with, or affect, neighboring roads or properties.

#### **3.2 Blade Failure**

It is estimated that approximately 1 in 10,000 wind turbine blades experience catastrophic failure a year (Flemish Government. 2019). This is typically a result of excessive voltage lightning strike or a structural defect in the blade. During these events the majority of the blade will fall to the ground, while some smaller, lighter fractions may become detached.

A 2022 peer-reviewed published paper on blade failure events and potential risk to adjacent roads concluded (Rogers and Costello, 2022):

*Results for these example turbines show that the typical setback of 1:1x tip height is generally sufficient at reducing risk to extremely low levels (between 1 impact in 1 million years and 1 impact in 10 million years) for roads in rural areas which tend to be lightly traveled.*

Rogers, J. and Ollson, C.A. 2025. Simulation Analysis and Safety Risk Assessment of a Wind Turbine Blade Failure Event. Wind Energy.

A recently released paper by Rogers and Ollson (2025) evaluated a major blade failure event caused by a lightning strike in the Kansas. The authors describe nature of the debris field, along with measurements of example blade fragments collected from the site. They then conducted a blade throw simulation model to simulate the release of a representative set of debris, informed by fragment sizes and weights collected from the debris field. The debris field produced by the simulation model matched the debris field observed empirically with reasonable accuracy. The bulk of the blade and heavier pieces landed within tip height of the turbine. While there were small and lighter debris fragments that were seen to be blown further in the 55+ mile an hour winds. The authors concluded:

*Ballistic impact models are used to determine whether any fragments thrown beyond 1.1 times the turbine tip height could have caused injury to a person. This ballistic analysis shows that debris that traveled beyond 1.1 times the tip height had relatively low kinetic energy and would be extremely unlikely to cause injury to a person.*

In 2013, MMI Engineering Ltd undertook a study titled “Study and development of a methodology for the estimation of the risk and harm to persons from wind turbines” for the United Kingdom government. Through their probabilistic assessment they determined that risk of fatality from wind turbine blade fragment throw is low in comparison to other societal risks. It was roughly equivalent to the risk of fatality from taking two aircraft flights a year or being struck by lightning.

During the initial Township applications for the Riverbend Wind Project, Dr. Jonathan Rogers of Persimia, and Professor of Aerospace Engineer at Georgia Tech, conducted site specific Riverbend Wind Project Ice Shed and Blade Failure Risk Assessment (Persimia, 2023). This report concluded, for wind turbines setback 1.1 times the turbine tip height, that:

*Modern wind turbines are equipped with structural health monitoring systems that make blade failures extremely unlikely. A comprehensive analysis that accounts for blade failure rates and blade throw distances shows that the risk to property or personnel due to blade throw is less than 1 impact per 10 million years, an extraordinarily small risk.*

All of these studies and reports align with, and support, the use of the Michigan PA233 standard of 1.1 times tip height to roads and neighboring nonparticipating property lines to ensure the protection of public safety.

### **3.3 Ice Throw**

Turbine ice throw refers to the phenomenon where pieces of ice detach from the rotating blades of a wind turbine and are propelled outward. This occurs when ice accumulates on the blades due to cold weather conditions and then breaks off or is flung off during turbine operation. The distance the ice travels depends on factors like blade speed, ice piece size and weight, and wind conditions. Ice throw can be a safety concern for wind farm operators and, in extreme cases, may pose risks to personnel, nearby structures, and public areas.

Some of the earliest work on ice throw was completed in Canada. In 2007, Garrad Hassan Canada Inc. was commissioned by the Canadian Wind Energy Association (CanWEA) to undertake a probabilistic risk evaluation of the likelihood of ice fragment throw from wind turbines would strike a member of the public. They used a hypothetical wind turbine, similar to those commonly in operation. Three scenarios were examined – Scenario A House, Scenario B Road and Scenario C Individual. The setback distances they used were consistent or less than those in the Michigan PA233 standard. Their findings are provided in Table 2.

**Table 2. Ice Throw Strike Probabilities (Garrad Hassan, 2007)**

Scenario A House	Scenario B Road	Scenario C Individual
<ul style="list-style-type: none"> <li>• 1000 ft<sup>2</sup> house</li> <li>• 1000 ft from turbine</li> <li>• 1 ice strike per 62,500 years</li> </ul>	<ul style="list-style-type: none"> <li>• north-south road is situated directly west of a turbine at 650 ft</li> <li>• 100 vehicles at 40 mph</li> <li>• 1 vehicle strike per 100,000 years</li> </ul>	<ul style="list-style-type: none"> <li>• ever-present individual between 65 ft to 1000 ft from turbine</li> <li>• 1 strike in 500 years</li> </ul>

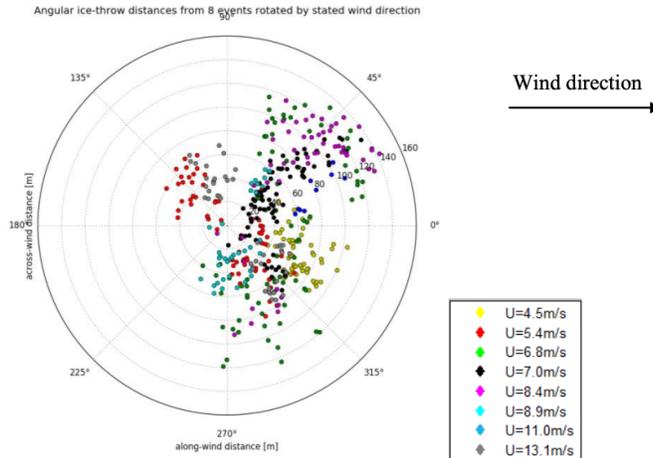
The results indicate an extremely low probability that an individual or vehicle would ever be struck. They are far less than risks that people face in everyday life (e.g., driving a car, being struck by lightning, or being in an airplane crash).

Significant work on ice throw potential and modelling has occurred in the Nordic countries over the past decade. Results indicate an extremely low probability that an individual or vehicle would ever be struck. There are far less than risks that people face in everyday life (e.g., driving a car, being struck by lightning, or being in an airplane crash). For example:

*Bredesen, R.E., Drapalik, M., and Butt, B. 2017 Understanding and acknowledging the ice throw hazard - consequences for regulatory frameworks, risk perception and risk communication J. Phys.: Conf. Ser. 926 012001*

The researchers combine the use of field studies involving icing of turbines in the field and then the recovery of ice chunks in the field surrounding the wind turbine under varying wind speeds. This data was then used to develop ice throw models. In fact, it is in part this data that Dr. Rogers of Persimia used to validate his own model.

Figure 1 provides an excellent illustration of how the majority of pieces of ice will be thrown within the tip height of a wind turbine. In this case a Vestas V90 model turbine with a tip height of 140 m was used.



**Figure 6.** 417 ice pieces from the IceThrower database for the considered V90 turbine with a tipheight of 140 m. The location of all ice pieces are rotated by the given wind direction for each given case. Events are listed A-H by colored markers for increasing wind velocities.

**Figure 1. Ice Pieces from the IceThrower Database shown to fall within tip height of the wind turbine.**

The Riverbend site-specific Persimia report also evaluated the potential risk from ice throw to cause harm to people and damage passing by cars (Persimia, 2023). When evaluating ice fall and ice throw risk for a specific wind project, it is important to account for the frequency of icing events. Local climate characteristics play a large role in determining the frequency of ice fall or ice throw for a given wind site. Generally, the International Energy Agency (IEA) classifies wind sites into five IEA Icing Classes, with IEA Icing Class 5 being at highest risk for ice accumulation and IEA Icing Class 1 being at lowest risk. The Icing Class determination for a given site is based on the expected number of icing days per year. The Riverbend project area in Speaker township is considered Class 1, which corresponds to the lowest icing risk, with only up to one day of icing expected to occur in a year.

The Riverbend Wind Project will include operating systems that can detect icing on all turbines, such that turbines can be shut down when significant icing or thawing events are detected. This will eliminate the possibility of ice throw. Instead, ice pieces will be shed directly beneath the stationary turbine blades, posing no risk to the surrounding area. The Persimia report evaluated the potential risk when the ice detection system was only working 75% of the time and ice could be thrown. Figure 4.1 in Persimia report shows that in the event that the ice detection system fails the vast majority of ice thrown would be within 1.1x tip height of the turbine and pose no risk to the public or vehicles. This is consistent with the work of Bredesen and Butt (2017). The authors concluded:

*Even in the event that these icing protection systems and procedures are only 75% effective, Persimia’s simulation models show that the probability that ice pieces impact surrounding homes, personnel, or vehicles is extremely low, less than 1 impact per ten thousand years.*

All of these studies and reports align with the use of the Michigan PA233 standard of 1.1 times tip height to roads and neighboring nonparticipating property lines to ensure the protection of public safety from risk of ice throw.

**Table 3. Setback requirements of wind turbines to various features**

Setback Description	Michigan	Illinois	Wisconsin	North Dakota	New York	Indiana
<b>Occupied community buildings and residences on nonparticipating properties</b>	2.1 times the maximum blade tip height to the nearest point on the outside wall of the structure	2.1 times tip height to non-participating receptors	The lesser of 1,250 feet or 3.1 times the maximum blade tip height	3 times the height of the turbine from an inhabited rural residence of a nonparticipating landowner, unless a variance is granted	2 times tip height	three (3) times the wind power device's blade tip height, as measured from the ground to the tip of the blade.
<b>Residences and other structures on participating properties</b>	1.1 times the maximum blade tip height to the nearest point on the outside wall of the structure	1.1 times the maximum blade tip height of the wind tower to the nearest point on the outside wall of the structure	1.1 times the maximum blade tip height	None	None	None
<b>Nonparticipating property lines</b>	1.1 times the maximum blade tip height	1.1 times the maximum blade tip height of the wind tower to the nearest point on the property line of the nonparticipating property	1.1 times the maximum blade tip height	1.1 times the height of the turbine from the property line of a nonparticipating landowner	1.1 times tip height	1.1 times tip height
<b>Public road right-of-way</b>	1.1 times the maximum blade tip height to the center line of the public road right-of-way	1.1 times the maximum blade tip height of the wind tower to the center point of the public road right-of-way	1.1 times the maximum blade tip height	Typically 1.1 times tip height	1.1 times tip height	1.1 times tip height
<b>Overhead communication and electric transmission, not including utility service lines to individual houses or outbuildings</b>	1.1 times the maximum blade tip height to the center line of the easement containing the overhead line	1.1 times the maximum blade tip height of the wind tower to the nearest edge of the property line, easement, or right-of-way containing the overhead line	1.1 times the maximum blade tip height	Typically 1.1 times tip height	1.5 times tip height	1.2 times tip height

North Dakota Century Code Chapter 49-22 ENERGY CONVERSION AND TRANSMISSION FACILITY SITING ACT  
 Wisconsin Chapter PSC 128 WIND ENERGY SYSTEMS  
 Michigan, PA 233 § 222  
 Illinois 55 ILCS 5/5-12020  
 New York ORES Title 16, Part 1101

#### 4 Health Research Supporting the Proper Siting of Wind Turbines - Sound

Over 150 studies have been published worldwide to examine the relationship between wind turbines and possible human health effects. Based on the findings and scientific merit of these studies, lead health and medical authorities have stated that when sited properly (i.e., based on distance and/or noise guidelines and setbacks), wind turbines are not causally related to adverse effects.

Appropriate science-based setbacks and sound limits are required to ensure the protection of public health and safety. One needs to ensure these protections for issues on:

- Sound (audible noise)
- Shadow Flicker
- Setback Distances – public safety

The focus of this report is on non-participating residences.

Perhaps one of greatest areas of research on the proper siting of wind turbines to avoid health issues is in relation to wind turbine sound and setback distances to homes. The past decade has seen numerous independent research efforts undertaken in the U.S., Canada, Europe and Australia.

In 2014, Health Canada released the findings of their Wind Turbine Noise (WTN) and Health Study. This is the most comprehensive study of its kind to date and its results will be referenced a number of times in this report. The following provides a high-level overview of the study design. This study was initiated in 2012 and was a partnership between Health Canada and Statistics Canada to understand the potential impacts of wind turbine noise on health and wellbeing of communities in Southern Ontario and Prince Edward Island (PEI). A total of 1238 households participated in the study, with an almost 80% response rate of all households within 6 miles (10 km) of projects investigated, making it the largest and most comprehensive study ever undertaken around the world.

Households were located between 820 ft (250 m) and 6 mi (10 km) from operational wind turbines. The A-weighted (dBA) sound levels (audible sound/noise) were grouped into 5 dBA increments with the loudest level in the study at the exterior of a home being 46 dBA Leq (highest nighttime level). These levels are lower than the typical Western state standards of 50 dBA at the exterior of homes or that of the Michigan PA233 standard of 55 dBA minus 5 dBA or 49 dBA.

In 2014, Health Canada released a Summary of their findings on their website (Health Canada, 2014).

<http://www.hc-sc.gc.ca/ewh-semt/noise-bruit/turbine-eoliennes/summary-resume-eng.php>

Health Canada's public brochure contains the following statement:

*"The Wind Turbine Noise and Health Study is a landmark study and the most comprehensive of its kind. Both the methodology used and the results are significant contributions to the global knowledge base and examples of innovative, leading edge research."*

Since 2015, Health Canada has published numerous peer-reviewed scientific publications with their results. This research will be discussed as appropriate throughout this report and is often referred to the “Michaud” work as Dr. David Michaud was typically the first author on these papers (Michaud et al., 2016; 2016a; 2016b; 2016c).

## **4.1 Audible Sound**

With any sound, sleep is the critical health endpoint that needs to be protected at residences. However, there are a number of other concerns that have been raised with living in proximity to wind turbines. The increase in wind power development in North America has been coupled with some who believe that wind turbines should be set miles back from residences, or else it will result in public health impacts. However, the weight of scientific evidence does not hold this to be true. The following section provides an overview of the most up to date, peer-reviewed published, evidence to understand how the proper operation of a wind turbine project should not interfere with sleep.

### **4.1.1 Sleep**

The critical effect from a health perspective in setting any nighttime sound source standard is to ensure that it is protective of sleep. Quality of sleep and sleep perception can be challenging to establish causation through self-reported surveys alone.

In 2006, the Institute of Medicine of the National Academies released the book “*Sleep Disorders and Sleep Deprivation: An Unmet Public Health Problem*” (IOM, 2006). At that time they reported that: “*It is estimated that 50 to 70 million Americans suffer from a chronic disorder of sleep and wakefulness, hindering daily functioning and adversely affecting health.*” In 2006 the population of the United States was 298 million, resulting in an approximately 23% of Americans with sleep disorders. This needs to be considered within any review of the sleep literature with respect to wind turbines in the American context.

The following provides an overview of a number of wind turbine specific sleep studies in relation to nighttime noise levels at the exterior of homes.

Michaud et al., 2016. Effects of Wind Turbine Noise on Self-Reported and Objective Measures of Sleep. *Sleep*, Vol. 39, No. 1 (Health Canada)

The journal *Sleep* is a highly respected scientific publication in this area of research. This is reflected in its five-year Impact Factor score of 5.8. The paper presents the peer-reviewed published findings of the Health Canada study (2014) of wind turbine noise on sleep. The sample size was the entire 1,238 participants from the overall study for self-reported sleep quality over the 30 days using the Pittsburgh Sleep Quality Index (PSQI) and additional questions assessing the prevalence of diagnosed sleep disorders and the magnitude of sleep disturbance over the previous year. For the first time, objective measures for sleep latency, sleep efficiency, total sleep time, rate of awakening bouts, and wake duration after sleep were recorded using the wrist worn Actiwatch2® for 654 participants, over a total of 3,772 sleep nights. It is the largest and most comprehensive of its kind ever undertaken for wind turbine noise.

The following excerpt from the paper discusses the study objective:

*“The current study was designed to objectively measure sleep in relation to WTN exposure using actigraphy, which has emerged as a widely accepted tool for tracking sleep and wake behavior. The objective measures of sleep, when considered together with self-report,*

provide a more comprehensive evaluation of the potential effect that WTN may have on sleep.”

The importance of this study is that for the first time objective measures of sleep using actigraphy were investigated for wind turbine noise.

“Table 2 presents the summary statistics for PSQI as both a continuous scale and a binary scale (the proportion of respondents with poor sleep; i.e., PSQI above 5) by WTN exposure categories. Analysis of variance was used to compare the average PSQI score across WTN exposure groups (after adjusting for provinces). There was no statistical difference observed in the mean PSQI scores between groups ( $P = 0.7497$ ) as well as no significant difference between provinces ( $P = 0.7871$ ) (data not shown). Similarly, when modeling the proportion of respondents with poor sleep (PSQI > 5) in the logistic regression model, no statistical differences between WTN exposure groups ( $P = 0.4740$ ) or provinces ( $P = 0.6997$ ) were observed (see supplemental material).”

Table 4 is an excerpt from Michaud et al. (2016; their Table 1) and provides an overview of the self-reported sleep magnitude and contribution of disturbance. It was reported that there was no statistical difference in self-reported sleep disturbance for participants living with exterior to home sound levels from <25 dBA to 40-46 dBA. They reported:

“The prevalence of reported sleep disturbance was unrelated to wind turbine noise levels.”

**Table 4. Self-reported magnitude and contributing sources of sleep disturbance.**

Variable	Wind Turbine Noise, dB(A)					Overall	CMH P value <sup>a</sup>
	< 25	25–30	30–35	35–40	40–46		
n	83	95	304	519	234	1,235	
Self-reported sleep disturbance n (%)							
Not at all	29 (34.9)	44 (46.3)	112 (36.8)	208 (40.1)	85 (36.3)	478 (38.7)	
At least slightly <sup>b</sup>	54 (65.1)	51 (53.7)	192 (63.2)	311 (59.9)	149 (63.7)	757 (61.3)	0.7535
Highly <sup>c</sup>	13 (15.7)	11 (11.6)	41 (13.5)	75 (14.5)	24 (10.3)	164 (13.3)	0.4300
Source of sleep disturbance (among participants at least slightly sleep disturbed) n (%)							
n <sup>d</sup>	53	51	186	298	138	726	
Wind turbine	0 (0.0)	2 (3.9)	4 (2.2)	45 (15.1)	31 (22.5)	82 (11.3)	< 0.0001
Children	9 (17.0)	12 (23.5)	21 (11.3)	36 (12.1)	20 (14.5)	98 (13.5)	0.2965
Pets	7 (13.2)	12 (23.5)	9 (4.8)	45 (15.1)	22 (15.9)	95 (13.1)	0.3582
Neighbors	6 (11.3)	5 (9.8)	9 (4.8)	13 (4.4)	5 (3.6)	38 (5.2)	0.0169
Other	41 (77.4)	35 (68.6)	162 (87.1)	232 (77.9)	87 (63.0)	557 (76.7)	0.0128
Stress/anxiety	6 (11.3)	2 (3.9)	21 (11.3)	33 (11.1)	11 (8.0)	73 (10.1)	0.8938
Physical pain	11 (20.8)	9 (17.6)	50 (26.9)	48 (16.1)	18 (13.0)	136 (18.7)	0.0289
Snoring	5 (9.4)	6 (11.8)	17 (9.1)	20 (6.7)	12 (8.7)	60 (8.3)	0.4126

Participants were asked to report their magnitude of sleep disturbance over the last year while at home by selecting one of the following five categories: not at all, slightly, moderately, very, or extremely. Participants that indicated at least a slight magnitude of sleep disturbance were asked to identify all sources perceived to be contributing to sleep disturbance. <sup>a</sup>The Cochran Mantel-Haenszel chi-square test was used to adjust for provinces. <sup>b</sup>At least slightly sleep disturbed includes participants indicating the slightly, moderately, very or extremely categories. <sup>c</sup>Highly sleep disturbed includes participants who reported the very or extremely categories. The prevalence of reported sleep disturbance was unrelated to wind turbine noise levels. <sup>d</sup>Of the 757 participants who reported at least a slight amount of sleep disturbance, 31 did not know what contributed to their sleep disturbance. Of the remaining 726, at least one source was identified. Columns may not add to sample size totals as some participants did not answer questions and/or identified more than one source as the cause of their sleep disturbance.

From the conclusions of the paper:

“The potential association between WTN levels and sleep quality was assessed over the previous 30 days using the PSQI, the previous year using percentage highly sleep disturbed, together with an assessment of diagnosed sleep disorders. These self-reported measures were considered in addition to several objective measures including total sleep

*time, sleep onset latency, awakenings, and sleep efficiency. In all cases, in the final analysis there was no consistent pattern observed between any of the self-reported or actigraphy-measured endpoints and WTN levels up to 46 dB(A) [820 ft]. Given the lack of an association between WTN levels and sleep, it should be considered that the study design may not have been sensitive enough to reveal effects on sleep. However, in the current study it was demonstrated that the factors that influence sleep quality (e.g. age, body mass index, caffeine, health conditions) were related to one or more self-reported and objective measures of sleep. This demonstrated sensitivity, together with the observation that there was consistency between multiple measures of self-reported sleep disturbance and among some of the self-reported and actigraphy measures, lends strength to the robustness of the conclusion that WTN levels up to 46 dB(A) [820 ft] had no statistically significant effect on any measure of sleep quality.*

The findings of Michaud et al., (2016) supports the position that residents living with exterior nighttime sound levels of <46 dBA at the exterior of homes should not experience sleep disturbance from the wind turbine sound.

The Health Canada findings are consistent with credible previously published peer-reviewed literature in the field.

Bakker et al. 2012. Impact of wind turbine sound on annoyance, self-reported sleep disturbance and psychological distress. Science of The Total Environment, Volume 425, 15 May 2012, Pages 42-51

Bakker et al., (2012) completed the most compelling research, prior to the Health Canada Study (2014), into wind sound awakenings. This research reported the number or percentage of awakenings with those living in proximity to wind turbines in a rural setting. As can be seen in Table 5 (Table 7 from the Bakker paper), more people in rural environments are awakened by people/animal sound and traffic/mechanical sounds than by the proximate wind turbines. In this study, people living in close proximity to wind turbines reported being awoken more by people/animal noise (11.7%) and rural traffic/mechanical noise (12.5%) than by turbine noise (6.0%). Sound levels in this study were as high as 54 dBA from wind turbines at the exterior of neighboring homes.

**Table 5. Sound sources of sleep disturbance in rural and urban area types, only respondents who did not benefit economically from wind turbines (Bakker et al, 201)**

**Table 7**

Sound sources of sleep disturbance in rural and urban area types, only respondents who did not benefit economically from wind turbines.

Sound source of sleep disturbance	Rural		Urban		Total	
	n	%	n	%	n	%
Not disturbed	196	69.8	288	64.9	484	66.8
Disturbed by people/ animals	33	11.7	64	14.4	97	13.4
Disturbed by traffic/ mechanical sounds	35	12.5	75	16.9	110	15.2
Disturbed by wind turbines	17	6.0	17	3.8	34	4.7
Total	281	100	444	100	725	100

From the Health Canada sleep study (Michaud et al., 2016):

*“Study results concur with those of Bakker et al. (2002), with outdoor WTN levels up to 54 dB(A), wherein it was concluded that there was no association between the levels of WTN and sleep disturbance when noise annoyance was taken into account”.*

Jalali et al. 2016. Before–after field study of effects of wind turbine noise on polysomnographic sleep parameters. *Noise Health*; 18:194-205.

The first study to be published regarding before-after effects of wind turbine noise on objectively measured sleep was conducted with 16 participants living within 1.25 mi (2 km) to a five-wind turbine project in Ontario, Canada. It should be noted that outdoor sound measurements ranged between 40 – 45 dBA before the wind turbines and 38-42 dBA after the turbines became operational. The average indoor sound level in the bedrooms was reported as 31 dBA while the wind turbines were operational. For the first time authors used portable polysomnography (PSG), which is a comprehensive system that objectively monitors people’s sleep in their homes.

Although there are concerns about the small sample size and that exterior sound levels were higher pre-operation of wind turbines, the authors concluded:

*“The result of this study based on advanced sleep recording methodology together with extensive noise measurements in an ecologically valid setting cautiously suggests that there are no major changes in the sleep of participants who host new industrial WTs in their community.”*

These findings are consistent with the previous reported studies.

Liebich et al. 2020. A systematic review and meta-analysis of wind turbine noise effects on sleep using validated objective and subjective sleep assessments. *Journal of Sleep Research*

Recently, researchers in Australia undertook a systematic review and meta-analysis of the published literature of how wind turbine noise may impact both objective and subjective sleep outcomes.

They retained nine studies for review, with five of them containing sufficient data that could be used in the meta-analysis of sleep outcomes. The systematic review includes the three publications already reviewed above in the OEHM report. They found:

*The meta-analysis of five studies found no evidence to support that objectively measured sleep latency, sleep efficiency, time spent asleep and awake during the night are significantly different in the presence versus absence of WTN exposure.*

They could not conduct a meta-analysis on the self-reported sleep outcomes because the measurement outcomes were not consistent enough between studies. They concluded:

*This systematic review and meta-analysis suggests that WTN does not significantly impact key indicators of objective sleep. Cautious interpretation remains warranted given variable measurement methodologies, WTN interventions, limited sample sizes, and cross-sectional study designs, where cause and-effect relationships are uncertain. Well-controlled experimental studies using ecologically valid WTN, objective and psychometrically validated sleep assessments are needed to provide conclusive evidence regarding WTN impacts on sleep.*

To date, this is the most comprehensive review of wind turbine sound exposure and sleep. It is acknowledged that the authors did suggest that further in home studies are needed to provide “conclusive evidence”. This additional research is currently underway in Australia.

Michaud et al., 2021. Sleep actigraphy time-synchronized with wind turbine output. SLEEPJ, 2021, 1–12. (Health Canada)

In March of 2021, the Health Canada team published their findings on a re-evaluation of their original collection of sleep data for those living around wind turbines. They further refined the data evaluation of the sleep actigraphy data to 10-minute intervals and time synchronized it to wind turbine supervisory control and data acquisition. Overall, they concluded:

*Maximum calculated nightly average wind turbine SPL reached 44.7 dBA (mean = 32.9, SD = 6.4) outdoors and 31.4 dBA (mean = 12.5, SD = 8.3) indoors. Wind turbine SPL in 10 min intervals, and nightly averages, was not statistically associated with actigraphy outcomes....Overall results showed that wind turbine SPL below 45 dBA was not associated with any consequential changes in actigraphy-measured sleep.*

The findings of the recent Health Canada research on sleep and wind turbine noise are consistent with their previous findings and the meta-analysis of sleep outcomes provided by Liebich et al. (2020).

Liebich et al. 2022. The effect of wind turbine noise on polysomnographically measured and self-report sleep latency in wind turbine noise naïve participants. SLEEPJ. Vol 45. No. 1. pg 1-11.

The objective of the study was to assess the impact of wind turbine noise (WTN) on polysomnographically measured and diary-determined self-reported sleep latency compared to a controlled background in a laboratory sleep chamber. There were 23 urban participants that were naïve (never heard before) to wind turbine sound. They were exposed to 33 dBA of interior bedroom previously recorded wind turbine sound. This mimics the expected sound level of a home that would have windows open and an exterior wind turbine sound level of 40 dBA or greater.

They concluded:

*“WTN effects on objective and subjective sleep latency were assessed via a two-night sleep study in a controlled sleep laboratory setting using polysomnography and sleep diary measures in a sample of health sleeps not typically exposed to WTN. No differences were found in objective or subjective sleep latency when WTN at 33 dB(A) was presented during the sleep onset period compared to control background noise at 23 dB(A). Furthermore, no differences were found in latency to N2 sleep, nor in the proportion of individuals who took >20 or >30 min to fall asleep in the presence versus absence of WTN.”*

Ellenbogen, JM, Kellam, CB, and Hankard, M. 2024. Noise-induced sleep disruption from wind turbines: scientific updates and acoustical standards. SLEEP, 47, 1–8.

The study’s lead author Dr. Jeffery Ellenbogen, is a physician that specializes in sleep disorders and was the lead researcher on the often-cited Wind Turbine Health Impact Study: Report of Independent Expert Panel commissioned by the Massachusetts Department of Health (2012). Michael Hankard is a highly regarded acoustician in the United States and completed the Riverbend Wind Project sound modeling study. Together they published a recent article on wind turbine sound, including low frequency noise and infrasound, at the exterior of people’s homes and what level is acceptable to avoid sleep disturbance. They concluded:

*Though the upper limit is not established, noise from wind turbines measured outside the residence, up to 46 dBA (or modeled up to 49 dBA using the new standard), poses no risk to human sleep. Not at this audible range, nor its associated infrasound or low-frequency noise levels. When there is controversy concerning whether wind turbine noise causes sleep disruption, this threshold can serve as a reasonable and evidence-based level, below which sleep disruption would not be expected. This value can be used to resolve specific conflicts by measurement of wind turbine noise at the residence in dispute.*

This US-based study in particular supports the Michigan PA233 adjusted sound modelled requirement of 49 dBA to ensure the protection of sleep of local residents.

### **Conclusion on Wind Turbine Noise and Sleep**

No individual study can answer all of questions about wind turbine noise and sleep. These studies were well executed, used sound scientific methodological approaches, and provided full details of their potential limitations. This suggests that the use of the Michigan PA233 standard, including a - 6 dBA penalty applied to account for potential façade pressure doubling at homes, or modeled 49 dBA, will ensure the protection of local residents' sleep.

### **4.2 Low Frequency Noise and Infrasound**

Infrasound is a term used to describe sounds that are produced at frequencies too low to be heard by the human ear at frequencies of 0 to 20 Hz, at common everyday levels. It is typically measured and reported on the G-weighted scale (dBG). Low frequency noise (LFN), at frequencies between 20 to 200 Hz, can be audible. It is typically measured and reported on the C-weighted scale (dBC) to account for higher-level measurements and peak sound pressure levels.

Universally wind turbine sound standard is set using audible dBA levels and approved based on modeling. The mere presence of measured LFN and infrasound does not indicate a potential threat to health or an inability for people to sleep. The fact that one can measure infrasound and LFN from wind turbines at either the exterior or interior of a home does not mean that it is at a level that poses a potential health threat. In addition, just because there may be a distinct acoustical signature that allows sound engineers to distinguish between low levels of infrasound or LFN from turbines does not mean that it results in health impacts.

Although wind turbines are a source of LFN and infrasound during operation, these sound pressure levels are not unique to wind turbines. Common natural sources of LFN and infrasound include ocean waves, thunder, and even the wind itself. Anthropogenic sources include road traffic, refrigerators, air conditioners, machinery, and airplanes.

Given the growing attention being paid to this issue several recent studies have been published.

Berger et al., 2015. *Health-based Audible Noise Guidelines Account for Infrasound and Low Frequency Noise Produced by Wind Turbines*" in the journal *Frontiers in Public Health* Vol 3, Art. 31

The purpose of this paper was to investigate whether typical audible noise-based guidelines for wind turbines account for the protection of human health given the levels of infrasound and LFN typically produced by wind turbines. New field measurements of indoor infrasound and outdoor LFN at locations between 1,312 ft (400 m) and 2,952 (900 m) from the nearest turbine, which were previously underrepresented in the scientific literature, were reported and put into context with existing published works. The analysis showed that indoor infrasound levels were below auditory

threshold levels while LFN levels at generally accepted setback distances were similar to background LFN levels.

The paper discusses two guidelines for exposure to infrasound (dBG), although neither is specific to wind turbine noise. The Queensland Department of Environment and Resource Management's Draft *ECOACCESS Guideline- Assessment of Low Frequency Noise* proposed an interior infrasound limit of 85 dBG (Roberts, 2004). This value was derived based on a 10 dB protection level from the average 95 dBG hearing threshold (Watanabe, 1990) and previous Danish recommendations for infrasound limits (Jakobsen, 2001). The Japanese Handbook on Low Frequency Noise provides an infrasound reference value of 92 dBG at 10 Hz and 1/3 octave bands up to 80 Hz (Kamigawara, 2006). These values were derived from investigations that monitored complaints of mental and physical discomfort from healthy adults exposed to low frequency sounds in a room (Kamigawara, 2006).

These guidelines for infrasound would not be reached in homes situated near the Glendive Wind Project. Quite simply, the homes are located too far back from the turbines based on audible sound criteria to have the accompanying infrasound levels that exceed these guidelines. In fact, these levels of infrasound are not reached even in close proximity to the wind turbines themselves.

Collectively, these data in conjunction with previous reports indicate that levels of infrasound and LFN are not sufficient to induce adverse health effects; therefore health-based audible noise guidelines are suitable for the protection of human health.

From the abstract of Berger et al., 2015:

*Overall, the available data from this and other studies suggest that health-based audible noise wind turbine siting guidelines provide an effective means to evaluate, monitor, and protect potential receptors from audible noise as well as Infrasound and Low Frequency Noise.*

Simply put, nighttime sound level on the A-weighted scale, and the setback to homes, act as a surrogates to ensure that levels of LFN and infrasound will not impact health or sleep.

In 2012, Turnbull *et al.* published a peer-reviewed paper titled *Measurement and Level of Infrasound from Wind Farms and Other Sources* to put this issue into context with other LFN and infrasound sources (Turnbull et al., 2012). The study was conducted in Australia around wind turbines and other common sources of infrasound and included the Clements Gap Wind Farm and the Cape Bridgewater Wind Farm. The Clements Gap Wind Farm is comprised of 27 Suzlon S88 2.1 MW wind turbines and the Cape Bridgewater Wind Farm is comprised of 29 Repower MM82 2.0 MW wind turbines. They determined that infrasound from wind turbines reached ambient (background) levels within 656 ft (200 m) to 1,180 ft (360 m). The levels were found to be lower than those measured around beaches, gas fired plants and major roadways. Indeed, humans are regularly exposed to infrasound from several natural and engineered sources at levels that exceed those produced by wind turbines. These findings are consistent with other scientific papers in the field.

With respect to low frequency noise (LFN) and infrasound it is important to understand that Health Canada's Wind Turbine Noise study (Health Canada, 2014; Keith et al., 2016; Michaud et al., 2016) also includes consideration of these sound levels and their impact on health.

Keith et al., 2016 (part of the Health Canada Research):

*“The simple relationship between A- and C- weighted levels suggests that there is unlikely to be any statistically significant difference between analysis based on either C- or A-weighted data.”*

Michaud et al., 2016:

*“In the current study, low-frequency noise was estimated by calculating C-weighted sound pressure levels. No additional benefit was observed in assessing low frequency noise because C- and A-weighted levels were so highly correlated. Depending on how dB(C) was calculated and what range of data was assessed, the correlation between dB(C) and dB(A) ranged from  $r = 0.84$  to  $r = 0.97$ .”*

Because LFN (dBC) and A-weighted (dBA) levels were so highly correlated, Health Canada’s conclusions on the absence of direct or indirect health effects for audible wind turbine noise <46 dBA are true also for the noise in the LFN (dBC) range around the wind turbines they studied. In other words, one does not have to conduct additional studies on LFN to determine potential noise health related impacts or sleep disturbance from wind turbines. Therefore, exposure to these frequencies are inherently included in the findings that no sleep disturbance was found in people living with up to 46 dBA audible sound (Michaud et al., 2016).

McCunney et al. (2014), published a study entitled “Wind Turbines and Health: A Critical Review of the Scientific Literature” in the Journal of Environmental and Occupational Medicine. This review came to similar findings of those published by others (e.g., Knopper and Ollson, 2011; MassDEP, 2012; Knopper et al., 2014; Merlin et al., 2014). This review conducted a significant review of infrasound and LFN levels from turbines and potential impact on health.

*“Sounds with frequencies lower than 20 Hz (ie, infrasound) may be audible at very high levels. At even higher levels, subjects may experience symptoms from very low-frequency sounds—ear pressure (at levels as low as 127 dB SPL), ear pain (at levels higher than 145 dB), chest and abdominal movement, a choking sensation, coughing, and nausea (at levels higher than 150 dB).<sup>80,81</sup> The National Aeronautics and Space Administration considered that infrasound exposures lower than 140 dB SPL would be safe for astronauts; American Conference of Governmental Industrial Hygienists recommends a threshold limit value of 145 dB SPL for third-octave band levels between 1 and 80 Hz.<sup>81</sup> As noted earlier, infrasound from wind turbines has been measured at residential distances and noted to be many orders of magnitude below these levels.”*

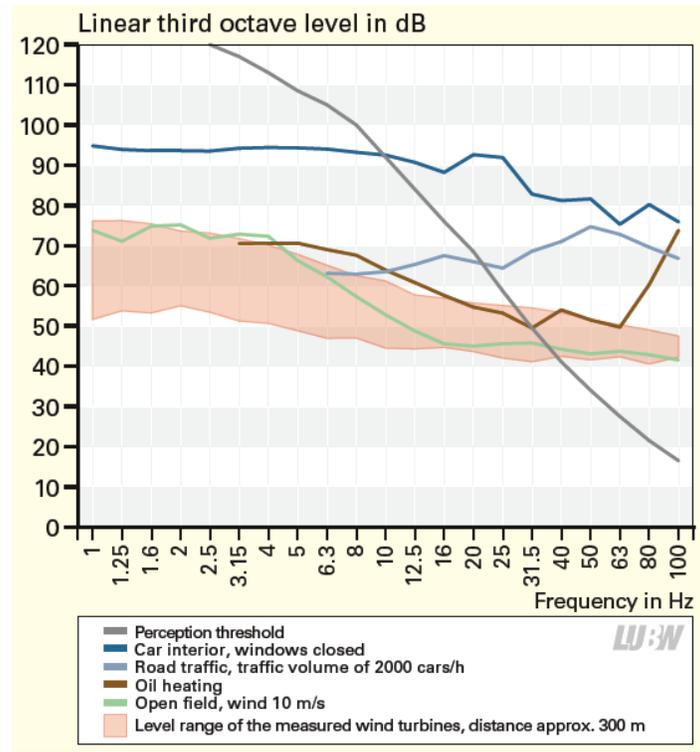
and

*“Components of wind turbine sound, including infrasound and low frequency sound, have not been shown to present unique health risks to people living near wind turbines.”*

In 2016 the Ministry for the Environment, Climate and Energy of the Federal State of Baden-Wuerttemberg in Germany reported on their study “Low-frequency noise including infrasound from wind turbines and other sources” (MECE, 2016). The objective of the research was to collect field measurement of infrasound and low-frequency noise around six different turbines by different manufacturers ranging in size from 1.8 to 3.2 MW. Measurements were taken at 492 ft (150 m), 984 ft (300 m) and 2,296 ft (700 m) from wind turbines.

Measurements of other common sources of infrasound and low frequency noise were also collected for comparative purposes.

Figure 2 provides detail on the range of infrasound and low frequency noise measured at 984 ft (300 m) from a wind turbine. It can be seen that the levels of infrasound from wind turbines were similar to that of just the wind in an open field. The levels were considerably lower than either being in the interior of a car, near the roadside traffic or in a home with oil heating. All infrasound levels (< 20 Hz) were below the perception threshold and international standards.



**Figure 2. Measurements of infrasound and low frequency noise 300 m from wind turbines compared to other sources.**

Overall, they concluded:

*“Infrasound and low-frequency noise are an everyday part of our technical and natural environment. Compared with other technical and natural sources, the level of infrasound caused by wind turbines is low. Already at a distance of 150 m, it is well below the human limits of perception. Accordingly, it is even lower at the usual distances from residential areas. Effects on health caused by infrasound below the perception thresholds have not been scientifically proven. Together with the health authorities, we in Baden-Württemberg have come to the conclusion that adverse effects relating to infrasound from wind turbines cannot be expected on the basis of the evidence at hand.*

*The measurement results of wind turbines also show no acoustic abnormalities for the frequency range of audible sound. Wind turbines can thus be assessed like other installations according to the specifications of the TA Lärm (noise prevention regulations).*

*It can be concluded that, given the respective compliance with legal and professional technical requirements for planning and approval, harmful effects of noise from wind turbines cannot be deduced.”*

Marshall et al. 2023. The Health Effects of 72 Hours of Simulated Wind Turbine Infrason: A Double- Blind Randomized Crossover Study in Noise-Sensitive, Healthy Adults. Environmental Health Perspectives. 131(3) March 2023

As part of the large Australian National Health and Medical Research Council of Australia (NHMRC) Targeted Call for Research into Wind Farms and Human Health, a group of researchers undertook a study to better understand the potential impacts of wind turbine infrasound on human physiology and sleep. Starting at noon, participants were subjected to either wind turbine infrasound, sham infrasound (same speakers not generating infrasound) and traffic noise for a 72-hour period, including 3 nights. The subjects did not leave the test setting that consisted of a bedroom with ensuite mimicking a studio apartment. Each of the 37 noise-sensitive but otherwise healthy adults (age 18 – 72; 51% female) were exposed to all three noise conditions for the 72-hour period, resulting in a double-blind triple arm study design.

Physiological and psychological measures and systems were tested for their sensitivity to infrasound: wake after sleep onset (WASO; primary outcome) and other measures of sleep physiology, wake electroencephalography, Wind Turbine Syndrome (WTS) symptoms, cardiovascular physiology, and neurobehavioral performance.

The researchers found:

*Our findings did not support the idea that infrasound cause WTS. High level, but inaudible, infrasound did not appear to perturb any physiological or psychological measure tested in these study participants.*

This is yet another study that strengthens the findings that infrasound emitted from wind turbines is not at a level that causes health impacts, symptoms, sleep effects or impairment of neurobehavioral performance.

### **Conclusion on Low Frequency Noise and Infrasound**

The hypothesis that low frequency noise or infrasound from wind turbines is a causative agent in health effects or sleep disturbance is not supported by the scientific and medical literature. Although infrasound and low frequency noise are emitted from wind turbines, the levels are typically within background levels at homes and are well below levels that could induce health impacts. Measurements at wind farms are similar, if not lower, than natural and anthropogenic sources of infrasound that we are exposed to, and are below international guidelines on infrasound. The Michigan PA233 audible sound requirements and setback distances to nonparticipating residences will ensure protection against any infrasound or low frequency noise impacts.

### **4.3 Other Potential Health Concerns**

Although with any sound source sleep is the critical health endpoint, there are a number of other concerns that have been raised with living in proximity to wind turbines.

#### **4.3.1 Peer Reviewed Studies on Self-Reported and Objective Measures of Health**

This section is focused on the literature investigating both self-reported and physical measures of health for those living around wind turbines. Given the extensive nature of the literature, it is not possible to summarize it all in this document. Rather, preference has been given to key references and those most recent, or extensive.

There are numerous peer-reviewed studies that have explicitly examined the relationship between levels of wind turbine noise and various self-reported indicators of human health and well-being (e.g., Health Canada 2014 and associated publications; Bakker et al. 2012; Janssen et al. 2011; Pedersen 2011; Pedersen and Persson Waye 2004; 2007). These studies have included a wide range of wind turbine models, manufacturers, heights and noise levels. They were conducted over several years, in some cases over 10 years, after wind turbines became operational. The study of wind turbine health concerns began in Europe in the early 2000s and most recently examined in Canada.

In general, peer reviewed studies do not support a correlation between wind turbine noise exposure and any other response other than annoyance. For example, various studies based on the results of two surveys performed in Sweden and one in the Netherlands (1755 respondents overall) found that no measured variable (e.g., self-reported evaluations of high blood pressure, cardiovascular disease, tinnitus, headache, sleep interruption, diabetes, tiredness, and reports of feeling tense, stressed, or irritable) other than annoyance was directly related to wind turbine noise for all three datasets (Pedersen, 2011) at noise levels below 45 dBA.

The most comprehensive study on health and living in proximity was that undertaken by Health Canada between May and September 2013. Again, this study had a 78.9% response rate of those living within 10 km of numerous wind projects in Ontario and PEI. In 2016, Health Canada released a series of peer-reviewed publications on their findings in a special edition of the Journal of Acoustical Society of America in late March of 2016. Given that it was the most comprehensive study undertaken—the most recent and comprehensive a cross-sectional epidemiological study undertaken on the topic—a great deal of weight on this research and its findings is placed on it. Their reported high response rate included 1238 randomly selected participants (606 males, 632 females) between the ages of 18-79 years old. In addition, the study included both self-reported and physical/objective measures of health in participants.

The following sections contain conclusions of the three papers examining the potential for health issues to manifest living as close as 820 feet from a turbine and sound levels of up to 46 dBA.

*Michaud et al. 2016a. Exposure to wind turbine noise: Perceptual responses and reported health effects.*

This paper provides the results of Health Canada's investigation into perceptual responses (annoyance and quality of life) and those of self-reported health effects by participants. Only the self-reported health results are discussed here. Health Canada developed a final questionnaire (Michaud, 2013) that consisted of socio-demographics, modules on community noise and annoyance, self-reported health effects, lifestyle behaviors, and prevalent chronic illness.

Table 6 is a reproduction of Table V in the study, which provides the list of self-reported health effects in the population studied broken down by varying wind turbine noise levels (dBA). Essentially this table reports the prevalence of each self-reported health effect, across varying sound levels, and then uses statistical analysis to provide a CHM *p-value* to determine if the self-reported health effects are significant. Simply put, if the CHM *p-value* is less than  $< 0.05$  then there is a difference amongst the reported effects across sound levels and vice versa (i.e., if it is greater than  $> 0.05$ , then there is no difference in how people are reporting effects across the sound groupings).

Health Canada reported that:

“The results from the current study did not show any statistically significant increase in the self-reported prevalence of chronic pain, asthma, arthritis, high blood pressure, bronchitis, emphysema, chronic obstructive pulmonary disease (COPD), diabetes, heart disease, migraines/headaches, dizziness, or tinnitus in relation to WTN exposure up to 46 dB. In other words, individuals with these conditions were equally distributed among WTN exposure categories.”

This resulted in the overall conclusion of the paper that:

“Beyond annoyance, results do not support an association between exposure to WTN up to 46 dBA and the evaluated health-related endpoints.”

The Health Canada results are consistent with the previous decade of research in the field.

**Table 6. Sample profile of health conditions (Michaud et al., 2016a).**

TABLE V. Sample profile of health conditions.

Variable n (%)	Wind turbine noise (dB)					Overall	CMH <sup>a</sup> p-value
	<25	[25–30]	[30–35]	[35–40]	[40–46]		
n	84 <sup>b</sup>	95 <sup>b</sup>	304 <sup>b</sup>	521 <sup>b</sup>	234 <sup>b</sup>	1238 <sup>b</sup>	
Health worse vs last year <sup>c</sup>	17 (20.2)	12 (12.6)	46 (15.1)	90 (17.3)	51 (21.8)	216 (17.5)	0.1724
Migraines	18 (21.4)	24 (25.3)	56 (18.4)	134 (25.8)	57 (24.4)	289 (23.4)	0.2308
Dizziness	19 (22.6)	16 (16.8)	65 (21.4)	114 (21.9)	59 (25.2)	273 (22.1)	0.2575
Tinnitus	21 (25.0)	18 (18.9)	71 (23.4)	129 (24.8)	54 (23.2)	293 (23.7)	0.7352
Chronic pain	20 (23.8)	23 (24.2)	75 (24.8)	118 (22.6)	57 (24.5)	293 (23.7)	0.8999
Asthma	8 (9.5)	12 (12.6)	22 (7.2)	43 (8.3)	16 (6.8)	101 (8.2)	0.2436
Arthritis	23 (27.4)	38 (40.0)	98 (32.2)	175 (33.7)	68 (29.1)	402 (32.5)	0.6397
High blood pressure (BP)	24 (28.6)	36 (37.9)	81 (26.8)	166 (32.0)	65 (27.8)	372 (30.2)	0.7385
Medication for high BP	26 (31.3)	34 (35.8)	84 (27.6)	163 (31.3)	63 (27.0)	370 (29.9)	0.4250
Family history of high BP	44 (52.4)	49 (53.8)	132 (45.5)	254 (50.6)	121 (53.8)	600 (50.3)	0.6015
Chronic bronchitis/emphysema/COPD	3 (3.6)	10 (10.8)	17 (5.6)	27 (5.2)	14 (6.0)	71 (5.7)	0.7676
Diabetes	7 (8.3)	8 (8.4)	33 (10.9)	46 (8.8)	19 (8.2)	113 (9.1)	0.6890
Heart disease	8 (9.5)	7 (7.4)	31 (10.2)	32 (6.1)	17 (7.3)	95 (7.7)	0.2110
Highly sleep disturbed <sup>d</sup>	13 (15.7)	11 (11.6)	41 (13.5)	75 (14.5)	24 (10.3)	164 (13.3)	0.4300
Diagnosed sleep disorder	13 (15.5)	10 (10.5)	27 (8.9)	44 (8.4)	25 (10.7)	119 (9.6)	0.3102
Sleep medication	16 (19.0)	18 (18.9)	39 (12.8)	46 (8.8)	29 (12.4)	148 (12.0)	0.0083
Restless leg syndrome	7 (8.3)	16 (16.8)	37 (12.2)	81 (15.5)	33 (14.1)	174 (14.1)	
Restless leg syndrome (ON)	4 (6.7)	15 (17.4)	27 (11.0)	78 (17.3)	28 (16.5)	152 (15.0)	0.0629 <sup>e</sup>
Restless leg syndrome (PEI)	3 (12.5)	1 (11.1)	10 (16.9)	3 (4.2)	5 (7.8)	22 (9.7)	0.1628 <sup>e</sup>
Medication anxiety or depression	11 (13.1)	14 (14.7)	35 (11.5)	59 (11.3)	23 (9.8)	142 (11.5)	0.2470
QoL past month <sup>f</sup>							
Poor	9 (10.8)	3 (3.2)	21 (6.9)	29 (5.6)	20 (8.6)	82 (6.6)	0.9814
Good	74 (89.2)	92 (96.8)	283 (93.1)	492 (94.4)	213 (91.4)	1154 (93.4)	
Satisfaction with health <sup>f</sup>							
Dissatisfied	13 (15.5)	13 (13.7)	49 (16.1)	66 (12.7)	36 (15.4)	177 (14.3)	0.7262
Satisfied	71 (84.5)	82 (86.3)	255 (83.9)	455 (87.3)	198 (84.6)	1061 (85.7)	

<sup>a</sup>The Cochran Mantel-Haenszel chi-square test is used to adjust for provinces unless otherwise indicated, p-values <0.05 are considered to be statistically significant.

<sup>b</sup>Columns may not add to total due to missing data.

<sup>c</sup>Worse consists of the two ratings: “Somewhat worse now” and “Much worse now.”

<sup>d</sup>High sleep disturbance consists of the two ratings: “very” and “extremely” sleep disturbed.

<sup>e</sup>Chi-square test of independence.

<sup>f</sup>Quality of Life (QoL) and Satisfaction with Health were assessed with the two stand-alone questions on the WHOQOL-BREF. Reporting “poor” overall QoL reflects a response of “poor” or “very poor,” and “good” reflects a response of “neither poor nor good,” “good,” or “very good.” Reporting “dissatisfied” overall Satisfaction with Health reflects a response of “very dissatisfied” or “dissatisfied,” and “satisfied” reflects a response of “neither satisfied nor dissatisfied,” “satisfied,” or “very satisfied.” A detailed presentation of the results related to QoL is presented by Feder et al. (2015).

#### 4.4 Recent Systematic Review on Wind Turbines and Health

Van Kamp, I & van den Berg, F. 2018. Health Effects Related to Wind Turbine Sound, Including Low-Frequency Sound and Infrasound Acoust Aust (2018) 46:31–57

Both authors work for public health agencies in the Netherlands and are highly regarded experts in the health research field. They conducted a systematic review of the published literature between 2009 to 2017 on health effects related to wind turbine sound, with particular emphasis on LFN and infrasound.

They concluded that there was no evidence of a specific health effect of the LFN or infrasound components of wind turbine sound. With respect to Dr. Alves-Pereira’s work in relation to infrasound from turbines, they found:

*Vibroacoustic disease and the wind turbine syndrome are controversial and scientifically not supported. At the present levels of wind turbine sound, the alleged occurrence of vibroacoustic disease (VAD) or the disease (VVVD) causing the wind turbine syndrome (WTS) is unproven and unlikely.*

Freiberg et al. 2019 Health effects of wind turbines on humans in residential settings: Results of a scoping review. *Environmental Research* 169 (2019) 446–463

The authors conducted a comprehensive systematic review of the potential health effects in humans living in proximity to wind turbines. The researchers retrieved 84 articles that varied significantly in methods and health outcomes assessed that met their study inclusion criteria. Overall, they found:

*Multiple cross-sectional studies reported that wind turbine noise is associated with noise annoyance, which is moderated by several variables such as noise sensitivity, attitude towards wind turbines, or economic benefit.*

*Wind turbine noise is not associated with stress effects and biophysiological variables of sleep.*

*Findings from cross-sectional studies of higher methodological quality – that were supported by findings from lower-quality observational studies – illustrated an existing association between wind turbine noise and annoyance and no association between noise from wind turbines and stress effects and biophysiological variables of sleep.*

*In higher quality studies, wind turbine noise was not associated with restricted quality of life, sleep disturbance, and anxiety and/or depression, which contrasts – at least partly – with findings from lower-quality studies."*

Van Kamp, I & van den Berg, F. 2021. Health Effects Related to Wind Turbine Sound: An Update. *Int. J. Environ. Res. Public Health* 2021, 18, 9133

The authors conducted an updated systematic review of the published literature between 2017 to 2020 on health effects related to wind turbine sound. Their conclusions were consistent with their previous literature review (van Kamp & van den Berg, 2018). They reaffirmed:

*There is no indication that the low-frequency component has other effects on residents other than normal sound nor that infrasound well below the hearing threshold can have any effect.*

Ellenbogen, J. 2022 Wind turbine noise and sleep. *Editorial. SLEEP*. 2022 1-3

Dr. Ellenbogen, MD is a highly regarded neurologist and sleep specialist whose focus is on noise-induced sleep disruption. He has been researching the potential for wind turbine noise to impact sleep since he was the lead author on the *Wind Turbine Health Impact Study: Report of Independent Expert Panel* report, prepared for the Massachusetts Department of Health (Ellenbogen et al., 2012). In this editorial he opines that:

*Between Health Canada and this paper by Liebich et al., it appears that the reasonable placement of wind turbines does not pose a risk to human sleep. ...If companies wish to remain in the reasonable window of protection against noise-induced sleep loss, they would do well to limit themselves to using the data demonstrated by Health Canada—allowing noises to not exceed 46 dBA measured outside the residence [8]. The actual, population-based threshold may be higher, but existing data support this number.*

The weight of scientific evidence continues to demonstrate that the common siting guidelines of a 50 dBA sound level and a 1,500 ft setback will ensure the protection of the community's health.

**Conclusions on Other Potential Health Impacts**

The weight of scientific evidence supports that permitting sound levels at the exterior of non-participating dwellings of up to 50 dBA Leq would not impact sleep or other objective or self-reported measures of health. Therefore, Michigan PA233 sound level requirements will ensure the projection of public health for local residents.

**4.5 Michigan Sound Guidelines**

Table 7 provides other jurisdictions with audible noise requirements at the exterior of non-participating dwellings that are similar to those in Michigan PA233. The Michigan sound requirement of no more than 49 dBA modelled at the exterior of a dwelling (including the -6dBA penalty) is consistent with sound requirements in neighboring jurisdictions.

Adherence to the Michigan PA233 sound requirement will ensure the protection of sleep and public health for nearby residents.

**Table 7. State-level sound requirements**

<b>State Examples</b>	
<b>Wisconsin (State)</b>	Section PSC 128.14 Noise Criteria (3)(a) Noise Limits. Except as provided in par. (b), subs. (4) (c) and (5), an owner shall operate the wind energy system so that the noise attributable to the wind energy system does not exceed 50 dBA during daytime hours and 45 dBA during nighttime hours
<b>Illinois (State)</b>	A county may not set a sound limitation for wind towers in commercial wind energy facilities or any components in commercial solar energy facilities that is more restrictive than the sound limitations established by the Illinois Pollution Control Board under 25 Ill. Adm. Code Parts 900, 901, and 901. This effective results in a ~47/48 dBA sound level at the exterior of non-participating homes.
<b>Michigan (State)</b>	The wind energy facility does not generate a maximum sound in excess of 55 average hourly decibels as modeled at the nearest outer wall of the nearest dwelling located on an adjacent nonparticipating property. Decibel modeling shall use the A-weighted scale as designed by the American National Standards Institute.
<b>Nebraska (County)</b>	Typically 50 dBA to non-participating residences
<b>Kansas (County)</b>	Typically to 50 dBA to non-participating residences

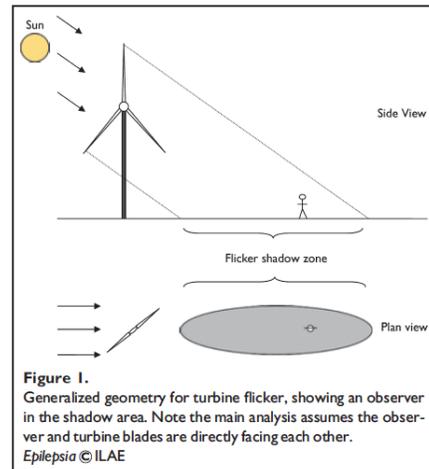
## 5 Shadow Flicker

Shadow flicker occurs when interruption of sunlight by the wind turbine blades results in a change in light intensity within a home or building. The flickering phenomenon does not occur unless one is inside a building or structure with windows. When one experiences shadowing from a turbine when standing outdoors it is simply a rotating shadow cast on the ground. Shadow flicker typically only occurs for a limited number of hours a year at a home. This is due to the fact that certain factors must be present:

- the sun must be in a precise location in the sky such that sunlight will cast a shadow from the wind turbine;
- the wind turbine must be in operation during this period (i.e., the wind must be of sufficient speed for the wind turbine to be operational);
- shadow will not be cast on overcast or cloudy days; and,
- the shadow will typically not be cast any further than 10x the total height of the turbine to any appreciable extent. For most modern turbines this would mean shadow flicker would not extend much past 2 km.

Conducting shadow flicker modeling has become common practice for proposed wind farm projects across United States. There are several commercially available software packages, including WindPro that are used to model the shadow flicker.

All models initially calculate a “Worst Case or Maximum Astronomical shadow” number of hours that a residence may experience shadow flicker. These numbers can then be adjusted to provide a “Adjusted, Realistic, Actual or Expected” number of hours of shadow flicker. It is important to distinguish between these scenarios, as some jurisdictions have adopted standards based on either astronomical or realistic shadow flicker hour predictions.



**Worst Case / Astronomical:** The models consider that the sun is always shining during daytime hours and there is no cloud cover, the wind turbines are always rotating, and the wind direction from each turbine is such that the wind turbine is always perpendicular to the residences so that shadows could be cast at the residences. This is a predicted extreme theoretical number hours that will not occur at any residence.

**Adjusted / Actual / Realistic / Expected:** The model is run in the astronomical mode and then the results are adjusted for percentage of monthly cloud cover (solar statistics) and operating hours of the wind project. Under these conditions shadow flicker will not be generated and it more accurately predicts the number of hours of shadow flicker at a residence.

There are other obstructions that can limit both the Worst Case and the Realistic modeled numbers of shadow flicker. These include trees, shrubs, and other ancillary non-occupied structures (e.g., barns) that could interrupt the predicted shadow flicker at a home. Neither of the two Assessment Case scenarios takes into account these types of obstructions at residential receptors. Another

layer of conservatism is that models are set-up and run in the “greenhouse mode”. This means each residence is oriented to have omni-directional windows and thus it will produce more conservative results since it assumes that there is always a window in direct line of site of each wind turbine and the sun.

The model outputs can show the exact days, the time of day, the duration and turbine of origin of shadow flicker. These values are then summed to provide the annual number of hours of shadow flicker predicted. For the Realistic scenario the percentage of cloud cover and operational downtime is used to adjust these values.

## 5.1 Shadow Flicker Health, Annoyance and Nuisance

Four peer-reviewed scientific research papers were retrieved that considered the potential for shadow potential to impact health and to increase annoyance or nuisance in people living near wind turbines.

The main health concern raised relating to shadow flicker is the potential risk of seizures in those people with photosensitive epilepsy. Photosensitive epilepsy affects approximately 5% of people with epilepsy where their seizures can be triggered by flashing light. The Epilepsy Society first investigated this issue in the United Kingdom in the late 2000s. They polled their members and determined that no one had experienced an epileptic seizure living or being in proximity to a wind farm from shadow flicker (Epilepsy Society, 2012).

Following on this informal polling two of the United Kingdom’s academic experts in epilepsy published scientific research articles in the area. I previously provided to the Commission that Harding et al. (2008) and Smedley et al. (2010) have published the seminal studies dealing with this concern. Both authors investigated the relationship between photo-induced seizures (i.e., photosensitive epilepsy) and wind turbine shadow flicker. Both studies suggested that flicker from turbines that interrupt or reflect sunlight at frequencies greater than 3 Hz pose a potential risk of inducing photosensitive seizures in 1.7 people per 100,000 of the photosensitive population. For turbines with three blades, this translates to a maximum speed of rotation of 60 revolutions per minute (rpm). The Nordex 169 5.5 MW turbine in the Updated Project has a nominal rotational speed of 11 rpm, well below a speed that could trigger epileptic seizure.

Two of the most comprehensive and widely cited published scientific review articles on this topic are Knopper & Ollson (2011) and McCunney et al. (2014). Both papers concluded that shadow flicker is not associated with health effects for those living in proximity to wind turbines. Knopper & Ollson (2011) concluded:

*“Although shadow flicker from wind turbines is unlikely [to] lead to a risk of photo-induced epilepsy there has been little if any study conducted on how it could heighten the annoyance factor of those living in proximity to turbines. It may however be included in the notion of visual cues. In Ontario it has been common practice to attempt to ensure no more than 30 hours of shadow flicker per annum at any one residence.”*

Since 2014, there have been two studies conducted that examined the potential for shadow flicker to lead to increased annoyance for those living near wind turbines.

Voicescu et al., 2016. Estimating annoyance to calculated wind turbine shadow flicker is improved when variables associated with wind turbine noise exposure are considered. J. Acoust. Soc. Am. 139 (3).

In 2016, Health Canada published a paper using the questionnaires of over 1200 people living as close as 800 feet from a turbine they attempted to determine if they could predict the percentage of people that were highly annoyed by varying levels of hours of shadow flicker (SF) a year or number of minutes on a given day. However, although annoyance did tend to increase with increasing minutes a day, they could not find a statistical relationship:

*“For reasons mentioned above, when used alone, modeled  $SF_m$  results represent an inadequate model for estimating the prevalence of  $HA_{WTSF}$  as its predictive strength is only about 10%. This research domain is still in its infancy and there are enough sources of uncertainty in the model and the current annoyance question to expect that refinements in future research would yield improved estimates of SF annoyance.”*

Haac et al. 2022. In the shadow of wind energy: Predicting community exposure and annoyance to wind turbine shadow flicker in the United States. Energy Research & Social Science 102471. Pg. 1-16.

This work was completed by the Lawrence Berkley National Laboratory (LBNL) in the United States as part of a large US Department of Energy (DOE) Wind Neighbors National Survey. The purpose of the study was to determine if the duration of shadow flicker could be correlated to shadow flicker (SF) annoyance in the population. Overall, the authors reported:

*This study modeled SF exposure at nearly 35,000 residences across 61 wind projects in the United States, 747 of which were also survey respondents. Using these results, we analyzed the factors that led to perceived SF and self-reported SF annoyance. We found that perceived SF is primarily an objective response to SF exposure, distance to the closest turbine, and whether the respondent moved in after the wind project was built. Conversely, SF annoyance was not significantly correlated with SF exposure. Rather, SF annoyance is primarily a subjective response to wind turbine aesthetics, annoyance to other anthropogenic sounds, level of education, and age of the respondent.*

Similar to the Health Canada findings (Voicescu, 2016), the US-based LBNL study could not correlate the number of theoretical (astronomical) or actual (adjusted case) hours a year or minutes at a time in duration of shadow flicker with annoyance in the population. In other words, limiting the number of hours of shadow flicker on an annual basis at a non-participating home is unlikely to decrease the annoyance the residents feel towards any shadow flicker at all or the turbines themselves.

Therefore, there is nothing in the scientific literature that suggests that shadow flicker should be limited, either for hours per year or total minutes at a time, to protect health or avoid annoyance.

## **5.2 Shadow Flicker Standards**

A number of North American jurisdictions, including Michigan, have adopted various ordinances and rules limiting shadow flicker on non-participating land. A threshold of no more than 30 hours of actual shadow flicker modeled on a residence (Adjusted / Assessment Case B) has almost become the universally adopted standard.

The origins of the North American 30 hours a year standard are traced to Germany in 2002. The German Territorial Committee for Emissions control released the document “Hinweise zur Ermittlung und Beurteilung der optischen Immissionen von Windenergieanlagen, Länderausschuss für Immissionsschutz [Notes on the identification and evaluation of optical emissions from wind turbines], (in German).” The standard was based on limiting the shadow flicker nuisance of local residents. They subsequently codified this formal shadow flicker guideline into a standard as part of the *Federal Emission Control Act* (Haugen, 2011). Similar standards to this have been adopted internationally with modifications for shadow flicker. The German standard is: no more than 30 hours of modeled shadow flicker (theoretical / worst case) a year, no more than 30 minutes of shadow flicker at a time, and no more than 8 hours of actual (adjusted) shadow flicker a year on a home.

The Michigan PA233 shadow flicker standard of:

*(ii) Each wind tower is sited such that any occupied community building or nonparticipating residence will not experience more than 30 hours per year of shadow flicker under planned operating conditions as indicated by industry standard computer modeling.*

The Michigan limit is the same as those other states with State-level siting requirements; such as, for example North Dakota, Wisconsin, Indiana, Illinois, Connecticut, and New York. Adherence to the Michigan PA233 shadow flicker requirement at non-participating residences will ensure the protection of public health and will reduce annoyance to the project for nearby residents.

## 6 Riverbend Wind Project and Compliance With Michigan PA233 Requirements

The Riverbend Wind Project plans to install up to 50 wind turbines across Speaker and Fremont Townships in Sanilac County, Michigan. The Project will have a nameplate capacity of approximately 300 MW. The final turbine make and model has yet to be determined so for the purpose of the permit application the Project considered five different turbine models, the Vestas V162-6.0 MW turbine with a hub height of 119 meters (tip height 200m), the Nordex 169/5.X turbine with a hub height of 112 meters (tip height 196.5 m), the Vestas V162-6.8 MW turbine with a hub height of 119 meters (tip height 200m), the Vestas V162-7.2 MW turbine with a hub height of 119 meters (tip height 200m), and the Vestas V163-4.5 MW turbine with a hub height of 118 meters (tip height 200m). Therefore, the tallest turbine being considered is 200 m or 656 ft in total tip height. All turbines will be equipped with Serrated Trailing Edge (STE) for both the Vestas and Nordex turbines.

Associated facilities include gravel access roads, underground cabling, and a substation. The substation includes two 150 megavolt ampere (MVA) step-up transformers.

### 6.1 Setback Compliance

Table 8 demonstrates that all Riverbend Wind turbines meet the minimum setback distances required by Michigan PA233. Therefore, the Riverbend Wind Project will not have an adverse impact on local residents' public safety. 1,050

**Table 8. Setback requirements of wind turbines to various features**

<b>Setback Description</b>	<b>Michigan PA233 Setback Distance (ft for a 656 ft turbine)</b>	<b>Riverbend Wind Minimum Setbacks (ft)</b>
Occupied community buildings and residences on nonparticipating properties	2.1x tip height (1,378 ft)	1,434 ft
Residences and other structures on participating properties	1.1x tip height	1,011 ft
Nonparticipating property lines	1.1x tip height (722 ft)	748 ft
Public road right-of-way	1.1x tip height (722 ft)	762 ft
Overhead communication and electric transmission, not including utility service lines to individual houses or outbuildings	1.1x tip height (722 ft)	822 ft to distribution line 1,050 to electric transmission line

### 6.2 Sound Compliance

Hankard Environmental prepared the *Pre-Construction Wind Turbine Noise Analysis (May 22, 2025)* for the Project (Appendix B of the Application). The report was prepared in accordance to the MPSC Final Rules U-21547 (the Order) that provide for Michigan-specific sound modeling guidelines. The report modeled the sound power levels for each of the five models of wind turbines under consideration, which range from 103.3 to 106.5 dBA. There were 1,469 dwellings (including 131 participants and 1,338 non-participants) located within approximately 1.25 miles of any Project noise source.

The sound levels at all dwellings were predicted to range between 29 dBA to 49 dBA Leq at the dwellings. When these model results were adjusted by a +6 dBA in accordance with the Order then they ranged between 35 dBA to 55 dBA Leq. Sound levels at all dwellings were in compliance with Michigan PA233 requirements. Therefore, the Project sound levels do not pose an adverse risk to public health.

### 6.3 Shadow Flicker Compliance

Stantec prepared the *Riverbend Wind Energy Facility Shadow Flicker Study Sanilac County, Michigan* (Appendix D of the Application). The expected annual hours of shadow flicker on each receptor were estimated for the Project area using the Shadow module of WindPRO Version 4.0 software. WindPRO is an agency and industry-accepted modeling program that calculates the number of hours and days per year that any given receptor may receive shadow flicker from the source five different models of source turbines.

The model included 1,194 non-participating and 130 participating residences within approximately 1.25 miles of potential Project turbine sites. The analysis was completed without considering the blocking effects of vegetation between the turbines. Overall, depending on the turbine model assessed there were approximately 60 to 70 nonparticipating residences that had modeled expected shadow flicker over 30 hours a year.

However, Riverbend wind has committed to either obtain a waiver from these residences or to implement mitigation measures at these residences. Mitigation measures that may be employed, with approval include, but are not limited to, the planting of trees and/or vegetative plantings, awning or curtain installation, and/or turbine curtailment.

Therefore, the Riverbend Wind Project will comply with the Michigan PA233 requirements for <30 hours a year of shadow flicker at non-participating residences and will not impact public health, nor cause undue annoyance to local non-participating landowners.

## 7 Conclusion on Michigan Wind Turbine Siting Standards and the Riverbend Wind Project

There are over two decades of research and more than 150 research papers that have been published in peer-reviewed scientific journals on the potential public health and safety impacts of living near wind turbines. In recent years a number of States have set State-wide siting standards that companies must adhere to when designing a wind project.

The State of Michigan Public Act 233, effective November 29, 2024 (Michigan PA233) provides overarching state-wide standards for wind turbine setback distances to various features, sound levels and shadow flicker requirements to ensure the protection of public health and safety (MCL 460.1226 Subsection (8)(b)). It was demonstrated in this report that the setback, sound and shadow flicker standards in Michigan PA233 are:

- i) consistent with other State siting requirements
- ii) designed to ensure the protection of public health and safety.

Furthermore, it was demonstrated that the Riverbend Wind Project adheres to all of the Michigan wind turbine siting requirements. Therefore, as designed the Riverbend Wind Project will not have an adverse impact on local residents' public health and safety.

**OLLSON ENVIRONMENTAL HEALTH MANAGEMENT**  
Christopher Ollson, PhD

## 8 References

Bakker RH, Pedersen E, van den Berg GP, Stewart RE, Lok W, Bouma J. Impact of wind turbine sound on annoyance, self-reported sleep disturbance and psychological distress. *Sci Total Environ* (2012) **425**:42–51.

Berger R.G., Ashtiani P., **Ollson C.A.**, Whitfield Aslund M., McCallum L.C., Leventhall G., Knopper L.D. 2015. *Health-based audible noise guidelines account for infrasound and low frequency noise produced by Wind Turbines*. Front Public Health. Vol 3, Art. 31

Bredesen, R.E., Drapalik, M., and Butt, B. 2017 Understanding and acknowledging the ice throw hazard - consequences for regulatory frameworks, risk perception and risk communication J. Phys.: Conf. Ser. 926 012001

Ellenbogen, JM, Kellam, CB, and Hankard, M. 2024. Noise-induced sleep disruption from wind turbines: scientific updates and acoustical standards. *SLEEP*, 47, 1–8.

Ellenbogen, J. 2022 Wind turbine noise and sleep. Editorial. *SLEEP*. 2022 1-3

Flemish Government. Department of Environment. 2019. Wind Turbine Manual: Guidelines for the risk calculations of wind turbines, Brussels, Belgium.

Freiberg et al. 2019 Health effects of wind turbines on humans in residential settings: Results of a scoping review. *Environmental Research* 169 (2019) 446–463

Garrad Hassan Canada. 2007. Recommendations for Risk Assessment of Ice Throw and Blade Failure in Ontario. Prepared for Candian Wind Energy Association.

Haac, R.T., Kaliski, K., Landis, M., Hoen, B., Rand, J., Firestone, J., Elliott, D., Hübner, G., Pohl, J. 2019 Wind turbine audibility and noise annoyance in a national U.S. survey: Individual perception and influencing factors. *Journal of the Acoustical Society of America* 146.

Harding G, Harding P, Wilkins A. Wind turbines, flicker, and photosensitive epilepsy: Characterizing the flashing that may precipitate seizures and optimizing guidelines to prevent them. *Epilepsia* (2008) **49**:1095-8.

Health Canada. Wind Turbine Noise and Health. The Government of Canada. 2014. Available online: <http://www.hc-sc.gc.ca/ewh-semt/noise-bruit/turbine-eoliennes/summary-resume-eng.php>

Hübner G, Pohl J, Hoen B, Firestone J, Rand J, Elliott D, Haac R. 2019. Monitoring annoyance and stress effects of wind turbines on nearby residents: A comparison of U.S. and European Samples *Environ Int*. 2019 Nov;132:105090. doi: 10.1016/j.envint.2019.105090. Epub 2019 Aug 19.

Illinois 55 ILCS 5/5-12020

Institute of Medicine of the National Academies. 2006. Sleep Disorders and Sleep Deprivation: An Unmet Public Health Problem

Jalali et al. 2016. Before–after field study of effects of wind turbine noise on polysomnographic sleep parameters. *Noise Health*; 18:194-205.

Jakobsen J. Danish guidelines on environmental low frequency noise, infrasound and vibration. *J Low Freq Noise V A* (2001) **20**:141-8.

Kamigawara K, Yue J, Saito T, Hirano T. Publication of "Handbook to deal with low frequency noise (2004)". *J Low Freq Noise V A* (2006) **25**:153-6.

Keith SE, Feder K, Voicescu SA, Soukhovtsev V, Denning A, Tsang J, Broner N, Richarz W, van den Berg F. 2016. Wind turbine sound power measurements. *J. Acoust. Soc. Am.* 139 (3), 1431-1435

Knopper, L.D., **Olsson, C.A.**, McCallum, L.C., Aslund, M.L., Berger, R.G, Souweine, K., and McDaniel, M. 2014. *Wind turbines and Human Health*. *Front. Public Health*, Vol. 2, Art. 63

Liebich et al. 2022. The effect of wind turbine noise on polysomnographically measured and self-report sleep latency in wind turbine noise naïve participants. *SLEEPJ*. Vol 45. No. 1. pg 1-11.

Liebich et al. 2020. A systematic review and meta-analysis of wind turbine noise effects on sleep using validated objective and subjective sleep assessments. *Journal of Sleep Research*.

McCunney, R.J., Mundt, K.A., Colby, D., Dobie, R., Kaliski, K., Blais, M. 2014. Wind Turbines and Health A Critical Review of the Scientific Literature. *JOEM* Volume 56, Number 11

Marshall et al. 2023. The Health Effects of 72 Hours of Simulated Wind Turbine Infrasound: A Double- Blind Randomized Crossover Study in Noise-Sensitive, Healthy Adults. *Environmental Health Perspectives*. 131(3) March 2023

Michaud et al., 2021. Sleep actigraphy time-synchronized with wind turbine output. *SLEEPJ*, 2021, 1–12. (Health Canada)

Michaud DS, Feder K, Keith SE, Voicescu SA, Marro L, Than J, Guay M, Denning A, Murray BJ, Weiss SK, Villeneuve PJ, van den Berg F, Bower T. 2016. Effects of Wind Turbine Noise on Self-Reported and Objective Measures of Sleep. *Sleep*. 2016 Jan 1;39(1):97-109

Michaud DS, Feder K, Keith SE, Voicescu SA, Marro L, Than J, Guay M, Denning A, McGuire D, Bower T, Lavigne E, Murray BJ, Weiss SK, van den Berg F. 2016a. Exposure to wind turbine noise: Perceptual responses and reported health effects. *J Acoust Soc Am*. 2016 Mar;139(3):1443-54.

Michaud DS, Keith SE, Feder K, Voicescu SA, Marro L, Than J, Guay M, Bower T, Denning A, Lavigne E, Whelan C, Janssen SA, Leroux T, van den Berg F. 2016b. Personal and situational variables associated with wind turbine noise annoyance. *J Acoust Soc Am*. 2016 Mar;139(3):1455-66.

Michaud DS, Feder K, Keith SE, Voicescu SA, Marro L, Than J, Guay M, Denning A, Bower T, Villeneuve PJ, Russell E, Koren G, van den Berg F. 2016c. Self-reported and measured stress related responses associated with exposure to wind turbine noise. *J Acoust Soc Am*. 2016 Mar;139(3):1467-79.

Michigan Act No. 233 of Public Acts of 2023, effective November 29, 2024 (Michigan PA233)

Ministry for the Environment, Climate and Energy of the Federal State of Baden-Württemberg Germany. 2016. Low-frequency noise including infrasound from wind turbines and other sources

MMI Engineering Ltd, 2013. Study and development of a methodology for the estimation of the risk and harm to persons from wind turbines. Prepared by for the Health and Safety Executive of the Government of the United Kingdom

New York ORES Part 1101 of Title 16

North Dakota Century Code Chapter 49-22 ENERGY CONVERSION AND TRANSMISSION FACILITY SITING ACT

Persimia. 2023. Riverbend Wind Project Ice Shed and Blade Failure Risk Assessment

Rogers, J, Costello, M. 2022. Methodology to assess wind turbine blade throw risk to vehicles on nearby roads. *Wind Engineering*. Vol. 46(4) 1187–1202

Rogers, J. and Ollson, C.A. 2025. Simulation Analysis and Safety Risk Assessment of a Wind Turbine Blade Failure Event. *Wind Energy*.

Smedley ARD, Webb AR, Wilkins AJ. Potential of wind turbines to elicit seizures under various meteorological conditions. *Epilepsia* (2010) **51**:1146-51.

Turnbull C, Turner J, Walsh D. 2012. Measurement and level of infrasound from wind farms and other sources. *Acoust Aust* **40**:45-50.

*Van Kamp, I & van den Berg, F. 2021. Health Effects Related to Wind Turbine Sound: An Update. Int. J. Environ. Res. Public Health 2021, 18, 9133*

Van Kamp, I & van den Berg, F. 2018. Health Effects Related to Wind Turbine Sound, Including Low-Frequency Sound and Infrasound *Acoust Aust* (2018) 46:31–57

Voicescu SA, Michaud DS, Feder K, Marro L, Than J, Guay M, Denning A, Bower T, van den Berg F, Broner N, Lavigne E.n 2016. Estimating annoyance to calculated wind turbine shadow flicker is improved when variables associated with wind turbine noise exposure are considered. *J Acoust Soc Am*. 2016 Mar;139(3):1480. doi: 10.1121/1.4942403

Wisconsin Chapter PSC 128 WIND ENERGY SYSTEMS