I. **Health Effects**

1. Wind Turbine Syndrome: A Report on natural experiment & Your Guide to Wind Turbine Syndrome…a road map to a complicated subject
2. Health Effects of Wind Turbine Testimony of Ben Johnson versus MidAmerican Energy
3. Wind Turbine Noise and Human Heath: A Four Decade History of Evidence that Wind Turbines Pose Risks
4. Infrasound from technical installations: Scientific basis for an assessment of health risks
5. Assessing Adverse Health Effects
6. Presentation before the Kansas Senate and Utilities Committee
7. Wind Turbines: Vacated/abandoned homes
8. A Fundamental basis for all living creatures, mechantransduction, is significantly endangered
9. Separating myth from fact on Wind Turbine Noise
10. Efficient finite difference modeling of infrasound propagation
11. Ontario's Green Energy Policy vs. Social Justice
12. Infrasound Impacts at the Cellular Level
13. Transcript of Ken Mattsson on Infrasound
14. Infrasound Affects the Briain
15. Understanding subjective and situational factors of wind turbine noise annoyance
16. Responses of the ear to low frequency sounds, infrasound and wind turbines
17. Infrasound Physiological process; Ursula Bellut Staeck
18. Effects of low frequency noise from wind turbines on heart rate variability in healthy individuals
19. Epidemiological study on long-term health effects on low frequency noise produced by wind power stations in Japan
20. Negative Effect on High- Level Infrasound on Human Myocardial Contractility
21. Wind Turbines Make Waves
22. Environmental Noise Pollution

23. Effects of Industrial wind turbine noise on sleep and health
24. Why Does Egg Mortality Increase Near New Wind Industry?
25. Infrasound from technical installations: Scientific basis for an assessment of health risks
26. Julie Clarkson Email- Health effects – General
27. Health Effects of Wind Turbines: Testimony of Ben Johnson vs. MidAmerican Energy (Madison County, Iowa)
28. Adverse health effects of industrial wind turbines
29. Carol Black April 28 Letter
30. Review/ Revue- Industrial Wind Turbines and Adverse Health effects
31. Infrasound & Low Frequency Noise Guide
32. Long-Term Quantification and Characterisation of wind farm noise amplitude modulation
33. Human Health, Rights and Wind Turbine Deployment in Canada

Setback Recommendations Per Various Studies

Name of Study	Date of Study	Author(s)	Link to Study	Author's Advised Setbacks	Notes
Wind Turbine Syndrome: A report on a natural experiment	**2009**	Dr. Nina Pierpont	N/A, PDF provided	**Setbacks from residences should be a minimum of 2 kilometers or 1.24 miles, but 2-3 miles in hilly terrain**	PDF provided to Planning Commission and BoCC
Your Guide to Wind Turboine Syndrome...a road map to a complicated subject	**July 2010**	Calvin Luther Martin, Phd	N/A, PDF provided	**Setbacks from residences should be a minimum of 2 kilometers or 1.24 miles, but 2-3 miles in hilly terrain**	This is a summary of Dr. Pierpont's book PDF provided to Planning Commission and BoCC
Health Effects of Wind Turbines: Testimony of Ben Johnson versus MidAmerican Energy (Madison County, Iowa) / Hearing before the Madison County Board of Health	**August 2019**	Dr. Ben Johnson, M.D.	https://www.masterresource.org/wind-turbine-noise-issues/health-effects-of-wind-turbines-testimony-of-ben-johnson-versus-mid-american-energy-project-in-madison-country-iowa/	**No recommendation given for a specific distance in this hearing. Afterwards the Madison County Board of Health passed a resolution recommending that any future turbines be built at least 1.5 miles from non-participating homes**	PDF provided to Planning Commission and BoCC
Wind Turbine Noise and Human Health: A Four-Decade History of Evidence that Wind Turbines Pose Risks	**Ocober 2016**	Professor Jerry L Punch and Professor Richard R James	https://hearinghealthmatters.org/wp-content/uploads/2023/03/16-10-21-Wind-Turbine-Noise-Post-Publication-Manuscript-HHTM-Punch-James.pdf	**Setbacks from residences are recommended at 1/2 mile to 2.5 miles, 1.25 miles is most favored by scientists.**	PDF provided to Planning Commission and BoCC
Infrasound from technical installations: Scientific basis for an assessment of health risks	**July 2021**	Dr. Werner Roos and Dr. Christian Vahl	https://www-asu--arbeitsmedizin-com.translate.goog/wissenschaft/wissenschaftliche-grundlagen-fuer-eine-bewertung-gesundheitlicher-risiken-infraschall?_x_tr_sl=de&_x_tr_tl=en&_x_tr_hl=en&_x_tr_pto=wapp	**Minimum setback from residences should be 10 X turbine height as in Bavaria Germany**	PDF provided to Planning Commission and BoCC
Assessing Adverse Health Effects-(Confirmed and Potential) from Industrial Wind Turbine Noise Emissions / Power point slides of presentation before the Kansas State Legislature	**2022**	Dr. Ben Johnson, M.D.	https://www.kslegislature.gov/li_2022/b2021_22/committees/ctte_s_utils_1/documents/testimony/20220207_01.pdf	**Setbacks of 1.25 miles from residences**	PDF provided to Planning Commission and BoCC
Presentation before the Kansas Senate and Utilities Committee: Effects of Wind Turbine Noise on Human Health	**2022**	Prof Jerry L Punch	https://www.kslegislature.gov/li_2022/b2021_22/committees/ctte_s_utils_1/documents/testimony/20220208_02.pdf	**Setbacks of 1.25 miles from property lines (specifically) should be considered**	PDF provided to Planning Commission and BoCC
Wind Turbines: Vacated/abandoned homes - Exploring participants' descriptions of their personal views, effects on safety, security, trust and social justice	**Dec 2023**	Carmen Marie Krogh, Robert Y McMurty, W Ben Johson, Jerry L Punch, Anne Dumbrille, Mariana Alves-Pereira, Debra Hughes, Linda Rogers, Robert W Rand, Lorrie Gillis	https://journals.lww.com/endi/fulltext/2023/08040/wind_turbines__vacated_abandoned_homes___exploring.2.aspx	**Residents living within 10 kilometers/6.21 miles of industrial wind turbines were documented having Adverse Health Effects**	See page 96 for the conclusion of the study regarding setbacks. PDF provided to Planning Commission and BoCC.
A fundamental basis for all living creatures, mechanotransduction, is significantly endangered by periodic exposure to impulsive infrasound and vibration from technical emitters - in particular cardiovascular and embryological functions	**June 2025**	Dr. Ursula Bellut-Staeck	https://www.scirea.org/journal/PaperInformation?PaperID=12440	**Setbacks of 10 kilometers / 6.21 miles from people and animals**	NOTE: The link shows the abstract and allows you to download the PDF PDF provided to Planning Commission and BoCC
Separating Myth from Fact on Wind Turbine Noise	**October 2025**	Prof Ken Mattsson	https://www.youtube.com/watch?v=nDwsd32SDEY	**Setbacks of at least 5 to 10 kilometers (3.1 to 6.2 miles) from residences**	Transcript PDF provided to Planning Commission and BoCC
Efficient finite difference modeling of infrasound propagation in realistic 3D domains: Validation with wind turbine measurements	**Feb 2026**	Ken Mattsson, Gustav Eriksson, Leif Persson, Jose Chilo, Kourosh Tatar	https://www.sciencedirect.com/science/article/pii/S0003682X25006280?ref=pdf_download&fr=RR-2&rr=9a872537bf69df1b	**No specific distance given, see notes for conclusion of study**	Conclusion of study page 14: This study also shows that modern, large-scale wind turbines generate infrasound levels substantially higher than those reported for older, smaller turbines / PDF provided to Planning Comm & BoCC

I-1

Wind Turbine Syndrome: A Report on a Natural Experiment

Nina Pierpont, MD, PhD

Executive Summary

12/20/2009

The core of the book is a scientific report presenting original, primary research on symptomatic people living near large industrial wind turbines (1.5-3 MW) erected since 2004.

These are the findings:

1) Wind turbines cause Wind Turbine Syndrome. We know this because people have symptoms when they are close to turbines and the symptoms go away when they are away from turbines. The study families themselves figured out that they had to move away from turbines to be rid of their symptoms, and nine out of ten have moved. Some sold and some abandoned their homes.

2) People do not abandon their homes out of "annoyance." Reported symptoms, such as sleep deprivation, dizziness, and nausea, cannot be dismissed as "annoyances."

3) The symptom cluster is consistent from person to person, hence the term "syndrome."

4) The symptoms are sleep disturbance and deprivation, headache, tinnitus (ringing in ears), ear pressure, dizziness, vertigo (spinning dizziness), nausea, visual blurring, tachycardia (fast heart rate), irritability, problems with concentration and memory, and panic episodes associated with sensations of movement or quivering inside the body that arise while awake or asleep.

5) Children are affected as well as adults, especially older adults.

6) People with pre-existing migraine disorder, motion sensitivity, or damage to inner ear structures (such as hearing loss from industrial noise exposure) are more susceptible than other people to Wind Turbine Syndrome. These results are statistically significant ($p < 0.01$).

7) Wind Turbine Syndrome symptoms are not statistically associated with pre-existing anxiety or other mental health disorders.

8) The sample size of 10 families/38 people was large enough for statistical significance with regard to susceptibility or risk factors.

9) The susceptibility factors are clues to the pathophysiology of Wind Turbine Syndrome. The symptom complex resembles syndromes caused by vestibular (inner ear balance organ)

dysfunction. The proposed mechanism is disturbance to balance and position sense by noise and/or vibration, especially low frequency components of the noise and vibration.

10) An extensive review of recent medical literature reveals how balance-related neural signals affect a variety of brain areas and functions, including spatial awareness, spatial memory, spatial problem-solving, fear, anxiety, autonomic functions (like nausea and heart rate), and aversive learning. These known neural relationships provide a robust anatomic and physiologic framework for Wind Turbine Syndrome.

11) Medical and technical literature on the resonance of sound or vibration within body cavities (chest, skull, eyes, throat, ears) is reviewed, since study subjects experience these effects.

12) Published studies of documented low frequency noise exposure (both experimental and environmental) are reviewed. These demonstrate effects on people similar or identical to Wind Turbine Syndrome. Indeed, one study from Germany in 1996 may indeed be Wind Turbine Syndrome.

13) Recent mail-in survey studies of people who live near wind turbines in Sweden and the Netherlands are reviewed. These show that people are severely annoyed at noise from wind turbines at much lower A-weighted noise levels than for traffic, train, or aircraft noise.

14) Published literature documenting the effects of environmental noise on cardiovascular health and children's learning are reviewed. For health reasons, the World Health Organization recommends lower thresholds for nighttime noise than are currently observed in most countries —especially when the noise has low-frequency components.

15) Wind Turbine Syndrome gives a name and medical description to a set of symptoms severe enough to drive people from their homes and establishes medical risk factors for such symptoms. This study and other studies reviewed in the report indicate that safe setbacks will be at least 2 km (1.24 miles) and even longer for larger turbines and in more varied topography. Further research is needed to clarify physical causes and physiologic mechanisms, explore other health effects of living near wind turbines, determine how many people are affected, and investigate effects in special populations, including children. Government funding and moratoria are appropriate.

The book further includes:

A) Full case histories—the words and experiences of all the study subjects (including children), presented in an organized tabular format.

B) The report presented again in non-scientific, layman's language, explaining the medical, technical, and statistical aspects of the study. This section is illustrated.

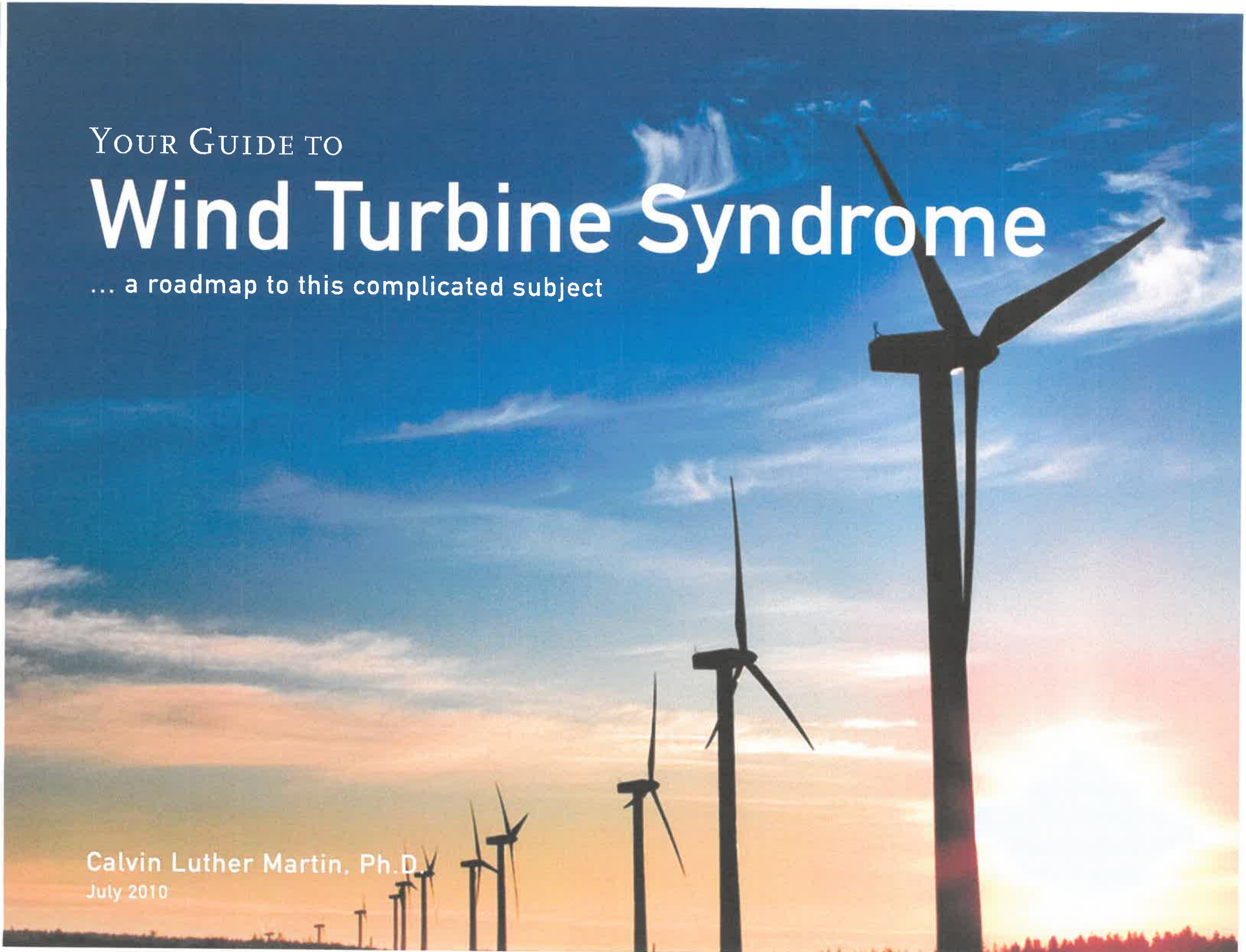
C) Peer reviews and commentary by scientists and university physicians.

D) Introduction, complete list of scientific and medical references, glossary, and list of abbreviations.

YOUR GUIDE TO

Wind Turbine Syndrome

... a roadmap to this complicated subject



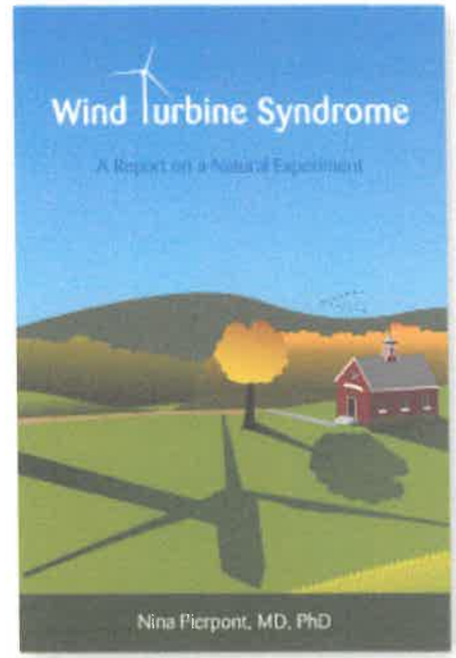
Calvin Luther Martin, Ph.D.

July 2010

The Symptoms

Wind Turbine Syndrome (WTS) is the clinical name Dr. Nina Pierpont has given to the constellation of symptoms experienced by many (not all) people who find themselves living near industrial wind turbines.

- sleep disturbance
- headache
- tinnitus (pronounced "tin-uh-tus": ringing or buzzing in the ears)
- ear pressure
- dizziness (a general term that includes vertigo, lightheadedness, sensation of almost fainting, etc.)
- vertigo (clinically, vertigo refers to the sensation of spinning, or the room moving)
- nausea
- visual blurring
- tachycardia (rapid heart rate)
- irritability
- problems with concentration and memory
- panic episodes associated with sensations of internal pulsation or quivering, which arise while awake or asleep



As wind turbines spring up like mushrooms around people's homes, Wind Turbine Syndrome has become an industrial plague. (See victims' Diaries & Reports and Videos). Nina Pierpont has been researching this "plague" for the past five years, and in November 2009 she published her results, *Wind Turbine Syndrome: A Report on a Natural Experiment* (Santa Fe, NM: K-Selected Books, 2009). Click on Read Peer Reviews to read the referee reports (all by medical school and university faculty). For purchase information, see Buy the book. For an in-depth radio interview with Dr. Pierpont, wherein she explains what's going on with WTS, click here. (With thanks to Radio CFCO, Ontario, Canada, 2-28-08, "Ask the Health Expert." Be sure your speakers are turned up.)

Before proceeding, a clarification. On August 2, 2009, The Independent, one of the UK's largest national newspapers, published a superb story on Nina Pierpont's research. (It's rare that the media gets WTS right. Margareta Pagano, the reporter who interviewed Pierpont, got it right.) Her article needs a correction, however, especially since portions of her report were reprinted verbatim in scores of newspapers and blogs around the world. Ms. Pagano wrote:

> **"Living too close to wind turbines can cause heart disease, tinnitus, vertigo, panic attacks, migraines and sleep deprivation, according to groundbreaking research to be published later this year by an American doctor."**

The problem is the claim "wind turbines can cause heart disease." Dr. Pierpont did not say this in her interview, nor does she write this in her book. Somehow, between the interview and the printing of the article, that (erroneous) statement crept into the text. Since newspaper articles are often edited by several levels of editor, it's conceivable another editor quite innocently inserted that line, confusing tachycardia with heart disease. (After all, these people are not clinicians.)

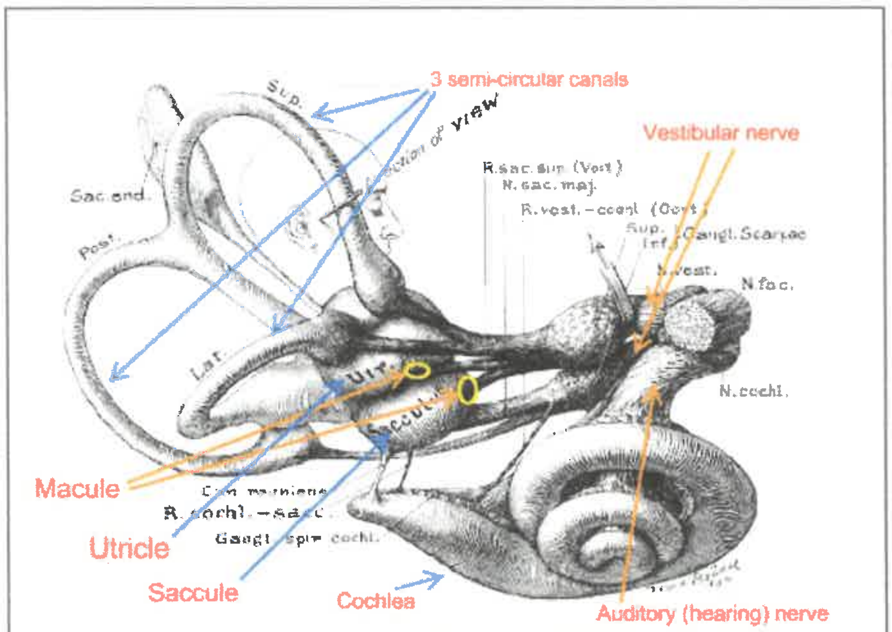
Nina Pierpont subsequently contacted Ms. Pagano to point out this needs correcting:

> **"My current research does not establish a connection between heart disease and wind turbine exposure, only between a rapid heart rate as part of a panic-like response (VVVD, as described in today's article) and wind turbine exposure. However, there is a substantial body of European (including UK) research showing that environmental noise exposure in general increases the risk for cardiovascular disease. This is an area in need of further research with regard to wind turbine exposure.**
>
> **"Thank you to the Editors for endorsing responsible development that scrutinizes both positives and negatives of new technologies."**

The Human Ear

To understand Wind Turbine Syndrome one must first understand the function of the human vestibular system: the utricle, saccule, and semicircular canals. Three tiny organs in the inner ear. The utricle and saccule, together, constitute the otolith organs. The otolith organs and the semicircular canals are not involved in hearing per se—that would be the cochlea—but are dedicated to detecting *balance* and *motion* and *position*, with far-reaching consequences for parts of the brain controlling cognition, mood, and certain physiologic functions (such as vertigo and nausea).

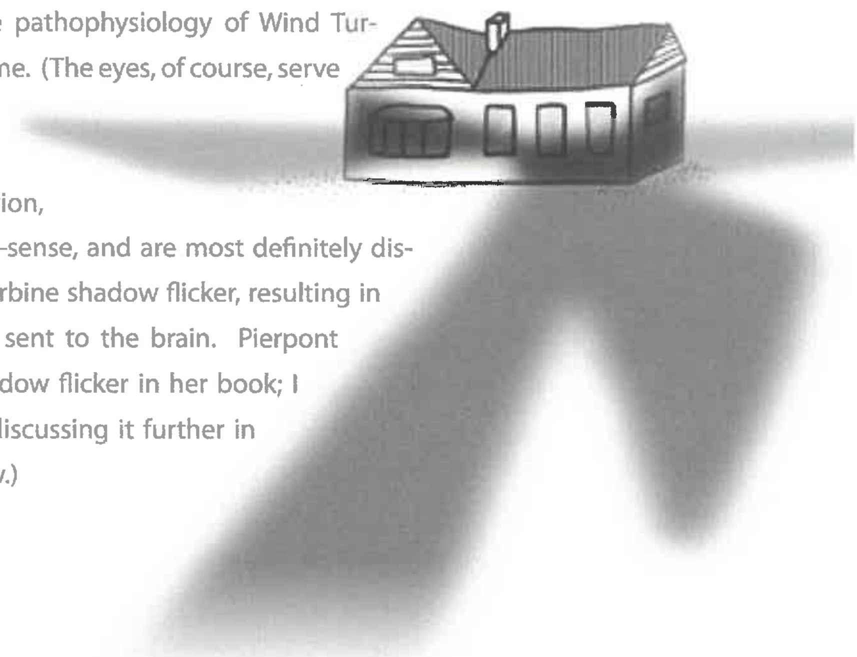
The vestibular system happens to be an ancient "command and control" center dreamed up and refined by Mother Nature over millions of years, long before there were human beings. We find a nearly identical command and control apparatus in fish and amphibians and a host of other vertebrates (back-boned animals), for whom it continues to perform important functions of cognition and behavior—just as it does in you and me.



Inner Ear (illustration ©Max Brodel 1934)

Expose Mother Nature's vestibular command and control center to wind turbines and the result is chaos. Low frequency noise (LFN) from turbines appears to send false signals to these exquisitely sensitive structures, causing dizziness, vertigo, and nausea, along with cognitive and memory deficits, along with anxiety and panic attacks. Yes, the latter behavioral symptoms are in fact tied to the inner ear, as any up-to-date otolaryngologist (Ear, Nose, Throat surgeon) can tell you.

Bear in mind that WTS is a constellation of symptoms, including sleeplessness and tinnitus (caused by cochlear disturbance). And bear in mind that WTS appears to derail several of the body's sensory systems, besides the inner ear. Even so, the vestibular structures of the inner ear are critical to understanding the pathophysiology of Wind Turbine Syndrome. (The eyes, of course, serve as another organ of balance, motion, and position-sense, and are most definitely disturbed by turbine shadow flicker, resulting in false signals sent to the brain. Pierpont explores shadow flicker in her book; I will not be discussing it further in this overview.)


Drawing by R. Forrest Martin

Re-thinking Turbines

Let's stand back for a moment. We need to re-think the notion of turbines solely as electricity-producing machines and wake up to the fact that, for all practical purposes, they function equally as *low frequency noise-producing machines*. People often object vehemently to turbines because they consider them ugly and outsized for their community. (Turn up your speakers and listen to Bob Lucas's "Green Energy Blue.")

Others object because they lower property value. (That's true, they do hammer property value.)

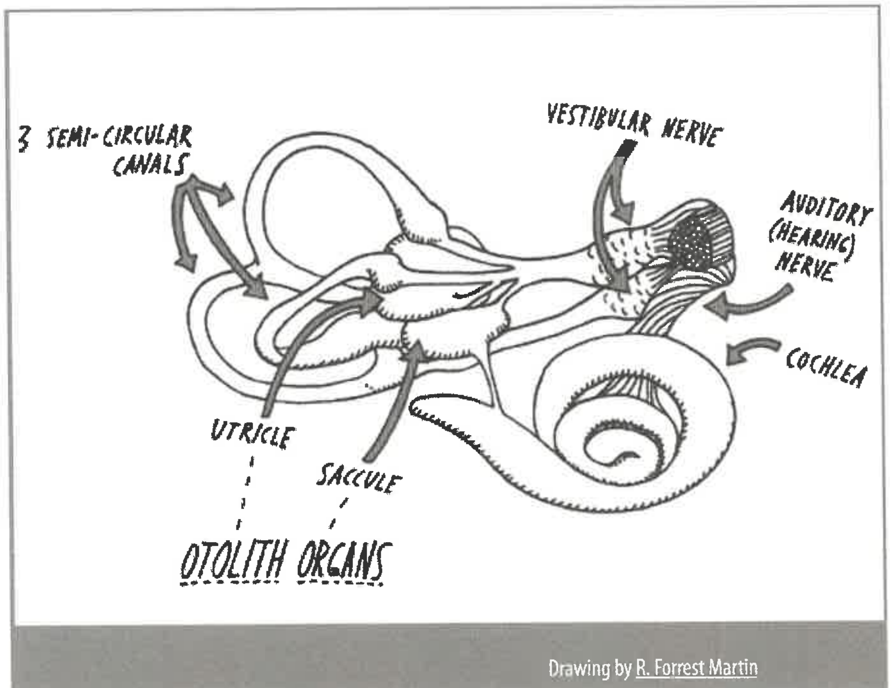
What eclipses eyesore and property value is the low frequency noise. It's a major health issue. This is more than a "nuisance." As Nina Pierpont puts it, "People experiencing WTS are not *annoyed*, they are *sick*!"

Folks who visit a wind farm and stand beneath a turbine generally have no idea that the vestibular organs of the inner ear, along with other motion, balance, and position sensors throughout the body, are being jack-hammered by a low frequency noise they can barely hear. (The amount of LFN produced during one's visit depends, of course, on whether the turbines are in fact generating, wind direction and wind speed, whether it's day or nighttime, and the degree of moisture in the air.)

Butler Ridge Project near Iron Ridge, Wisconsin, May 2, 2009, with thanks to Better Plan Wisconsin. (WTS.com has taken editorial liberties with this photo.)

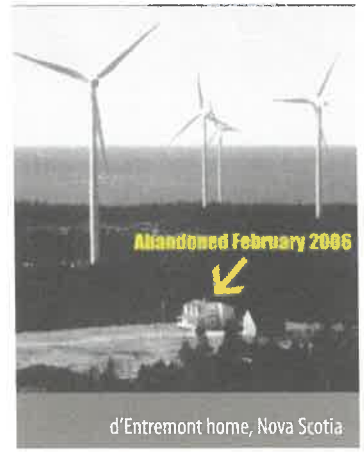
Anyhow, people stand next to a turbine and exclaim, *"Gee, my cochlea [the organ within the inner ear that picks up audible sound] hears almost nothing at all! Merely a whooshing noise! Sounds like a humming refrigerator, just like the developer said! What's the problem?"*

Now for the bad news. The utricle, saccule, and semicircular canals don't register the "refrigerator-like" audible noise but, rather, the less apparent yet health-threatening sub-audible vibration. Hence, people don't say, *"Gee, despite my cochlea detecting only a mild hum, my utricle, saccule, and semicircular canals are sending weird signals! Come to think of it, my other organs of balance, motion, and position are, as well! Hey, what's going on??!!"* (Incidentally, noise and vibration are one and the same in physics.)



Drawing by R. Forrest Martin

Organs of balance, motion, and position may (and do) respond rapidly and alarmingly in some people—for instance, when visiting a windfarm and standing, marveling, beneath a turbine for 10 minutes. But for most of us the effect takes longer to sink in—not till turbines are up and running, 1000′ or 1500′ or more from one's back door and exposure is 24/7. Then, for people like this Nova Scotia family (right), it's too late.



d'Entremont home, Nova Scotia

Likewise for Barbara Ashbee (a realtor, incidentally) and her husband Dennis. They used to live here. (They count themselves among the lucky ones. The wind developer bought them out, after which Barbara & Dennis had to sign a gag agreement. The developer refuses to buy out the d'Entremonts, above, who remain homeless—camping out with various relatives. Yes, their family is broken up as a result.)

But I digress. Who is especially susceptible to WTS? That's easy to answer. "Statistically significant risk factors for symptoms during exposure include *pre-existing migraine disorder, motion sensitivity, or inner ear damage* (pre-existing tinnitus, hearing loss, or industrial noise exposure)" (Pierpont 2009). Motion sensitivity? If you got car-sick as a kid, or get seasick, you're at high risk. How many people suffer from pre-existing migraine disorder? Studies show it's a substantial proportion of the population (6% for males, 18% for females)—all human populations studied so far.

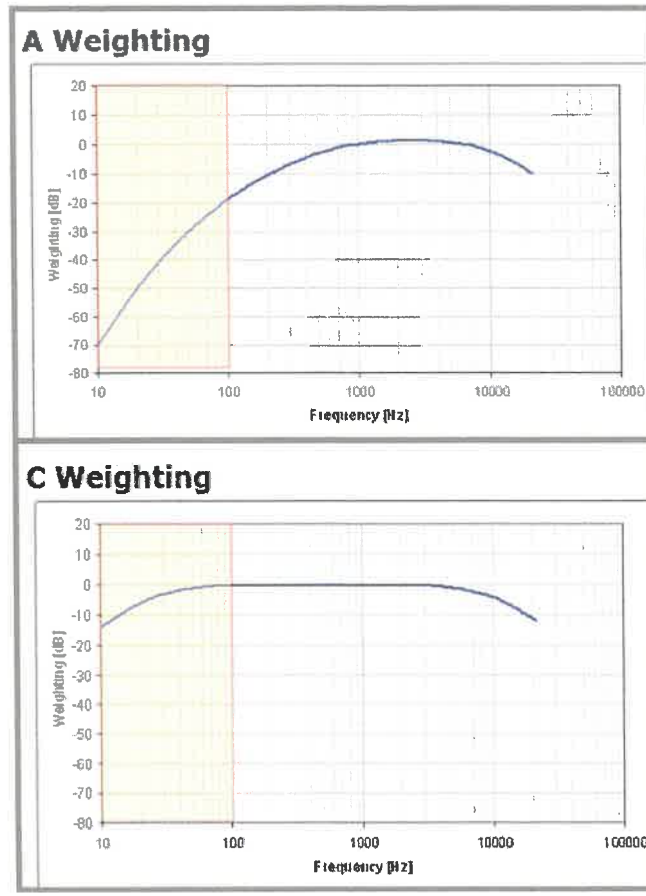
Again, the chief culprit appears to be low frequency noise.

- dB = decibel
- "A" refers to *A-filtering* (also known as *A-weighting*)
- "C" refers to *C-filtering (C-weighting)*
- therefore dBA = *noise measurement with an A-filter (or A-weighted filter)*
- and dBC = *noise measurement with a C-filter (or C-weighted filter)*

Noise

Tragically, most people living near turbines, or contemplating turbines for their community, fail to grasp the magnitude of all this. This happens in part because the developers get away with what are basically deceptive noise measurements. How are they deceptive? Because wind developers insist on using A-weighted (dBA) measurements. *A-weighting filters out nearly all the low frequency noise and, even lower, infrasound, both of which are produced in abundance by turbines.*

Take a look at the following graphs (right), showing the difference between dBA and dBC noise measurements.



With appreciation to diracdelta.co.uk

It's obvious that a C-weighted filter picks up vastly more noise (literally, exponentially more) in the low frequency and infrasound range—the yellow zone on both graphs. It's equally obvious that an A-weighted filter picks up exponentially less and less LFN and infrasound as the frequency drops. (Notice that the noise data are plotted on logarithmic graph paper. This explains why the intervals between levels of frequency are unequal. Frequency is measured in Hz = Hertz.)

A-weighting is designed to pick up what the human ear normally hears in conversation. It filters out almost all the lower range of sound—the sound we barely hear (depending on how low it is), *sound that is detected as vibration by the inner ear's vestibular organs together with a variety of other motion, position, and balance sensors throughout the body.* A-weighting, in short, is designed to measure what the cochlea (the organ we hear with) detects, not what the utricle, saccule, semi-circular canals and other organs of motion, position, and balance detect.

Using A-weighted filters is a cheap trick by wind developers and the acousticians who work for them. And people suffer as a result. Rephrasing this, wind developers swindle everyone by using pseudoscience: scrupulously taking A-weighted noise measurements (dBA) without measuring for the proverbial elephant in the room—the low frequency noise. With A-weighted filters, they can get away with the claim that their turbines are no louder than a refrigerator, a library reading room, or a babbling brook—which is all technically true, but irrelevant. What their literature neglects to point out is that the 400-foot-tall whirling "refrigerator" (turbine) they just installed in your backyard is also producing major low frequency noise/vibration—something my refrigerator, local library reading room, and backyard babbling brook don't produce. And yours don't, either.

German windplant. (This photo was not enhanced in any manner; this is exactly how the windplant appears to the naked eye.)

When the developers show up to do their sound measurements prior to construction or after you complain about the noise from their damn turbines, their "engineers" whip out—you guessed it!—an A-filtered noise meter. Not C-filtered. (Yes, Dorothy, this is The Land of Oz, and wind developers are that corny, childish, and sleazy.)

The good news is that LFN can be adequately detected using a C-weighted filter. However, even with a C-weighted filter combined with A-weighted readings, taking proper measurements is a tricky, highly specialized, and complicated business. Easily botched—or fudged. (See How Loud Is Too Loud?)

Fudged? Does this suggest fudging?

"When our town council went to a windfarm [open house] hosted by the Canadian Wind Energy Association, first they were treated to gourmet snacks on the bus and given the wonderful story on wind. Then they brought them right underneath the turbines to show them how quiet they were. The councilors said the turbines were turning like crazy and yet were as quiet as a mouse.

"Being suspicious, my husband checked the Sygration site and, lo and behold, for that time period the turbines were not producing any energy. Though not a turbine technician, my husband is an industrial mechanic and said this could be done very easily by just disengaging the clutch that actually runs the rotors, and it's all done from a remote computer.

"We presented this information to our town council, but they wouldn't believe the nice wind fellows would do something like that."

—Maureen Anderson (Ontario, Canada), 9/6/09

Wisconsin windfarm (photo courtesy of Gerry Meyer)

"Calvin Luther Martin is correct [that] wind farm noise measurements must be obtained secretly to ensure normal wind turbine operating conditions. Rick James has made it clear that wind farm operators can and do reduce the noise emission quickly if someone is spotted measuring the wind farm noise.

"Over many decades of industrial noise emission measurements, I have learned the best atmospheric conditions (worst case for noise impacted residents) for obtaining the highest immission noise level is during an otherwise quiet night, when the atmosphere is stable. For wind farm noise immission measurements, this means a clear night with only a slight breeze (<2m/s) from the wind farm near ground level and the wind turbines operating near full power. I normally informed only the local law enforcement before my night measurements, so they could address any calls from residents concerned about my presence in the street.

"We would be interested in any wind farm noise data you care to share with us. Please do glance through "How Loud Is Too Loud?" referenced at the end of Calvin's message, to better understand the dBA and dBC noise data we desire, to better understand the nature of the noise impact on residents. Your results would be even more valuable if you found an opportunity to also measure the noise immission environment on the same or similar night with the wind turbines not operating."

—George Kamperman, P.E., 9/6/09
Bd. Cert. Member Institute of Noise Control Engineers
Fellow Member Acoustical Society of America

Wind developers add insult to injury by flatly denying any health effects from their LFN-generating turbines. Whose LFN, I emphasize, they refuse to measure, whether properly or improperly. They refuse because (a) they either deny LFN exists, or (b) if they grudgingly acknowledge it does, they claim it's so minuscule as to be inconsequential. Their rule of thumb being, "if you can't hear it, it can't hurt you"—a notion that has been refuted by recent research. (See especially the work of Todd et al. in the attached References from Pierpont's 2009 report.)

Indiana (with thanks to the Indianapolis Star)

"The University of Ballarat has begun investigating noise levels near Waubra Wind Farm [Australia], with residents claiming low frequency turbine sound is affecting their health. Some say they have experienced headaches, nausea and sleep deprivation since the turbines began operating. . . .

"University of Ballarat engineering lecturer Graeme Hood said previous monitoring results indicated a high level of infrasound. 'It's like having a truck going past your place constantly, although you can't hear it,' Mr Hood said. . . .

"Acciona Energy, which owns Waubra Wind Farm, says it is monitoring post-construction noise to ensure it complies with industry standards. But Mr Hood said the standards did not take infrasound into account. . . ."

In summary, WTS seems to be triggered by the organs of motion, position, and balance being commandeered by turbine low frequency noise. The result is that these organs send scrambled signals to brain centers controlling memory, concentration, learning, emotions (including panic & anxiety), sleep, balance, and so on. See the above list.

The clinical literature is clear on what frequencies cause what pathologies. For instance, Todd et al. have demonstrated that 100 Hz sets off fire alarms in the utricle and saccule (see, for example, "Tuning and sensitivity of the human vestibular system to low-frequency vibration"). One hundred (100) Hz is low-frequency. (Note that at 100 Hz, A-weighting reduces sound measurement by a factor of 1000 [30 dB]. At 31 Hz, A-weighting reduces sound measurement by a factor of 10,000 [40 dB].)

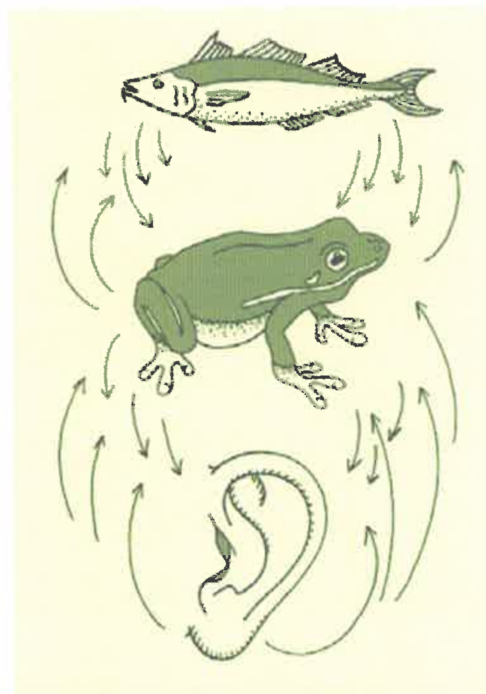
The clinical literature likewise shows symptoms down around 10 Hz and below in what is technically considered the infrasound range..

"Most exciting, Todd et al. provide direct experimental evidence that at the 100 Hz tuning peak, the vestibular organs (probably utricle) of normal humans are much more sensitive than the cochlea to low-frequency bone-conducted sound/vibration. The researchers applied vibration directly to the skin over the bony mastoid prominence behind the subjects' ears, adjusting the power by measuring the tiny whole-head acceleration produced by each vibration force and frequency. They were able to elicit and measure neural signals of the vestibulo-ocular reflex (OVEMP) at vibration intensities 15 dB below the subjects' hearing thresholds.

"In other words, the amount of vibration/bone-conducted sound was so small that the subjects could not hear it, yet the vestibular parts of their inner ears still responded to the vibration and transmitted signals into the balance and motion networks in the brain, resulting in specific types of eye muscle activation. Since dB is a base 10 logarithmic measure, *15 dB below* means a signal 0.0316 ($10^{-1.5}$), or about 3%, of the power or amplitude of the signal these normal subjects could hear.

"The researchers note that 'the very low thresholds we found are remarkable as they suggest that humans possess a frog- or fish-like sensory mechanism which appears to exceed the cochlea for detection of substrate-borne low-frequency vibration and which until now has not been properly recognized.'

"Thus the potential exists, in normal humans, for stimulation of balance signals from the inner ear by low-frequency noise and vibration, even when the noise or vibration does not seem especially loud, or even cannot be heard. In the presence of pre-existing inner ear pathology, thresholds for vestibular stimulation by noise or vibration are even lower than in normal subjects.



Drawing by R. Forrest Martin

“Each part of the body has its own resonance frequency with regard to vibration. When an object is vibrated at its resonance frequency, the vibration is amplified. The resonant frequency of the thoraco-abdominal system, as it moves vertically towards and away from the lungs, lies between 4 and 8 Hz for adult humans. Vibrations between 4 and 6 Hz set up resonances in the trunk with amplification up to 200%. Related chest and abdominal effects are found in the same frequency range. Vibrations in the 4-8 Hz range influence breathing movements, 5-7 Hz can cause chest pains, 4-10 Hz abdominal pains, and 4-9 Hz a general feeling of discomfort. In small children under 40 pounds, the vertical resonance or power absorption peaks at 7.5 Hz, as opposed to 4-5 Hz for adults.”

—Pierpont, “Report for Clinicians,” ch. 2 in *Wind Turbine Syndrome* (2009)

WTS Victims

People suffering from Wind Turbine Syndrome feel desperate. Oftentimes they feel they are losing their minds. This being neither surprising nor unreasonable, given that they are losing their ability to concentrate and remember things. And they panic. (The panic is not because they're weenies, but because low frequency noise acting on vestibular organs triggers panic. Panic is an inevitable neurological response to LFN.)

Ironically, all this is a normal response to vestibular signals. Except that the vestibular signals in this instance are happening under unnatural conditions, and are sending a mish-mash of mis-information to targeted brain centers.

Consider the following diary entry by Ann Wirtz (Wisconsin).

"Completely exhausted, I went to bed at around 10 p.m. I fell asleep quite fast, as usual. At 12:05 I woke up and looked at the clock. I tried to think, "Sleep, sleep, sleep, and don't wake up." But it was no use; I was wide awake.

"I had the feeling I often get of pressure in the room. I went out on our back porch. I sat down and could feel the eerie sensation even stronger outdoors. I had a feeling of pressure—the sensation you have for those few seconds when you are at the top of a rollercoaster, just before you go down. But this [feeling] is constant.

"I also felt the swoosh, swoosh of the turbines. It was [not] real loud, yet the feeling to me was very strong. The swoosh, swoosh sensation, along with the pressure, made me feel nauseous."

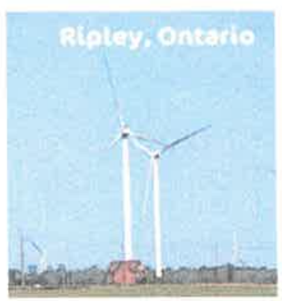
Picture it this way. Ann's utricle, saccule, and semi-circular canals are screaming at her brain, *"Oh my God, Ann is upside down and spinning!"* Alternatively, *"Oh my God, it's 1 a.m., and Ann is on a wild and crazy carnival ride!"*

In reality, Ann is sitting on her back porch in her bathrobe at 1 a.m., wondering why she can't get back to sleep. Her brain says, "No, you're wrong! You only *think* you're sitting on your porch listening to peepers and the gentle swish of turbines. I, your brain, *know for a fact* you're on the North Atlantic in a ridiculously small boat and there's a helluva storm tossing you around like a cork, and I'm trying like the dickens to keep your motion, position, and balance in proper order."

VVVD

As Pierpont explains in her report, Ann's weird midnight symptoms were likely a result of her vestibular apparatus being hijacked by turbine LFN, as outlined above. Alternatively, they were caused by a clinical phenomenon which Pierpont has christened *Visceral Vibratory Vestibular Disturbance* (VVVD), whereby LFN *literally vibrates internal organs*, thus setting off stretch, pressure, and vibration receptors and detectors (called visceral graviceptors, see Balaban) in and around internal organs.

Symptoms of VVVD resemble those of vestibular disturbance, with the added sensation of internal quivering or "crawling." "When the turbines get into a particular position (facing me)," reports one of Pierpont's subjects, "I get real nervous, almost like tremors going through your body. . . . It's more like a vibration from outside. . . . Your whole body feels it, as if something was vibrating me, like sitting in a vibrating chair but my body's not moving."



Visceral Vibratory Vestibular Disturbance (VVVD). For all you WTS sufferers who wonder what the heck is happening to you: What you're experiencing is a new clinical phenomenon. Yeah, you're making medical history. You're the guinea pigs for VVVD.

This is why Pierpont subtitled her book, "A Report on a Natural Experiment." *You're the experiment!* No clinician would get away with performing this outrageous experiment on people, but the wind developers pull it off because they claim ignorance. And when Pierpont and other physicians point out that they are messing with people's health, the windies have the gall simply and flatly to deny it—relying on advice from acousticians. (Hello! Acousticians and physicists are not clinicians.) Or they rely on advice from wind turbine salesmen and engineers, likewise not clinicians.

The outrage doesn't end there. The windies like to tell anyone within earshot that Pierpont's sample size (10 families, 37 people) is too small to establish any connection between the turbines next door and people's symptoms. (Wind developers are salesmen. Keep this in mind. And corporate environmentalists, for the most part, are wind developer shills. Keep this in mind, too. Neither wind developers, corporate environmentalists, politicians, public agency bureaucrats, or Barack Obama, for that matter, are clinicians.)

The windy crowd doesn't understand that *Pierpont's sample size was large enough to establish statistical significance on the question she was addressing, which was, "What aspects of a person's past medical history make him (her) susceptible to becoming sick when exposed to wind turbines?"*

This man—not a salesman, not a wind company consultant, not an acoustician or physicist, not a corporate environmentalist or politician or government job holder—grasps the significance of the statistical significance Pierpont has demonstrated. Unlike the above list of "nots," this man is an expert on the subject of LFN and vestibular dysfunction. Unlike the above crowd, he is worth listening to. Dr. Black is an Ear, Nose, Throat (ENT) physician. In fact, he's more than that; he's considered by fellow physicians to be the gold standard in otolaryngology and neuro-otology (ENT) research. Ironically, the American government also considers him the gold standard, for he regularly consults for the US Navy and NASA on vestibular disorders in astronauts and deep sea navy divers. (See F. Owen Black, MD, FACS.[1])

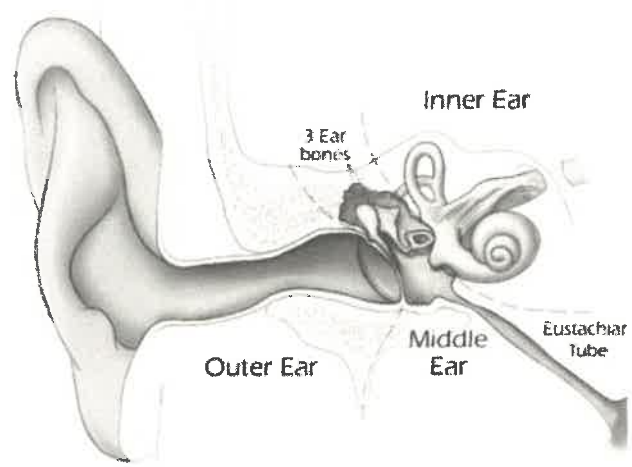
"Dr. Pierpont has clinically defined a new group of human subjects who respond to low frequency, relatively high amplitude forces acting upon the sensory and other body systems. Her rigorous clinical observations are consistent with reports of the deleterious effects of infrasound on humans, including, but not limited to, the low frequency sonar effects on divers. There are clinical conditions (such as dehiscent superior semicircular canals) that might explain some of Dr. Pierpont's clinical symptom review, but this relatively rare condition cannot explain all of her observations.

"Dr. Pierpont's astute collection of observations should motivate a well-controlled, multi-site, multi-institutional prospective study."

—F. Owen Black, MD, FACS, Senior Scientist and Director of Neuro-Otology Research, Legacy Health System, Portland, Oregon. Dr. Black is widely considered to be one of the foremost balance, spatial orientation, and equilibrium clinical researchers in America.

After reading this, you'd think responsible setbacks *à la* Nina Pierpont would be a no-brainer. The fact that clinically responsible setbacks are ignored by the above crowd is a scandal of large proportions. And getting larger by the

"I believe [Pierpont's] study is an important initial contribution to understanding the effects of low frequency pressures on the inner ear and other organs."



day, as Barack Obama and Congress pour billions of dollars into the pockets of this completely unregulated industry.

Yes, Dorothy, this is The Land of Oz, and wind developers and their shills are that brazen, sleazy and, if I understand the Geneva Convention's definition of torture, criminal.[2]

Torture? Here's what a woman named Nikki was doing at 10:42 pm on June 28, 2009. Tell me if this meets the definition.

". . . I began to feel a periodic vibration. It was strange. I even looked through the bed to see if a toy was vibrating or a cell phone was left there. Okay here is the part that may sound very strange and quite frankly has me very worried. Today the windmills were very loud and turning quickly. It is dark now so I can't see them, but they are loud this evening. Gerred [my husband] is still awake from the sound (he had a bad day today because he took the boys outside to play and swim and he said it felt like living next to an airport! Talk about Loss of Enjoyment of your property) . . . Anyway, I am feeling a vibration-like feeling just above my pelvic bone. It literally feels like when your cell phone vibrates but it is within my body. . . . I cannot describe it well, and even as I type I am having a hard time believing it myself. I wasn't even thinking about the turbines, I was just watching the movie with the kids when it started but now it's not stopping . . . . It feels very invasive . . . I don't like it at all . . . . I remember one of the doctors saying that vibration can be conducted in gaps between bones, like at the jaw below the ear or something like that. . . . I wonder if this could be happening at the top of the pelvic bone? If anyone can provide me with any information, it would be greatly appreciated . . . . This is the most unnerving thing that has happened

so far . . . If anyone can let me know any possible cause it would be greatly appreciated . . . . I hope you don't all think I am crazy, I know it sounds strange, but it is definitely happening . . . . I just timed it out with the turbines and it seems to be following the same pattern . . . . I will definitely be seeking medical advice on this one."

Nikki lives in Ontario, Canada. You can read her daily diary here, My Next Door Neighbour Is a Wind Turbine. Ann Wirtz lives in Wisconsin. You can read about her hellish life, here.

Ann's wild ride and Nikki's vibrating guts—the stories of two human guinea pigs—this is what Nina Pierpont's report is all about. Except that her report features 10 families, not just 2, from Europe and North America, analyzed in painstaking clinical detail. Ten families who have either abandoned their homes for good, or simply moved away to temporary lodging and hope someday to return. To this the wind developers and their acoustician & physicist hirelings respond, *"Nonsense!"*

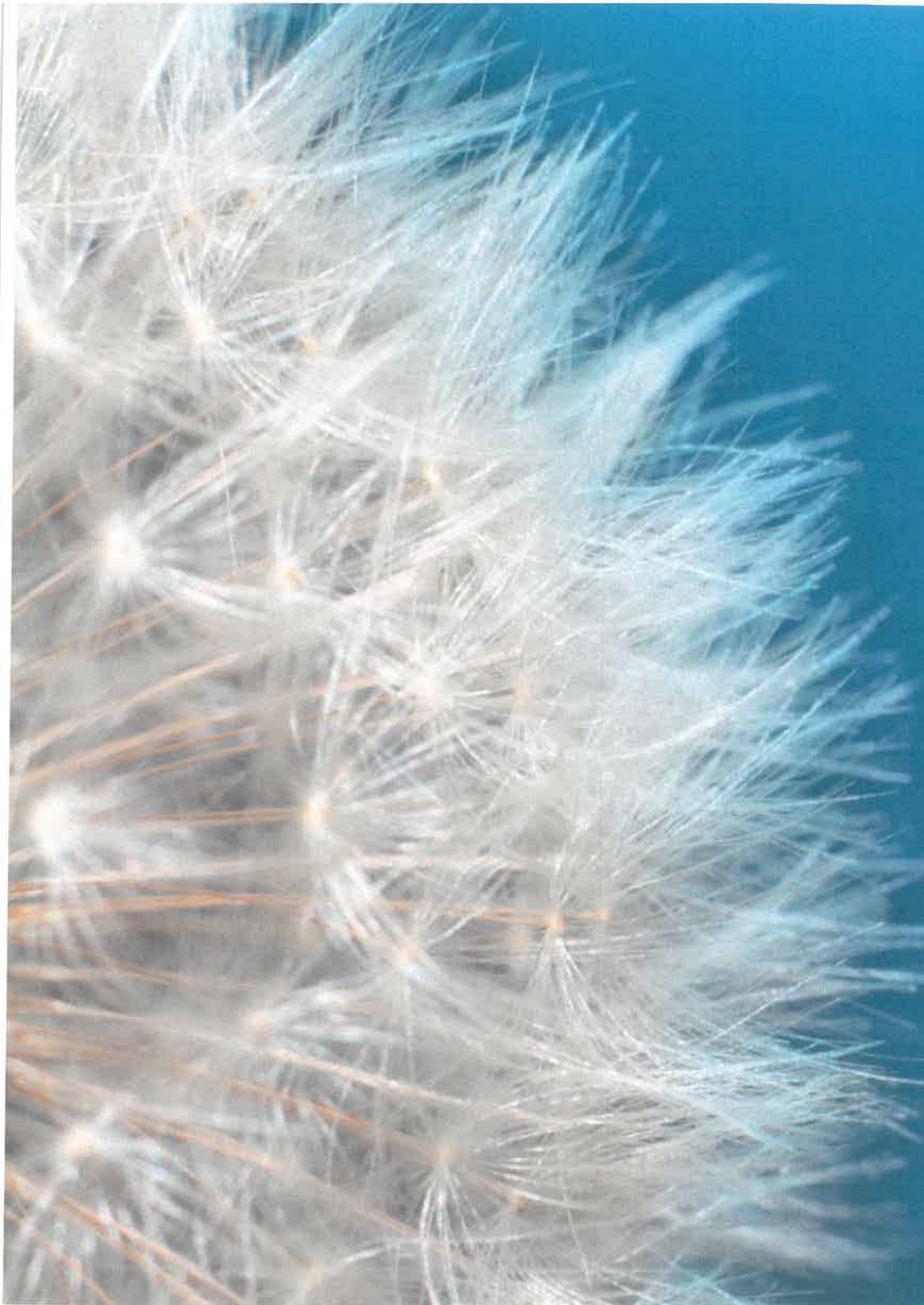
"On Friday night Julian and I went to a meeting in a local village hall to give a presentation on our experiences of having turbines as neighbours. The developers were there also. To our horror and absolute amazement, one of the directors of the company proposing the development said that it couldn't be true that the noise from the turbines was louder at our home 930m away from the turbines than it was 100m away or underneath them. *And she laughed at us* [emphasis added].

"It is so worrying when someone purporting to be a chartered engineer with 15 years experience of building wind farms, has absolutely no understanding of how large, moving structures (330+ feet high) create sound waves, and how those waves propagate. As at the Wind Turbine Noise 2009 Conference [we attended] in Aalborg, Denmark, June 17-19, 2009, we found that many (not all) who spoke had no experience of wind turbine noise in the raw, real world. No experience of the swish, the whoomph, the roar, the ever present hum, the lash, the grinding—none at all—and yet they purport to be able to predict what "noise" the nearest receptors (that's "homes" to you and me) will suffer from.

"They do not understand and seemingly do not care, either!"

—Jane Davis, Lincolnshire, England, 7/5/09. (Listen to Jane's account, "We've Now Abandoned Our Home.")

And your government, dear reader, lets the wind industry get away with all this. (Yes, Alice, you are now in Windfarmland.)



I am a physician and scientist; my expertise lies in clinical and environmental matters. Whether or not wind proves to be a viable source of power, it is absolutely essential that windmills not be sited any closer than 1.25 miles (2 km) from people's homes or anywhere else people regularly congregate. (Highways are also a problem for motorists with seizure and migraine disorders and motion sensitivity, from the huge spinning blades and landscape-sweeping shadow flicker.)

I consider a 1.25 mile set-back a minimum figure. In hilly or mountainous topographies, where valleys act as natural channels for noise, this 1.25 mile set-back should be extended anywhere from 2-3 miles from homes.

Let me be clear. There is nothing, absolutely nothing, in the wind energy proposition that says windmills must be sited next door to people's homes. Siting, after all, is the crux of the issue.

Irresponsible siting is what most of the uproar is about. Corporate economics favors building wind turbines in people's backyards; sound clinical medicine, however, does not.

Nina Pierpont, MD, PhD
Fellow of the American Academy of Pediatrics

References

1 Dr. Black's clinical resumé:

F. Owen Black MD FACS

Senior Scientist
Director of Neurotology Research
Telephone: 503-233-6068 (Clinic); 503-413-5332 (Research)

Dr. Owen Black is the Director of Neurotology Research for Legacy. An internationally known neurotologist and human vestibular physiologist, he received his MD degree from the University of Missouri in 1963. After completing a residency in otolaryngology at the University of Colorado and an NIH-sponsored fellowship in otology, he served as a combat surgeon in Vietnam with the US Navy.

Dr. Black completed his research training in 1974 through the assistance of an NIH Research Career Development Award, and held appointments at the University of Florida and University of Pittsburgh before joining the Robert S. Dow Neurological Sciences Institute in Portland in 1982. He established his lab with Legacy in 1997. Dr. Black has received continuous funding from the NIH and NASA for his research for over twenty years. In addition to his research pursuits, Dr. Black has an active clinical practice at Balance and Hearing Northwest.

Research Interests

Dr. Black's research focuses on disorders of the human vestibular system and the effects of microgravity on human postural control, with a major emphasis on the role played by otolith function. His recent studies are centered on determining how trauma, disease and certain drugs adversely affect vestibular function, and in quantitatively assessing the consequences of vestibular placticity. A component of his work is investigating how visual cues the brain receives from the eyes work with the inner ear to help control balance.

His NASA-funded research involves the impact that the zero gravity of space has on astronaut balance control. Weightlessness adversely affects how the brain interprets information received from the inner ear, causing space motion sickness and difficulties in regaining a sense of balance once returning to Earth. He regularly travels to the JohnsonSpace Center in Houston and the Kennedy Space Center in Florida to meet with his NASA collaborators, and serves on the medical advisory team for the space shuttle program.

These studies are leading to a further understanding of the human vestibular system and its role in spatial orientation, equilibrium, balance, and debilitating disorders such as motion sickness that will lead to new diagnostic and therapeutic methods.

2 Part I, Article 1 of the **Convention against Torture and Other Cruel, Inhuman or Degrading Treatment or Punishment:** *"For the purposes of this Convention, torture means any act by which severe pain or suffering, whether physical or mental, is intentionally inflicted on a person … for any reason based on discrimination of any kind, when such pain or suffering is inflicted by or at the instigation of or with the consent or acquiescence of a public official or other person acting in an official capacity." And Article 16: "Each State Party shall undertake to prevent in any territory under its jurisdiction other acts of cruel, inhuman or degrading treatment or punishment which do not amount to torture as defined in Article 1, when such acts are committed by or at the instigation of or with the consent or acquiescence of a public official or other person acting in an official capacity. In particular, the obligations contained in articles 10, 11, 12 and 13 shall apply with the substitution for references to torture or references to other forms of cruel, inhuman or degrading treatment or punishment."*

Setback Recommendations Per Various Studies

Name of Study	Date of Study	Author(s)	Link to Study	Author's Advised Setbacks	Notes
Wind Turbine Syndrome: A report on a natural experiment	2009	Dr. Nina Pierpont	N/A, PDF provided	Setbacks from residences should be a minimum of 2 kilometers or 1.24 miles, but 2-3 miles in hilly terrain	PDF provided to Planning Commission and BoCC
Your Guide to Wind Turboine Syndrome...a road map to a complicated subject	July 2010	Calvin Luther Martin, Phd	N/A, PDF provided	Setbacks from residences should be a minimum of 2 kilometers or 1.24 miles, but 2-3 miles in hilly terrain	This is a summary of Dr. Pierpont's book PDF provided to Planning Commission and BoCC
Health Effects of Wind Turbines: Testimony of Ben Johnson versus MidAmerican Energy (Madison County, Iowa) / Hearing before the Madison County Board of Health	August 2019	Dr. Ben Johnson, M.D.	https://www.masterresource.org/wind-turbine-noise-issues/health-effects-of-wind-turbines-testimony-of-ben-johnson-versus-mid-american-energy-project-in-madison-country-iowa/	No recommendation given for a specific distance in this hearing. Afterwards the Madison County Board of Health passed a resolution recommending that any future turbines be built at least 1.5 miles from non-participating homes	PDF provided to Planning Commission and BoCC
Wind Turbine Noise and Human Health: A Four-Decade History of Evidence that Wind Turbines Pose Risks	Ocober 2016	Professor Jerry L Punch and Professor Richard R James	https://hearinghealthmatters.org/wp-content/uploads/2023/03/16-10-21-Wind-Turbine-Noise-Post-Publication-Manuscript-HHTM-Punch-James.pdf	Setbacks from residences are recommended at 1/2 mile to 2.5 miles, 1.25 miles is most favored by scientists.	PDF provided to Planning Commission and BoCC
Infrasound from technical installations: Scientific basis for an assessment of health risks	July 2021	Dr. Werner Roos and Dr. Christian Vahl	https://www-asu--arbeitsmedizin-com.translate.goog/wissenschaft/wissenschaftliche-grundlagen-fuer-eine-bewertung-gesundheitlicher-risiken-infraschall?_x_tr_sl=de&_x_tr_tl=en&_x_tr_hl=en&_x_tr_pto=wapp	Minimum setback from residences should be 10 X turbine height as in Bavaria Germany	PDF provided to Planning Commission and BoCC
Assessing Adverse Health Effects-(Confirmed and Potential) from Industrial Wind Turbine Noise Emissions / Power point slides of presentation before the Kansas State Legislature	2022	Dr. Ben Johnson, M.D.	https://www.kslegislature.gov/li_2022/b2021_22/committees/ctte_s_utils_1/documents/testimony/20220207_01.pdf	Setbacks of 1.25 miles from residences	PDF provided to Planning Commission and BoCC
Presentation before the Kansas Senate and Utilities Committee: Effects of Wind Turbine Noise on Human Health	2022	Prof Jerry L Punch	https://www.kslegislature.gov/li_2022/b2021_22/committees/ctte_s_utils_1/documents/testimony/20220208_02.pdf	Setbacks of 1.25 miles from property lines (specifically) should be considered	PDF provided to Planning Commission and BoCC
Wind Turbines: Vacated/abandoned homes - Exploring participants' descriptions of their personal views, effects on safety, security, trust and social justice	Dec 2023	Carmen Marie Krogh, Robert Y McMurty, W Ben Johson, Jerry L Punch, Anne Dumbrille, Mariana Alves-Pereira, Debra Hughes, Linda Rogers, Robert W Rand, Lorrie Gillis	https://journals.lww.com/endi/fulltext/2023/08040/wind_turbines__vacated_abandoned_homes___exploring.2.aspx	Residents living within 10 kilometers/6.21 miles of industrial wind turbines were documented having Adverse Health Effects	See page 96 for the conclusion of the study regarding setbacks. PDF provided to Planning Commission and BoCC.
A fundamental basis for all living creatures, mechanotransduction, is significantly endangered by periodic exposure to impulsive infrasound and vibration from technical emitters - in particular cardiovascular and embryological functions	June 2025	Dr. Ursula Bellut-Staeck	https://www.scirea.org/journal/PaperInformation?PaperID=12440	Setbacks of 10 kilometers / 6.21 miles from people and animals	NOTE: The link shows the abstract and allows you to download the PDF PDF provided to Planning Commission and BoCC
Separating Myth from Fact on Wind Turbine Noise	October 2025	Prof Ken Mattsson	https://www.youtube.com/watch?v=nDwsd32SDEY	Setbacks of at least 5 to 10 kilometers (3.1 to 6.2 miles) from residences	Transcript PDF provided to Planning Commission and BoCC
Efficient finite difference modeling of infrasound propagation in realistic 3D domains: Validation with wind turbine measurements	Feb 2026	Ken Mattsson, Gustav Eriksson, Leif Persson, Jose Chilo, Kourosh Tatar	https://www.sciencedirect.com/science/article/pii/S0003682X25006280?ref=pdf_download&fr=RR-2&rr=9a872537bf69df1b	No specific distance given, see notes for conclusion of study	Conclusion of study page 14: This study also shows that modern, large-scale wind turbines generate infrasound levels substantially higher than those reported for older, smaller turbines / PDF provided to Planning Comm & BoCC

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Summary of an articled entitled **"Health Effects of Wind Turbines: Testimony of Ben Johnson versus MidAmerican Energy (Madison County, Iowa)"** from the August 2019 issue of Master Resource

(Compiled by Tom Thompson Dec 2025)

The article presents the testimony of Ben Johnson, a cardiologist who spoke before the Board of Health in Madison County, Iowa, warning of potential health harms from nearby industrial wind turbines operated by MidAmerican Energy. Johnson and others report a range of complaints — heart palpitations, ringing ears, dizziness, nausea, sleep disruption, and other symptoms — among residents living near turbines.

Johnson's main concerns center on noise, especially low-frequency noise and infrasound (below about 160 Hz, even less than 20 Hz), which turbines emit. He argues that conventional "A-weighted" sound measurements used by developers fail to capture these frequencies, yet these low-frequency sounds can still be sensed and may provoke strong physiological reactions.

He links chronic noise exposure — including intermittent "pulsating" turbine noise and associated sleep disturbance — to long-term stress on the body's autonomic and endocrine systems. According to Johnson, repeated sleep disruption may lead to elevated sympathetic activity, insulin resistance, hypertension, atherosclerosis, and increased risk of cardiovascular disease, stroke, or arrhythmia.

Johnson also raises broader psychological, social, and cognitive concerns: that persistent annoyance or distress from noise and visual intrusion can degrade mental well-being and social functioning, and that chronic noise exposure has been associated in other studies with impaired concentration, memory, and children's academic performance.

Finally, while Johnson does not claim the existing research definitively "proves" wind turbines cause disease, he argues that there is already "an enormous amount of scientific data" pointing to plausible causal links between turbine noise and health harms. He criticizes proponents' reliance on industry-funded consultants, calls for precautionary and suggests that more rigorous long-term studies are needed—studies that, in his view, have not yet been done.

NOTE: After the presentation at some point, the Madison County (Iowa) Board of Health passed a resolution recommending a 1.5-mile minimum distance from residences for future turbines.

Health Effects of Wind Turbines: Testimony of Ben Johnson versus MidAmerican Energy (Madison County, Iowa)

MR masterresource.org/wind-turbine-noise-issues/health-effects-of-wind-turbines-testimony-of-ben-johnson-versus-mid-american-energy-project-in-madison-country-iowa

August 23, 2019

By Sherri Lange -- August 23, 2019

> "The annoyance of sight and the heard pulsating wind turbulence creates indirect adverse health effects. This combined with the direct effects of sleep disturbance may activate the body's autonomic nervous system to increase sympathetic-mediated responses with endocrinological consequences."
>
> "Increasingly activated, risk factors that promote adverse cardiovascular consequences may then promote/facilitate/enhance cardiovascular disease – most easily named as hypertension, arteriosclerosis, ischemic heart disease and stroke."
>
> – Ben Johnson, Testimony before the Madison County Board of Health, Madison Country, Iowa.

Individuals and communities are collectively reporting the same NOCEBO effects, heart palpitations, ringing in the ears, dizziness, nausea, disorientation, sleep disorders, and other disorders from nearby industrial wind. There is no global conspiracy, there is only a mountain of data (data is when you have enough anecdotes) contradicting the narrative that such wind power is clean, safe and free.

Pro-developer witnesses lined up recently at the Iowa Madison County Board of Health's hearing into wind turbines and health, led by the Iowa Policy Project and the Iowa Environmental Council. Their nine-page, "Wind Turbines and Health" referenced Fiona Crighton (nocebo effect), and Dr. Robert J. McCunney (known for his voluminous rapid-fire testimonies on behalf of wind companies). Their thesis: *if you are being reimbursed by the wind turbine company, or hosting, you are much less likely to experience health impacts.*

McCunney's critical review of 2014, states that he received funding from the Canadian Wind Energy Association but that it was all nicely arm's length and editorially free of any conflict-of-interest. Other dubious references inside the Iowa Policy Project-sponsored report attempt to validate findings by the Canadian Council of Academies, the book end review of wind turbine impacts to the Health Canada bogus study. Some have called these reference materials, studies, reviews, disingenuous, even fraudulent.

These "findings" by conflicted persons, reporting for government agencies and directly for developers and CanWEA or AWEA, find their way through the cooperating, often unknowing persons, in policy and permitting systems: in this instance, the Madison County Board of Health hearings.

Dr. Ben Johnson, Cardiologist, IOWA

Enter Iowa Cardiologist Dr. Ben Johnson, testifying *pro bono* on the meticulous research behind the "guidelines" recently provided by the World Health Organization (WHO).

WHO advocates a political and moral standard that encourages the burden of proof to fall upon those advocating for a possible challenge to impacts to health. The burden of proof has never rested with the industry: it has fallen on the victims of wind, and their advocates, to prove and test on their own homes, document health impacts for themselves, livestock, pets, and wildlife. Despite the magnitude of the complaints, the similarity, and the universal nature of the harm, the industry continues to provide "experts," paid consultants whose shabby appearance of scientific endeavor continue to insult not only victims, but also the real science, and true advocates who provide clarity and conscience.

The Board of Health of Madison County, Iowa passed a resolution last week recommending a 1.5-mile setback to protect residences from wind turbine nuisances and harms.

The following excerpts from Dr. Johnson's testimonies (three) relied on his expertise and study of Adverse Health Effects (AHE) based on his specialty, Cardiology. His CV is about electrophysiology – pacing and defibrillator technology, clinical trials, failed implantable lead technology and developing (with industry) new technologies- -particularly optimizing implantable devices to improve heart performance.)

Dr. Johnson provides the following conclusions to MasterResource.

Industrial Wind Turbines and Adverse Health Effects:

High Level Summary of the Issues:

1) Health – defined (WHO – 2001)

Health should be regarded as a "state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity." Note that this would include not only serious health disease — cardiovascular disease, hypertension, insulin-resistance — but also most of the described consequences of wind-turbine annoyance that affect mental and social well-being and contribute to physical debilities.

2) Annoyance: By itself, is considered as having adverse health effects

Noise is the principle impactor, but visually mediated and psychological adverse reactions are frequent causing health impacts to people living in the vicinity of wind turbines.

Cognitive effects are also associated with noise exposure. These include reading, concentration, memory and attention issues. Chronic noise exposure impairs cognitive function (reading comprehension and long-term memory) and a dose-response relationship between the two is supported by both laboratory and field studies. Over 20 studies have reported that noise adversely effects children's academic performance.

3) Concept of Noise and Sleep Disturbance

Noise pollution in our towns and cities in increasing. More than a nuisance, excessive noise is a health risk. As stated in the WHO 2018 guidelines, "noise is unpleasant and effects the quality of life." It disturbs and interferes with activities of the individual, including concentration, communication, relaxation and sleep.

Besides the psycho-social effects of community noise, there is concern about the impact of noise on public health, particularly regarding cardiovascular outcomes. The auditory system is **continuously** analyzing acoustic information, which is filtered and interpreted by different cortical and sub-cortical brain structures.

Arousal of the autonomic nervous system and the endocrine system is associated with repeated temporal changes in biological responses. In the long run, chronic noise stress may affect the homeostasis of the organism due to dysregulation, incomplete adaptation and/or the physiological costs of the adaptation. Noise is considered a nonspecific stressor that may cause adverse health effects in the long run. Such noise may be associated with disordered sleep.

Serious scientific studies of human sleep only began about 50 years ago. According to the restorative theory of sleep, body tissues heal and regenerate during non-REM sleep — particularly stages 3 and 4 associated with predominately slow-wave activity. Brain tissue "heals" during REM sleep and memories of the prior day's events becomes more "permanent". Interruption of the mostly ordered transitioning between/to deeper stage sleep by noise can occur with awakenings (>15 secs – associated with subsequent recollection) or with arousals (<15 seconds that may be repetitive and not acknowledged by affected sleeper).

Such recurrent sleep disruptions lead to non-restorative sleep with subsequent activation of the autonomic nervous system. More-heightened sympathetic activation triggers multiple downstream physiologic consequences — hypertension, insulin resistance and complex atherosclerotic vascular disease which may promote plaque build-up and increase potential consequences of fatal and non-fatal heart attacks, angina, stroke and heart arrhythmias.

Indeed, there has been a surge in the incidence of atrial fibrillation (AF) — a fast, chaotic atrial arrhythmia. AF is very frequently associated with obstructive sleep apnea which triggers sleep arousals (among a myriad of other consequences) that lead to non-restorative sleep. Untreated patients with sleep apnea commonly have hypertension, various degrees of insulin resistance and a higher incidence of vascular disease. It is truly remarkable how patients may deny any "trouble sleeping" but suffer from severe sleep apnea that may be amenable to treatment. Treatment in an affected population leads both to less AF and is associated with a decrease the prevalence of associated cardiovascular disease.

Sleep disturbance is reported for those who **report hearing** wind turbine sound. IMPORTANTLY, there are other disease states where disrupted sleep is triggered by non-awakening "arousals" (e.g. due to apneic/brief hypoxic events associated with obstructive sleep apnea). Similarly, there are recent pilot studies and now ongoing research measuring the observed physiologic changes of accurately reconstructed sound emissions (frequency and loudness) produced during formal sleep studies. **The pilot studies suggest that the unique properties of wind noise do adversely affect some aspects of normal sleep architecture.** *(Our emphasis)*

4) Infrasound and Low Frequency Noise (ILFN)

It has been established for nearly 35 years, that industrial turbines emit infrasound (<20 Hz) and low-frequency noise (<160 Hz). Analyzed frequency and sound pressure characteristics of industrial wind turbines emission has shown the emitted sound content (noise) to have these frequencies.

Wind turbine noise is complex, highly variable and has unique characteristics. The amount and type of sound emitted by a wind farm at a given time and in a given location is influenced by many variables including topography, temperature , wind speed, turbine design, the extent to which they are maintained, the number of turbines and their mode of operation.

It has also been established via multiple means of evaluation that the brain can "sense" infrasound as a tonal frequency transitions to a perceptible vibratory quality as the sound frequency lessens. Generally 35-40 dB are described as being needed to "sense/hear" those low frequency noises. Interestingly, ILFN "loudness" may be greater indoors than outdoors at the same location and can cause a building to vibrate resulting in resonance.

A significant proportion of the sound emitted by wind turbines is in the lower frequency range, i.e., below 20 Hz. Humans are more sensitive to low frequency noise, and it can therefore cause greater annoyance than higher frequency sound. The dB(A) weighting (filtering) system is not designed to measure these lower frequency sounds and is not an appropriate way of measuring it. The best way to assess ILFN is to through "raw" unweighted measurements which are not averaged across time and then subjected to detailed "narrow-band" analysis.

5) Evolving Quantification of Societal Impact of Noise Emission

With the published October, 2018 WHO statement, **DALYs** (Disability-Adjusted Life-Years — which is the sum of years of life lost due to ill-health, disability or early death) have been calculated. One DALY is equivalent to one year of health life lost.

Given measured sound exposures and their exposures to inhabitants in European Union cities, the WHO estimates that 1-1.6 million health life years are lost from traffic noise. Sleep disturbance and annoyance related to traffic noise comprise the main burden (903,000 DALYs for sleep disturbance; 654,000 DALYs for annoyance; 61,000 for ischemic heart disease and 45,000 for cognitive impairment). *Clear sleep disturbance is the largest mechanism of harm due to environmental noise.*

Rural Iowa does not have significant "background traffic, aviation or train sound emissions," but could have significant ongoing turbine sound emissions which (although not quantified yet) could, being another environmental noise, reach the impacts like those DALY consequences noted above.

Relatively fewer people are exposed to industrial-size wind turbines, but those individuals would still be experiencing sound emissions with potentially adverse health effects. Unfortunately, the consequences would be greater for the more vulnerable parts of society — the young and elderly.

6) Why don't we know **for sure r**egarding the health impacts?

Wind Energy has never proven that exposure to industrial wind turbines is safe.

The 2018 WHO statement, for the first time, listed industrial wind turbines as a source of environmental noise and carefully weighed the available data. There were no studies at the time of statement publication to assess the incidence of ischemic heart disease, nor hypertension among other endpoints.... the studies simply had not been done with those studies being quite complex to perform. Indeed, in section 3.4 of the 2018 WHO statement, evidence quality was specifically written as "no studies were available" acknowledging that there was no available data (yet) to confirm an association of sound to adverse cardiovascular outcomes.

The WHO's turbine noise "conditional" rating of "strength of recommendation" for implementing guidelines reflects a policy-making process with substantial debate and involvement of various stakeholders. Recommendations are rated as either strong or conditional.

In accordance with the prioritization process, the GDG (Guidelines Development Group), set a guideline exposure level of 45 dB L(day-evening-night) average reflective of analysis of an exposure-response curve of four available studies from "highly annoyed populations" showing significant higher adverse health risks above 45 dB.

They felt unable to specify a lower night sound emissions level (during sleep — where sleep disruption is more critical). *This omission has been widely criticized by anti-wind factions. Indoor/open-window nighttime sleeping sound levels are best at <33 dB) (Our emphasis)*

Another health concern from turbines is the potential harm from radio/electromagnetic exposure emitted by the turbines. This is debated globally. Authors who have voiced their concern of health safety over this have recommended that governmental regulators advise the public of potential risks of exposure and establish limits that incorporate all sources of radio/electromagnetic energy, including wind turbines. They further state: "Until these limits are established, governments should take precautionary and proactive measure to protect public health..."

Similarly, the public and landowners placed at direct and immediate risk of catastrophic turbine failure, have not been provided with recommended radius safety-zone dimensions specific to the Vestas, Model 1100 — which is the turbine model proposed for Madison County.

Despite repeated requests, this critical safety information remains unknown, even in public hearings when MAE (MidAmerican Energy) and Madison County officials who are responsible for public safety are directly questioned. This is relevant in that the last (smaller) model of IWTs (Industrial Wind Turbines) did have guidelines published.

Concerningly, there may be future replacement of existing MAE turbines with larger, more powerful models (on the fixed, existing pedestals). Reportedly, that possibility of up-sizing turbine capacity is reflected in recent Adair County planning minutes for the turbines placed there. Such larger turbines would likely increase the strength of the emissions and, with that, increase the endpoints of incidence and prevalence of turbine-related adverse health effects.

7) At the second of three Madison County public hearing on the variance request by MAE, comments made by the MAE engineers/representatives included that :

1) they "never" assess sound by means other than A-weighting analysis. Because humans cannot hear sounds <20 Hz.

2) they "never" measure any sounds from within the house – "only to the front door"

3) Sound intensities (pressures) from the proposed turbine sites are "calculated." Only upon recurrent resident requests, will they come to acquire actual sound measurements.

4) They commented that the WHO publications on environmental noise were "getting crazy"

Their industry-paid consultant neurologist/sleep specialist from Boston also spoke at a BOA (Board of Adjustment) meeting, noting:

1) symptoms of annoyance (depression, hopelessness, nausea, vertigo, etc.) could not be associated with the presence of the turbines alone but likely reflect a non-associated separate medical problem

2) he felt it was impossible that ILFN would travel that far from the turbine to actually cause sleep disruption.

All those points are rejected in the most current medical literature. And these points have been included/itemized in successful legal judgements against Wind Energy defendants when reviewing adverse health effects to affected residents.

8) Indeed, data is accumulating about the pivotal but insidious connection of environmental noise causing sleep disturbance and cardiovascular disease.

(These studies are included on page #4 of summarizing information I provided to The Madison County Board of Health). In a more detailed description of the impact of environmental sound, Dr. Dominguez noted a "graded response" of objectively measure vascular disease and quantity and quality of sleep. Extensive multivariate analysis was performed to adjust for a wide range of confounding variables. The presenter noted that the more average times an individual awoke per night, the greater number of vascular plaques were documented. Dr. Fountas did a meta-analysis review of 11 prospective studies correlating self-reported daily sleep duration and cardiovascular morbidity and mortality of over one-million patients without clinical baseline cardiovascular disease that were followed an average of 9.3 years. Those sleeping <6 hrs or >8 hrs had a higher risk of fatal or non-fatal cardiovascular disease compared to those sleeping 6-8 hours which is considered a normal amount to achieve restorative sleep. Longer sleep duration was felt by the authors to possibly reflect morning exhaustion prompting additional sleep hours to "catch-up".

With that idea of "sleep catch-up," notable is a *Journal of the American Medical Association* article published about a month ago that suggested that those who attempted "sleep catch-up" on the weekend actually may have even worse outcomes than those who just resume a "normal" sleep pattern. This was measured by tests of insulin resistance that most directly varies with adrenalin responses to stress. (That article was given to the Madison County Board of Health at their most recent every two-month meeting). Elevated serum insulin levels due to adrenergically-driven insulin resistance is felt to be one of the consequences of sleep disturbance.

9) Recognizing that complete data is lacking to definitely link industrial wind turbines with adverse health, I cite Wind Energy's apparently sponsored University of Iowa expert panel of the scientific evidence regarding various complaints (which) led to several conclusions (Wind Turbines and Health, Thorne, Osterberg, Johannsen):

1) The current evidence is **sufficient** to establish a causal relationship between a person's exposure to wind turbine noise and feelings of annoyance.

2) The current evidence is **limited** for a causal relationship between exposure to wind turbine noise and sleep disturbance. The panel defined "limited" of a causal relationship **as plausible**, but that chance, bias and confounding factors could not be ruled out with reasonable confidence. This is in keeping with the WHO stance noted above.

I would ask you, why would you erect a very expensive, contentious (highly to some), greater than 500 foot high tower– with large moving blades without a stated safety radius by the manufacturer, that reportedly will operate for nearly 40 years *(Editor's Note: turbines rarely survive the stated working life of 20 years, and begin to degrade and require repairs and experience serious lost performance between twelve years and fifteen years)* and that has never been proven to safe nor free of adverse health effects, that **possibly (it is plausible)** will cause sleep disturbance and that will likely contribute to some degree of future cardiovascular disease in the nearby affected citizens who had very little to say about it? This when other technologies are available with essentially no health risk (photovoltaic)?

Finally, recognizing someone who has spent his entire professional career reviewing evidence that Wind Turbines Pose Risks, Jerry Punch, Professor emeritus from Michigan State University who recently wrote a peer-reviewed 72-page article that addressed each of two wind energy claims and positions stated the following:

> the available literature, which includes research reported by scientists and other reputable professionals in peer-reviewed journals, government documents, print and web-based media and in scientific and professional papers presented at society meetings, is sufficient to establish a general causal link between a variety of commonly observed adverse health effects and noise emitted by industrial wind turbines.

Returning to the 2001 WHO statement in the first paragraph above defining health, "health" is viewed as beyond an absence of acquired physical disease, it also includes mental and social wellness. The mere presence of these huge turbines placed, as proposed, in close proximity to our county residence creates lasting annoyance in at least 20% of those exposed at the proposed siting distances.

Hopefully you are aware of the social outcry of your county against the intrusion of these unwanted disturbances. The annoyance of sight and the heard pulsating wind turbulence creates indirect adverse health effects. This combined with the direct effects of sleep disturbance may activate the body's autonomic nervous system to increase sympathetic-mediated responses with endocrinological consequences.

Increasingly activated, risk factors that promote adverse cardiovascular consequences may then promote/facilitate/enhance cardiovascular disease – most easily named as hypertension, arteriosclerosis, ischemic heart disease and stroke.

Importantly:

1) Does this **prove** that "wind turbines" cause disease? — **NO**

2) Has Wind Energy ever shown that wind turbines are safe and free of adverse health effects? **Absolutely Not**

3) There is an enormous amount of scientific data to suggest that wind turbines may **possibly** cause adverse health effects. As noted above, the U of I paper likely paid for by the Wind Energy faction **AGREES that there is a plausible causal relationship between exposure to wind turbine noise and sleep disturbance.**

The scientific data is rapidly accumulating and getting us closer to absolute confidence that wind turbines "cause disease." It will be an association, like all disease prevalence, that is statistical… the large numbers needed to prove a correlation that are adjusted for confounding variables in exposed populations with highly predictive statistical significance, are hard to obtain…. but the data is coming.

Wind Energy could do the research needed by exposing monitored residence living various distances from the wind turbines in large enough numbers to meet anticipated statistical significance. All disease-markers/endpoints variables would be catalogued and measured consistently over at least 20 years. All these "test (treated) groups" would be compared with matched control groups without wind turbine exposure and monitored for the same disease process in the same method as the actively "treated" groups. This study would require a supervising Investigative Review Board to protect the test subjects. It would require informed consent from the study participants. Having been a Chairman for the Des Moines Area Investigative Review Board where conducted human research proposals are reviewed, approved and monitored, I seriously doubt that such a study could be done. This is because the health consequences are not completely known, but what is known is adverse in nature (thus making informed consent not possible) and the participants may not derive potential benefit from the study (the EXACT situation for the Madison County residents who would be forced to live with turbine presence) among many other considerations.

Such a pattern of increasing possibility/likelihood and linked causality in our scientific, world-wide evaluations of potential adverse health effects from wind turbine noise and annoyance is impressive. The Oct 2018 WHO report reflects that opening of scientific understanding and the evolving clarification of that risks. The lack of respect for this data by Wind Energy is equally impressive.

I ask you to speak for your neighbors, your family, your community, and for the impacts of Wind Energy will have in future generations, and to those who look to you in your elected position of leadership. Protect the citizens of Madison County against

the possibly harmful effects of Wind Energy development as currently proposed by Mid-American Energy. (*Bold is the author's emphasis)*

Respectfully, W. Ben Johnson, M.D. Cardiologist/Electrophysiologist, Des Moines, Iowa

***Update: WINTERSET, Iowa** —The Madison County Board of Health says there is the potential that wind turbines could be bad for your health. The board passed a resolution recommending that any future turbines be built at least a mile and a half from non-participating homes.*

21 Comments

1. SegueC • August 23, 2019 at 3:00 pm

   The dedication of the good Doctors on the right side of history in the fight to preserve the health and safety of rural residents afflicted by wind industry torture restores faith in humanity. Their courage is also admirable.

   Reply

2. steven cooper • August 23, 2019 at 4:15 pm

   Examination of the Crichton material will find that the test signal was NOT the infrasound signal that is commonly attributed to wind trubines. The signal was not one of pulsations and was a single tone (5 Hz in one experiment and 9 Hz in another).
   Hence the title of the paper is incorrect as the testing was not of wind turbine infrasound.
   Hence the concept of Nocebo as presented by Crichton becomes questionable.
   I have spent years investigating the actual acoustic signature of wind turbines and as a memeber of the Acoustical Society of America's Wind Turbine Working Group have presented multiple papers as to the techical aspects of the acoustic signature.
   Because of the short time span of the puslations it is questionable if there is actually infrasound in the sense of a tone.
   Pulsations that occur at rate less than 10Hz were defined by Zwicker and Fastl as "fluctuations". Fluctuations are sensed by the body – not heard.
   Persons sensitised to wind turbine noise can identify in the laboratory the prescence of the test signal even when they cannot hear it (see paper to ASA in New Orleans in Dec 2017).
   New material in relation to the Crichton "Nocebo" is to be presented in two weeks at the 2019 Internaltional Congress on Acoustics in Germany.

   Reply

3. Sherri Lange • August 23, 2019 at 4:21 pm

Thank you, Segue. This meaningful comment reminds me of the other doctors, medical personnel, researchers, of the mindset to tell the truth, and explore wind lies as well. Some are listed in the WHO letter to the (World Health Organization), and the list of Quebec physicians, writing for a moratorium, and also the French Academy of Medicine, similarly declaring wind turbines a "nuisance," asking for a full stop.

https://www.windturbinesyndrome.com/2011/40-doctors-sign-wind-turbine-syndrome-petition-quebec/

Add Dr Ben Johnson, who took likely hundreds of hours to research and present not once, but three times, to his local Board of Health, Madison County.

A substantial list of deniers, mercifully now discredited, can be found on the Waubra Website, 2014. More can be added, certainly. But the accruing numbers of physicians, experts, now in the hundreds and multiples of hundreds, show us that right will stand up to might.

Dr Hallstein, of Falmouth, MASS, is quoted by Waubra:

"There is extensive clinical experience and a body of peer reviewed research evidence, which supports clinical concerns about the adverse health consequences of both chronic sleep deprivation, and chronic stress, regardless of the specific cause of that sleep deprivation or stress. 54,55,56,57 Dr William Hallstein, a psychiatrist from Falmouth, USA stated the following in a recent letter to the Falmouth Board of Health 58:

"In the world of medicine illnesses of all varieties are destabilized by fatigue secondary to inadequate sleep. Diabetic blood sugars become labile, cardiac rhythms become irregular, migraines erupt and increase in intensity, tissue healing is retarded, and so forth, across the entire field of physical medicine. Psychiatric problems intensify and people decompensate. Mood disorders become more extreme and psychotic disorders more severe."

"Those who are young and fit report taking longer to be adversely impacted by exposure to wind turbine noise, unless they have underlying physical and mental health conditions or acknowledged risk factors such as a history of migraines, inner ear pathology or motion sickness, which make them more vulnerable or susceptible."

Reply

4. Sherri Lange • August 23, 2019 at 4:27 pm

Thanks, Steven Cooper. We are all looking forward to receiving news of your upcoming presentations in Germany at the International Congress on Acoustics. I hope you will let us interview you again. Fiona Crichton also is of the fame that: wind turbine "syndrome" is a "communicated disease." Of course, that theory has gone down now with a solid "THUD" in the world of victims and experts.

Thank you again, very sincerely, for all you do, to expose a more meaningful Language and Understanding of the multi faceted pieces of wind turbine 'noise.'

Reply

5. Sommer • August 24, 2019 at 2:15 pm

Listening to the raw truth from people reporting harm from turbines, that are sited too close to their homes, and watching the deterioration of health has been a devastating experience. These people chose to live in the quiet countryside in 'deep silence' in order to optimize their mental and physical health. They chose to be close to nature for their well being. They did not consent to being harmed!
Cardiovascular related episodes, caused by surrounding turbines, when barometric pressure fluctuations and certain wind speeds occur, are downright traumatizing.
Anecdotal reports ought to be more than enough to cause ethical people to demand that these turbines be turned off.
And forced relocation is absolutely unacceptable. Anyone suggesting that people leave their homes is complicit in this crime.

Many medical people have not made the connections between people reporting well known psychological and physical symptoms of harm and the turbines in their communities. Instead these doctors are prescribing drugs to mask the symptoms. These drugs can have serious side effects and lead to iatrogenic disease.

This is a human rights violation and those who are being harmed should not have to endure further harm and stress trying to satisfy legal or scientific requirements to validate their harm. This is also a violation of the Nuremberg Code. Kurt Devlin was right about this!
The harm from LFN and infrasound, according to expert, Dr. Mariana Alves-Pereira, is both cumulative and irreversible. She has publicly declared that knowing what she knows about the harm, she would not live within 20 km from wind turbines!
Only those who have genocidal ideology toward rural residents, who are forced to live with these turbines, would insist on having people who are honestly reporting harm, waste vital time and energy proving it somehow.
Both the legal and scientific process to prove harm is within a 'rigged box' designed to delay… delay… delay. These delays have serious consequences.
The liability for those who are responsible for this harm, at a moral level, must be/will be fully realized.
People who acknowledge their birth right to act out of free will and follow their conscience understand this clearly.
True advocates for people being harmed act out of courage and a sense of urgency.

Reply

6. Sherri Lange • August 24, 2019 at 9:32 pm

Thank you, Pauli. And thank you for organizing with Professor Mann, the upcoming event at the University of Waterloo with Mariana Alves-Pereira. She is a brilliant communicator. I pray they will receive records and reports from their testing at homes and so on, if that is what they are agreeing to. I am sure Ms Alves-Pereira will respond appropriately and accept the challenge of the acoustic testing demands, which are complex and varied. As noted, this is a professor with vast knowledge of VAD (Vibro Acoustic Disease) and ILFN. Anyone lucky enough to hear of her studies and findings is very fortunate.

More and more, people are finding physicians like Dr. Ben Johnson, who are ringing the bell for honesty, and who are finding the tentative or very concrete relationships between sleep deprivation and chronic or advancing disease. We are very grateful for this kind of pro bono testimony. It is so purely driven, and offered with the intent of helping his IOWA Coalition, and more beyond that.

Reply

7. Falmouth 110 Db Wind Turbines For Sale Setbacks 1.5 Miles - admin • August 25, 2019 at 8:44 am

[…] https://www.masterresource.org/wind-turbine-noise-issues/health-effects-of-wind-turbines-testimony-o… […]

Reply

8. Michael Spencley • August 28, 2019 at 1:58 pm

The overwhelming and constantly mounting scientific and medical evidence linking industrial wind turbines to very serious (and sometimes catastrophic) health effects is well sampled in this article by the author, Lange.

Dr. Ben Johnson, a Cardiologist, from Iowa, has given testimony before the Madison County Board of Health, Madison Country, Iowa, in the form of a well-articulated treatise covering the known health dangers. The bravery of a medical specialist like Dr. Johnson, going on record without remuneration to sound the warning and an altruistic cry for protection and justice against the industrial wind turbine catastrophy is the stuff of "David and Goliath" and quite extraordinary. He is one of the well respected, independent and unpaid Cardiac experts that will surely face the wrath of the "Green Brigade" (those who try to bury the health problems caused by industrial wind turbines).

I applaud Dr. Johnson's initiative and I applaud Master Resource and Sherri Lange for continuing to document the evidence and call the wind lobby's farcical bluff.

Reply

9. Sherri Michael • August 28, 2019 at 2:13 pm

Many thanks, Michael Spencley. Praise is indeed due: important to note that likely every person on the pro side of the project testifying at the Board of Health, was remunerated. Not the witnesses against, nor of course Dr. Johnson.

I am very impressed with the wide scope of reading and study that Dr Johnson did in order to prepare. One needs to zig zag between the last 30 or so years, and then weight the evidence. It is overwhelming now. And the link to cardiac health, or not, is key to our understanding of basic survival and health. Many that we hear of, have family members who have suffered cardiac events since turbines have arrived in their community. Of course it is not all about the heart. It is also every organism and mechanism of health and life.

"The Golden West Wind Energy Center in Calhan, Colorado, which consists of 145 453-foot tall industrial wind turbines, has been fully operational since October 2015. Residents living within the wind farm project's footprint have reported negative physical and psychological effects from the turbines. Concern has now shifted to the suspected effects the turbines are having on the animals in the area.

According to the September 2015 issue of "The New Falcon Herald," the effects on humans range from dizziness and nausea to concerns about dirty electricity and the potential for the electromagnetic waves to cause an irregular heartbeat, or atrial fibrillation.

Domestic animals are in grave danger, too, based on worldwide accounts."

Thank you.

Reply

10. Sommer • August 28, 2019 at 4:42 pm

This event has been arranged by Professor Richard Mann at the University of Waterloo.

Speaker: Mariana Alves-Pereira
Title: Infrasound & Low Frequency Noise: Physics, Cells, Health and History
Date: Thursday September 12, 2019
Time: 1 pm
Location: University of Waterloo
Room: DC 1302 (Davis Center)

Speaker Bio:
Mariana Alves-Pereira holds a B.Sc. in Physics (State University of New York at Stony Brook), a M.Sc. in Biomedical Engineering (Drexel University) and a Ph.D. in Environmental Sciences (New University of Lisbon). She joined the multidisciplinary research team investigating the biological response to infrasound and low frequency noise in 1988, and has been the team's Assistant Coordinator since 1999. Recipient of three scientific awards, and author and co-author of over 50 scientific publications (including peer-reviewed and conference presentations), Dr. Alves-Pereira is currently Associate Professor at Lusófona University teaching Biophysics and Biomaterials in health science programs (nursing and radiology), as well as Physics and Hygiene in workplace safety & health programs. Mariana Alves-Pereira can be readily reached at: m.alvespereira@gmail.com.

Reply

11. Sherri Lange • August 31, 2019 at 2:13 pm

Thank you, Pauli Sommer. This is an important event and we hope that participants/attendees will include politicians who have been invited from the Ontario Legislature.

Reply

12. [Mark Twichell](#) • [September 8, 2019 at 11:45 am](#)

I'm so thankful for the testimony of Dr. Ben Johnson and its publication on this site. As usual the quality of comments here is outstanding. The contributions of Steven Cooper and Mariana Alves-Pereira will be further augmented by their presentations in Germany and Ontario respectively. On that note I wish to share announcement of a Wind Turbine Noise/Public Health Discussion co-sponsored by NYS Senator Robert Ortt and wind opposition group Save Ontario Shores. The event will feature presentations by audiologist Dr. Jerry Punch and acoustician Robert Rand. Additionally, environmental attorney Gary Abraham will speak about the intersection of wind turbine noise concerns and NY State wind turbine permitting policy. Negatively impacted wind turbine neighbors from across NY State will give brief statements of their experiences of adverse health effects. This panel discussion is the first of its kind in NY State. It is scheduled from 4 to 6 pm at Erie Community College North Campus, 6205 Main St., Williamsville, NY , Gleasner Hall Auditorium. Parking and admission are free.

Reply

13. Sherri Lange • September 24, 2019 at 9:33 am

Thank you, Mark. Dr. Mariana Alves-Pereira gave a wonderful, as usual, presentation. This is available for viewing on this link. She urged people who are impacted to leave their homes at least for respite trips, but also to consider long term exposures and how much they could manage it. Dose response seriously important.

Please also send us the link for the presentation in NY organized by Save Ontario Shores?

Talk:
https://uwaterloo.ca/computer-science/events/seminar-infrasound-and-low-frequency-noise-physics-cells

Webcast ("Live Stream"):
https://livestream.com/itmsstudio/events/8781285

Reply

14. LETTER FROM DR. MAARTEN BOKHOUT, ACTING MEDICAL OFFICER OF HEALTH, HURON PERTH, LETTER TO RESIDENT CARLA STACHURA: A shameful exhibit of carelessness, callousness, and/or negligence? | Great Lakes Wind Truth • September 24, 2019 at 10:26 am

[…] Please also note his reference to the newly minted cautions by the Madison County Board of Health. Clearly he has read the work of Dr. Ben Johnson, whose testimony certainly led to the Board's decision to request larger setbacks. See excerpt below, Dr Johnson quoted on Master Resource. […]

Reply

15. LETTER FROM DR. MAARTEN BOKHOUT, ACTING MEDICAL OFFICER OF HEALTH, HURON PERTH, TO RESIDENT CARLA STACHURA: A shameful exhibit of carelessness, callousness, and/or negligence? | Great Lakes Wind Truth • September 24, 2019 at 5:16 pm

[…] Please also note his reference to the newly minted cautions by the Madison County Board of Health. Clearly he has read the work of Dr. Ben Johnson, whose testimony certainly led to the Board's decision to request larger setbacks. See excerpt below, Dr Johnson quoted on Master Resource. […]

Reply

16. Sherri Lange • September 25, 2019 at 1:57 pm

https://www.kcci.com/article/madison-county-to-decide-on-wind-turbine-setbacks/29204876#

WINTERSET, Iowa —
Madison County Supervisors on Tuesday approved a second reading of a proposal to enforce wind turbine setbacks on solar energy projects.

The proposal will get at third and final reading in two weeks.

September 24, 2019

Reply

17. Wind Turbines in Court: What Are the Issues? - Master Resource • October 3, 2019 at 8:08 am

[…] given the general pushback in North America by communities, public health agencies such as Madison IOWA, declaring that wind turbines can cause harm, and arguing for larger setbacks. With Facebook and […]

Reply

18. noname • November 19, 2019 at 12:03 pm

The Madison County Board of Health says there is the potential that wind turbines could be bad for your health. The board passed a resolution recommending that any future turbines be built at least a mile and a half from non-participating homes.

Reply

19. Al Schafbuch • June 12, 2022 at 9:34 pm

There needs to be a moratorium on all wind turbines in the United States.

Restart coal and start approval of Safe Nuclear power plants.

Reply

20. Lonnie Appleby • March 21, 2024 at 5:05 pm

I'm still trying to figure out how wind turbines cause all of these issues, yet the hundreds of thousands (if not millions) of cars that pass along I-80 every year (which I can clearly hear from my current home and could from my childhood home…the sound used to lull me to sleep on hot, humid summer nights with the windows open) are not responsible for this also. We have had the Eisenhower Highway System in place for how many decades now? I know president Trump tried to make these a bogey man by claiming they make a noise that sounds like, "RRRRrrrr RRRrrrrrr." Having stood directly below one as the blades were whizzing past, I can attest that they made a "WHOOOOfffff WHOOOOffff" sound and nothing more that I could detect. If noise causes all of these issues, we had better stop construction of skyscrapers, because the noise generated from construction can be deafening when you walk directly past a site; and having worked in buildings next to a 35-story building going up, you hear the noise all day long. My ticker is still going strong. We all hear and believe what we want to hear and believe. I, however, speak from my own experience with constant traffic noise from I-80 in Newton from age 4 to day (that totals 51 years of nearly constant traffic noise…it did shut down for a major accident and some snow storms over the years) and from standing directly beneath a spinning turbine. I can only tell you what I know from personal experience…and I take studies and opinions with a shaker of salt these days. By the age of 55, I know to trust my own "lying ears and eyes."

Reply

rbradley • March 25, 2024 at 9:33 pm

Industrial wind turbines, first of all, are creatures of special government favor and wound the grid by their dilute, intermittent nature. They are an intrusion on nature from politics.

There is permanent noise and light flicker, and other nuisances are present. The neighboring home owners report a lot of negatives from the enormous structures. That is why a 'civil war' is going on at the grassroots from on-the-spot environmentalists.

Reply

Leave a Reply

Setback Recommendations Per Various Studies

Name of Study	Date of Study	Author(s)	Link to Study	Author's Advised Setbacks	Notes
Wind Turbine Syndrome: A report on a natural experiment	**2009**	Dr. Nina Pierpont	N/A, PDF provided	**Setbacks from residences should be a minimum of 2 kilometers or 1.24 miles, but 2-3 miles in hilly terrain**	PDF provided to Planning Commission and BoCC
Your Guide to Wind Turboine Syndrome...a road map to a complicated subject	**July 2010**	Calvin Luther Martin, Phd	N/A, PDF provided	**Setbacks from residences should be a minimum of 2 kilometers or 1.24 miles, but 2-3 miles in hilly terrain**	This is a summary of Dr. Pierpont's book PDF provided to Planning Commission and BoCC
Health Effects of Wind Turbines: Testimony of Ben Johnson versus MidAmerican Energy (Madison County, Iowa) / Hearing before the Madison County Board of Health	**August 2019**	Dr. Ben Johnson, M.D.	https://www.masterresource.org/wind-turbine-noise-issues/health-effects-of-wind-turbines-testimony-of-ben-johnson-versus-mid-american-energy-project-in-madison-country-iowa/	**No recommendation given for a specific distance in this hearing. Afterwards the Madison County Board of Health passed a resolution recommending that any future turbines be built at least 1.5 miles from non-participating homes**	PDF provided to Planning Commission and BoCC
Wind Turbine Noise and Human Health: A Four-Decade History of Evidence that Wind Turbines Pose Risks	**Ocober 2016**	Professor Jerry L Punch and Professor Richard R James	https://hearinghealthmatters.org/wp-content/uploads/2023/03/16-10-21-Wind-Turbine-Noise-Post-Publication-Manuscript-HHTM-Punch-James.pdf	**Setbacks from residences are recommended at 1/2 mile to 2.5 miles, 1.25 miles is most favored by scientists.**	PDF provided to Planning Commission and BoCC
Infrasound from technical installations: Scientific basis for an assessment of health risks	**July 2021**	Dr. Werner Roos and Dr. Christian Vahl	https://www-asu--arbeitsmedizin-com.translate.goog/wissenschaft/wissenschaftliche-grundlagen-fuer-eine-bewertung-gesundheitlicher-risiken-infraschall?_x_tr_sl=de&_x_tr_tl=en&_x_tr_hl=en&_x_tr_pto=wapp	**Minimum setback from residences should be 10 X turbine height as in Bavaria Germany**	PDF provided to Planning Commission and BoCC
Assessing Adverse Health Effects-(Confirmed and Potential) from Industrial Wind Turbine Noise Emissions / Power point slides of presentation before the Kansas State Legislature	**2022**	Dr. Ben Johnson, M.D.	https://www.kslegislature.gov/li_2022/b2021_22/committees/ctte_s_utils_1/documents/testimony/20220207_01.pdf	**Setbacks of 1.25 miles from residences**	PDF provided to Planning Commission and BoCC
Presentation before the Kansas Senate and Utilities Committee: Effects of Wind Turbine Noise on Human Health	**2022**	Prof Jerry L Punch	https://www.kslegislature.gov/li_2022/b2021_22/committees/ctte_s_utils_1/documents/testimony/20220208_02.pdf	**Setbacks of 1.25 miles from property lines (specifically) should be considered**	PDF provided to Planning Commission and BoCC
Wind Turbines: Vacated/abandoned homes - Exploring participants' descriptions of their personal views, effects on safety, security, trust and social justice	**Dec 2023**	Carmen Marie Krogh, Robert Y McMurty, W Ben Johson, Jerry L Punch, Anne Dumbrille, Mariana Alves-Pereira, Debra Hughes, Linda Rogers, Robert W Rand, Lorrie Gillis	https://journals.lww.com/endi/fulltext/2023/08040/wind_turbines__vacated_abandoned_homes___exploring.2.aspx	**Residents living within 10 kilometers/6.21 miles of industrial wind turbines were documented having Adverse Health Effects**	See page 96 for the conclusion of the study regarding setbacks. PDF provided to Planning Commission and BoCC.
A fundamental basis for all living creatures, mechanotransduction, is significantly endangered by periodic exposure to impulsive infrasound and vibration from technical emitters - in particular cardiovascular and embryological functions	**June 2025**	Dr. Ursula Bellut-Staeck	https://www.scirea.org/journal/PaperInformation?PaperID=12440	**Setbacks of 10 kilometers / 6.21 miles from people and animals**	NOTE: The link shows the abstact and allows you to download the PDF PDF provided to Planning Commission and BoCC
Separating Myth from Fact on Wind Turbine Noise	**October 2025**	Prof Ken Mattsson	https://www.youtube.com/watch?v=nDwsd32SDEY	**Setbacks of at least 5 to 10 kilometers (3.1 to 6.2 miles) from residences**	Transcript PDF provided to Planning Commission and BoCC
Efficient finite difference modeling of infrasound propagation in realistic 3D domains: Validation with wind turbine measurements	**Feb 2026**	Ken Mattsson, Gustav Eriksson, Leif Persson, Jose Chilo, Kourosh Tatar	https://www.sciencedirect.com/science/article/pii/S0003682X25006280?ref=pdf_download&fr=RR-2&rr=9a872537bf69df1b	**No specific distance given, see notes for conclusion of study**	Conclusion of study page 14: This study also shows that modern, large-scale wind turbines generate infrasound levels substantially higher than those reported for older, smaller turbines / PDF provided to Planning Comm & BoCC

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Summary of a study entitled: **Wind Turbine Noise and Human Health: A Four Decade History of Evidence That Wind Turbines Pose Risks, by Prof Jerry L Punch and Prof Richard R James, 2019**

(Compiled by Tom Thompson Dec 2025)

- Reviews evidence linking industrial wind turbine (IWT) noise, especially infrasound and low-frequency noise (ILFN), to adverse health effects (AHEs) such as sleep disturbance, headaches, dizziness, vertigo, and ear pressure, collectively called "Wind Turbine Syndrome"

- Challenges 12 industry claims denying causation; ILFN affects 20%+ of nearby residents via direct physiological mechanisms

- Debate is polarized: industry groups (AWEA, CanWEA) dismiss links while experts cite overlooked peer-reviewed studies, surveys, and reports; aims to inform policy/legal discussions and protect rural communities from "sacrifice zones"

- Methods: comprehensive literature search (Google Scholar, PubMed, etc.); analysis of noise spectra, inner ear physiology, epidemiology, lab experiments, field measurements; applied Hill's causation criteria and McMurtry's case definitions (symptoms within 5 km)

- IWTs produce ILFN (<20 Hz, 60–70 dB peaks) and modulated pulses that vibrate homes and resonate with body frequencies (1–10 Hz); impulsive/tonal ILFN penetrates barriers, causing subconscious sensations without audible awareness (Kelley et al.)

- Physiological mechanisms: ILFN overstimulates vestibular/cochlear systems; outer hair cells respond to infrasound, triggering tinnitus, balance issues, and stress via inner ear fluid movement; no hearing loss but links to fatigue, cardiovascular strain, psychological distress

- Health findings: 11–15% report sleep disruption at <40 dBA in quiet areas; annoyance correlates with proximity/dose, escalating to AHEs; 45% hear noise up to 4 km; symptom relief occurs upon exposure cessation; WHO classifies annoyance as a health stressor

- **Measurement and setbacks: A-weighted metrics underestimate ILFN; recommend C-weighted/narrow-band alternatives; current setbacks (1,000–1,500 ft.) inadequate; suggest 0.5–2.5 miles (0.8–4 km) or <30–40 dBA to protect sleep and vulnerable groups**

- Alternatives and nocebo: non-acoustic causes (EMF, views) insufficient; nocebo explains some variance but not exposure-timed or pre-awareness symptoms; critiques "communicated disease" models

- Discussion: causation biologically plausible and consistent across studies; unique amplitude modulation amplifies indoor effects; calls for refined standards (ANSI/ASA, ISO), industry cooperation, precautionary siting

- Conclusions: evidence refutes industry denials; recommends greater setbacks, low noise thresholds, dose-response research, symptomatic treatment including relocation; emphasizes evidence-based policy to prevent AHEs in exposed populations

Wind Turbine Noise and Human Health: A Four-Decade History of Evidence that Wind Turbines Pose Risks*

Jerry L. Punch,[i] Richard R. James[ii]

Abstract

Many expert-review panels and some individual authors, in the U.S. and internationally, have taken the position that there is little literature to support concerns about adverse health effects (AHEs) from noise emitted by industrial wind turbines (IWTs). In this review, we systematically examine the literature that bears on some of the particular claims that are commonly made in support of the view that a causal link is non-existent. Investigation of the veracity of those claims requires that multiple topics be addressed, and the following specific topics were targeted for this review: (1) emissions of infrasound and low-frequency noise (ILFN) by IWTs, (2) the perception of ILFN by humans, (3) the evidentiary bases for establishing a causative link between IWTs and AHEs, as well as the physiological bases for such a link, (4) recommended setback distances and permissible noise levels, (5) the relationship between annoyance and health, (6) alternative causes of the reported health problems, (7) recommended methods for measuring infrasound, (8) foundations for establishing a medical diagnosis of AHEs due to IWTs, (9) research designs useful in establishing causation, (10) the role of psychological expectations as an explanation for the reported adverse effects, (11) the prevalence of AHEs in individuals exposed to IWTs, and (12) the scope and quality of literature addressing the link between IWT noise and AHEs. The reviewed evidence overwhelmingly supports the notion that acoustic emissions from IWTs is a leading cause of AHEs in a substantial segment of the population.

*Revised October 21, 2016

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Key Words: Adverse health effects, human health, industrial wind turbines, infrasound, inner ear, low-frequency noise, wind turbine noise

Introduction

Whether infrasound and low-frequency noise (ILFN) from industrial wind turbines (IWTs) is detrimental to human health is currently a highly controversial topic. Advocates of industrial-scale wind energy assert that there is no credible scientific evidence of a causal relationship, while many reputable professionals believe that there is sufficient scientific evidence to establish a causal link between IWTs and detrimental health effects *for a non-trivial percentage of individuals who reside in communities hosting IWTs*. The veracity of claims regarding the effects on human health is being debated on a global scale by the wind industry; individuals living near IWTs; attorneys and expert witnesses in courts of law; print and web-based media; documentary films (which currently include *Windfall*, *Wind Rush*, and *Down Wind*); and scientists and other professionals in government reports, on the Internet, and in scientific and professional papers presented at society meetings and published in peer-reviewed journals.

The debate surrounding IWTs extends to many controversial issues, including physical safety, visibility, shadow flicker, and threats to property values and wildlife. Many problems involving wind turbines, including mechanical failures, accidents, and other mishaps, have been discussed on the Internet. At least one website has extensively catalogued these incidents,[1] and the large number of incidents reported by that site is described by its webmaster as grossly underestimating the actual number of documented incidents. The most vigorous debate, however, centers on ILFN and its effects on human health.

The overall purpose of this article is to provide a systematic review of legitimate sources that bear directly and indirectly on the question of the extent to which IWT noise leads to the many health complaints that are being attributed to it. The authors accessed most articles and reports referenced in this review by employing Google, Google Scholar, and PubMed as the primary search engines. Our basic aim was to provide a comprehensive and representative—though not exhaustive—review of the literature that is relevant to many of the claims made by wind industry advocates. An exhaustive review is an elusive and impractical goal, given the large volume of directly and indirectly related work done in this area over the past several decades and the current pace of such work.

The role of evidentiary facts

Adverse impacts on people and property are among the most contentious issues that are typically the focus of legal proceedings involving IWT noise. Based on the forensic and research experiences of the authors, we believe that a resolution of the controversial aspects of this debate will require not just relevant scientific research, but rather a series of legal judgments based on the effective evaluation and interpretation of the existing research. In fact, much research and some already-rendered legal decisions show convincingly that some segments of the population suffer damaging effects from exposure to wind turbine noise (WTN). What is needed among the scientific community, local and national governmental agencies, and political leaders, is honest discourse about methods for reducing carbon emissions in ways that do not turn some rural communities into *sacrifice zones*.[2, 3]

Many symptoms and complaints of adverse health effects (AHEs) related to IWTs have been self-reported by individuals living near wind turbines and described in published case reports. There is a group of core symptoms and complaints, however—including sleep disturbance, headache, dizziness, vertigo, and ear pressure or pain—that are remarkably common worldwide. Dr. Nina Pierpont was the first to report these core symptoms in a case series,[4] and she termed these core symptoms *Wind Turbine Syndrome*. For the sake of brevity, we will on occasion refer to Wind Turbine Syndrome as a substitute for this group of common symptoms and complaints, even though the phrase itself is currently not utilized as a medical diagnostic entity.

Numerous reviews of the literature have already been published that allege that there is no credible link between WTN emissions and AHEs. Those reviews have typically been sanctioned by state or provincial government agencies that have missions to support the development of wind energy, and which in turn appoint *expert panels* whose members hold views that regularly favor the wind industry and, therefore, may have conflicting interests. Too often, in the opinion of the authors, such reviews are biased in support of political policy decisions that promote the financial interests of wind developers, and perceived financial benefits to local communities, over the common good. None of those reviews has been specifically targeted toward describing or explaining the relationship between exposure to complex, dynamically modulated infra- and low-frequency sound from wind turbines or other industrial sources (e.g., noise-induced Sick Building Syndrome) and AHEs. Our primary objective in this article is to review the existing scientific and professional literature that is frequently overlooked in such reviews conducted by wind energy proponents. Such literature can be useful in legal proceedings in questioning and articulating the available evidence of risks to people who live in the footprint of utility-scale wind energy projects.

Some of the published reviews have been criticized for their failure to meet the standards noted by Horner,[5] who reminds us that readers should regard literature reviews with caution, and employ an audit strategy in evaluating their completeness, accuracy, and objectivity. Authors, including ourselves, have an inherent obligation to ensure that such reviews cite all known legitimate sources that serve as the basis for their views of the issues and reflect accurately the contents of all references cited.

Some courts of law in the U.S. and other countries now tend to rely heavily on testimony that adheres to the principle that proof of evidence of causation of AHEs from IWTs be based on the peer-reviewed literature. Presumably, that practice in the U.S. stems at least partially from advocacy by the Office of Management and Budget[6] that internal and external government science documents be peer-reviewed government-wide for the purpose of increasing the quality and credibility of scientific information generated by the federal government. Peer-review standards are considered paramount in that effort.

While the peer-review process has many virtues, it also has its shortcomings, which are well known. For example, not all journals or individual reviews of submitted manuscripts are of equal quality, as specific journals and specific reviewers may have ideological or philosophical biases, which may or may not be surmised from the journals' mission statements. Nonetheless, the peer-review process is one of the most widely acknowledged ways to control the quality of published works. We contend, however, that there are other credible sources of information, even though those sources may not have been subjected to as rigorous a peer-review process as that employed by many scientific journals. Such sources include papers presented at meetings of scientific and professional societies; reports and other documents commissioned by state and local governmental agencies, especially if such documents are authored by independent researchers; legal testimony given under oath by qualified scientists and professionals; and some information available on the Internet, especially if written by professionals who have reputable track records in their disciplines. Although we will emphasize the peer-reviewed literature in this article, we will also cite some of these additional sources as authoritative. Our citing of selected non-peer-reviewed reports, with a few exceptions, is based on our familiarity with the professional reputations of the authors of those reports, normally earned through publication of a solid body of work in the peer-reviewed literature and by acceptance of their work by other professionals and peers. Typically, individuals so referenced enjoy positive national or international recognition in their respective fields of expertise.

We begin this review by calling attention to a quote from geophysicist Marcia McNutt, who once headed the U.S. Geological Survey and is now editor of the prestigious journal *Science*. McNutt has been quoted as stating: "Science is not a body of facts. Science is a method for deciding whether what we choose to believe has a basis in the laws of nature or not."[7] In fact, science consists of a variety of overlapping methodological approaches, which must be interwoven to discover answers to complex problems. That conviction has guided our attempt to re-examine the controversial topic at hand.

Review of wind industry claims and positions

Our review is organized by summarizing the past and present literature that addresses each of 12 selected statements, listed below, that encapsulate specific claims, or positions, commonly taken by advocates for the wind industry:

1. Infrasound is not an issue, as infrasound generated by wind turbines is not perceptible to humans.
2. There is nothing unique about wind turbine noise, as infrasound and low-frequency noise are commonly produced by the body and by many environmental sources.
3. There is no evidence that wind turbine noise, audible or inaudible, is the cause of adverse health effects in people, and there are no physiological mechanisms to explain how inaudible acoustic energy can be harmful.
4. Setback distances of 1,000-1,500 ft. (approximately 0.3-0.5 km) are sufficiently safe to protect humans from harm, regardless of height or other physical characteristics of the IWTs.
5. Annoyance is a nuisance, but it is not a health issue.
6. Noise cannot account for all of the complaints of people living in the vicinity of wind turbines; there must be another, unknown reason for the complaints.
7. Infrasound from wind turbines is sufficiently correlated to the A-weighted sound emissions to allow an A-weighted model to be used to predict how much infrasound is present in homes.
8. Wind Turbine Syndrome has not been accepted as a diagnostic entity by the medical profession, so medical professionals cannot diagnose or treat it.
9. Peer-reviewed epidemiological literature is the only acceptable basis for proving a causative relationship between wind turbine noise and adverse health effects.
10. The nocebo effect, a manifestation of psychological expectations, explains why people complain of adverse health effects when living near wind turbines.
11. Only relatively few people, if any, are adversely impacted by wind turbine noise, and the majority have no complaints.
12. There is no evidence in the literature to support a causative link between wind turbine noise and adverse effects.

Statement 1: Infrasound is not an issue, as infrasound generated by wind turbines is not perceptible to humans.

The argument that infrasound as a cause of AHEs is not an issue has been advanced in the published literature primarily by Dr. Geoff Leventhall,[8, 9] with support from several other researchers. Those researchers have dismissed the influence of infrasound on human health by describing it as not exceeding the thresholds of audibility, and therefore ineffectual, without noting that those thresholds were established using steady pure tones instead of the complex, dynamically modulated tones emitted by wind turbines. Leventhall claims that infrasound from wind turbines is not a problem and that it is misunderstood largely because of mischaracterization by the media and by "those with limited knowledge" (p. 29). He states that there may be noise problems associated with wind turbines, but that such problems are due to *audible* swishing sounds due to interactions of the blades with the tower. Supporters of wind energy have generally followed Leventhall's lead, although his own research has shown conclusively that exposure to modulated ILFN produced by large industrial equipment, including heating, ventilating and air-conditioning (HVAC) systems, leads to mental fatigue, lack of concentration, headaches, reduced performance, and work dissatisfaction. Indeed, there is a long history of noise-induced *Sick Building Syndrome*, stemming from investigations in the 1970s-1990s of the effects of low-frequency noise on knowledge workers (see James[10] and Schwartz[11] for reviews of that research). Leventhall[12] stated:

> "Low frequency noise causes extreme distress to a number of people who are sensitive to its effects. Such sensitivity may be a result of heightened sensory response within the whole or part of the auditory range or may be acquired. The noise levels are often low, occurring in the region of the hearing threshold, where there are considerable individual differences" (p. 4).

Later in the same document, he states:

> "There is no doubt that some humans exposed to infrasound experience abnormal ear, CNS (central nervous system), and resonance induced symptoms that are real and stressful. If this is not recognised by investigators or their treating physicians, and properly addressed with understanding and sympathy, a psychological reaction will follow and the patient's problems will be compounded. Most subjects may be reassured that there will be no serious consequences to their health from infrasound exposure and *if further exposure is avoided* (emphasis added) they may expect to become symptom free" (p. 60).

Leventhall has also stated that the ear is designed to protect us from infrasound and that, in essence, *If you can't hear it, you can't feel it.*[13, 14] The idea that ILFN from wind turbines does not affect health was further reinforced in a 2009 white paper co-authored by Leventhall and sanctioned by the wind industry,[15] to be reviewed later.

The position that infrasound from wind turbines is not harmful to humans because it is not perceptible to the human ear also has support from Møller & Pedersen,[16] who investigated noise emissions from 48 wind turbines with electrical output capacities of between 2.3 and 3.6 MW. They stated:

> "The turbines do emit infrasound (sound below 20 Hz), but levels are low when human sensitivity to these frequencies is accounted for. Even close to the turbines, the infrasonic sound pressure level is much below the normal hearing threshold, and infrasound is thus not considered as a problem with turbines of the investigated size and construction" (pp. 3742-3743).

Evans et al[17] found that levels of infrasound measured at two residential locations near wind projects in South Australia were within the range of infrasound levels experienced in other urban and rural environments. Although Colby et al[15] and Bolin et al[18] dismiss wind turbines as a cause of AHEs, they acknowledge that turbines emit ILFN. A number of authors indicate that large turbines emit more such noise than smaller turbines (see, for example, Bolin et al[18] and Møller & Pedersen.[16]) George Kamperman (personal communication, 2009) has concluded that the amount of low-frequency noise generated by IWTs increases by 3–5 dB for every megawatt of electrical power generated.

Evidence that IWTs produce perceptible levels of infrasound, in addition to audible low-frequency noise above 20 Hz, has been available since the 1980s. In their seminal research on large-scale wind turbines, which was funded by the U.S. Department of Energy, Kelley et al[19] measured noise levels emitted by a DOE/NASA MOD-1 wind turbine operating near Boone, North Carolina, in response to noise complaints. They concluded that:

> "…one of the major causal agents responsible for the annoyance of nearby residents by wind turbine noise is the excitation of highly resonant structural and air volume modes by the coherent, low frequency sound radiated by large wind turbines. Further, there is evidence that the strong resonances found in the acoustic pressure field within rooms actually measured indicates a coupling of subaudible energy to human body resonances at 5, 12, and 17-25 Hz, resulting in a sensation of whole-body vibration" (p. 120).

Those conclusions were further strengthened in a subsequent report.[20] In a second follow-up report, also funded by the Department of Energy, Kelley[21] electronically simulated three interior environments resulting from low-frequency acoustical loads radiated from both single and grouped upwind and downwind turbines. (These terms refer to the placement of the rotor and blades with respect to the tower. With upwind designs, the more contemporary design, the airflow strikes the blades before striking the tower, and with downwind designs, the airflow strikes the tower before striking the blades.) Relatively low levels of low-frequency acoustic noise from a single, 2-MW MOD-1 wind turbine led to annoyance of residents of the surrounding community, largely through interaction with residential structures. Most importantly, Kelley found that the turbines radiated their peak sound power in the infrasonic range, typically between 1 and 10 Hz. An extensive investigation revealed that the reported annoyance was the result of a coupling of the turbine's impulsive low-frequency acoustic energy into the structures of some of the surrounding homes, and that annoyance was "frequently confined to *within the home itself*" (p. 1). Despite these early findings that IWTs generate infrasonic levels that produce acoustic energy, vibrations, and resonances that affect people in their homes, the wind industry has chosen to regard them as insignificant or only applicable to obsolete, downwind wind turbine designs.

The basis for discounting the research by Kelley and associates is predicated on the assumption that pressure changes of equal levels to wind turbines occur in natural environments and do not cause any similar complaints. The authors find that their own experiences with rapidly changing pressures have caused similar experiences. If these rather short-duration sensations were to continue over days, weeks, and months, as they do for people living near wind projects, they would likely find them to be unacceptable.

The primary argument of people who deny any effects is encapsulated by Leventhall[9] in his *Child on a Swing* example:

> "A child on a swing experiences infrasound at a level of around 110dB and frequency 0.5Hz, depending on the suspended length and the change in height during the swing" (p. 30).

The inference is that because children often swing on swings, there are no adverse sensations. That fails to acknowledge that the experience of swinging is one that elicits many visceral sensations that are pleasant to the child as long as the sensations stop when the swing stops. The example, however, misses one major point. The duration and motion of the swing provide a smooth, sinusoidal pressure change that has two high pressure points (at the top of each swing) that occur over a period of several seconds or so. This is a completely different experience to that of pressure pulses lasting 100 msec or less. If one considers a swing with a period of 3.5 sec, there is a pressure change at 1.75 sec, resulting in a frequency of 0.57 Hz. The pressure changes are approximately 120 dB peak-to-peak, or 110 dB rms. The overall G-weighted value in this example is -60 dB, with a smooth pressure change, resulting in a net 50 dBG for the child, versus the 75 dBG experienced as a pulse for a person living near a wind turbine (calculations provided by Malcolm Swinbanks, personal communication, 2010).

The assertion that wind turbine infrasound immissions, especially when received in the bedroom of a quiet home, must be at or above the threshold of hearing to cause adverse effects has been disproved, as noted above in the works of Kelley and colleagues in the 1980s.[19, 20, 21] The significant finding of the Kelley studies is that when the intruding infrasound is dynamically modulated short-duration pulses (generally under 100 msec and as short as 4 msec), the thresholds of sound pressure levels (SPLs) for non-auditory perception are in the range of 60 to 70 dB. In the work by one of the authors of this paper (James, with Mr. Wade Bray, INCE, of Head Acoustics, GMBH), infrasound pulsations were measured from a GE 1.5-MW wind turbine with a blade-pass frequency of 1 Hz that reached a level as high as 100 dB.[22] The people living in the home 'felt' the pulsations when the crests of the pressure waves were as low as 60 dB at 1 Hz. During similar measurements, Swinbanks, who has reported that he is sensitive to infrasound pulsations, was present at the test site. His experience was that he could feel the pulsations outside the home at similar SPLs.

Subsequent to the papers by Kelley and colleagues, several other studies have also reported the thresholds for significant experiences at similar thresholds, all substantially below the threshold for audibility of steady pure tones. In many of those tests, the rms SPL of the dynamically modulated blade-pass tone and its harmonics has been as low as 40 dB when using narrow-band analysis with windows of 40 to 80 sec, providing the crest of the pressure waves are 10 to 15 dB higher than the rms levels. These studies include the works of Robert Rand, INCE, and Stephen Ambrose, Bd. Cert., INCE, in their study of homes of complainants in Falmouth, Massachusetts;[23] Walker, Hessler, Hessler, and Schomer, in their work at the Shirley Wind project in Brown County, Wisconsin, for the Wisconsin Public Health Service;[24] and most recently, Steven Cooper's study of the Cape Bridgewater project in Victoria, Australia.[25] All of these studies report similar findings, namely that perception, generally non-auditory in character, begins when the rms SPLs of the modulating tones are as low as 40 dB rms, with increasing impacts as the rms levels rise to 50, 60, and to 70 dB and higher levels. In all these studies, the dynamic modulation of the blade-pass tones produce pressure peaks that are often 10 dB or more, sometimes much more, than the rms values.

In the opinion of the authors, a paper prepared by Swinbanks for the 2015 conference on wind energy in Glasgow, Scotland, shows the impact of dynamically modulated infrasound on a sensitive individual—himself—along with high-quality measurements of the environments in which he experienced the sensations.[26] That paper shows that a highly respected acoustician and scientist with expertise in infra- and low-frequency sound also responds to this acoustic energy in a way that is similar to the many complaints from others, both in the location of his tests and at other wind energy projects around the world. In the paper, Swinbanks reports that he was able to differentiate the pulsations in the test data from at least six separate wind turbines in a project consisting of 46 1.5-MW GE models. He also reports that he was able to perceive the effects of the pulsations in his home's basement, approximately 3 km from the nearest operating wind turbine, with the SPLs of the blade-pass frequency and harmonics summing to about 55 dB rms. At closer locations, he measured positive-going pressure peaks of 87 dB with corresponding negative-going peaks of equal level. It is worth noting that at the Glasgow conference, Swinbanks presented the paper as a poster session,[27] as he was informed by the conference moderator that time restraints prevented him from presenting his paper to conference attendees.

In the 2012 investigation of infrasound at the Shirley Wind project, where local regulations require that the Nordex 2.5-MW turbines be sited at least 1,250 ft., or 381 m, from residences, Walker et al reported infrasound levels at one of the three test homes.[24] WTN was not audible outside the residence where infrasound was greatest, supporting the position that infrasound is at the root of at least some of the complaints. The blade-pass frequency and harmonics were clearly evident from the measurements inside that one home, and the family had moved far away for a solution.

Following the Shirley Wind team study, several members of the community conducted a series of micro barometer measurements inside homes ranging from 1,280 ft. to approximately 6 mi. from the wind turbine towers. Infrasonic tones at blade-pass frequencies and harmonics were found at all test sites, including test sites at distances of several miles or more from towers under downwind conditions. Testimony to Wisconsin's Brown County Board of Health by people with homes more than 4 mi. from the nearest wind turbines reported AHEs during the times the turbines operated. In mid-October 2014, the Brown County Board of Health went on record declaring that wind turbines at the Shirley Wind site "...are a human health hazard."[28] That action, which appears to be a precedent in the U.S., meant that Duke Energy's Shirley Wind utility were forced to prove to the Board that the utility was not the cause of the health complaints documented in the study and voiced by community residents. The outcome could result in a shut-down order, but no final decision had been made in that case at the time of this writing. Other examples of legally ordered turbine shutdowns include those in Massachusetts[29, 30] and Portugal.[31]

We will return to the issue of perceptibility of infrasound later in this paper, as we describe the physiological bases for perceptibility.

Statement 2: There is nothing unique about wind turbine noise, as infrasound and low-frequency noise are commonly produced by the body and by many environmental sources.

To begin, when the spectral characteristics of IWT noise, as depicted in several papers,[24, 32, 33] are compared to the spectra of subsonic jet transport planes,[34] five different types of aircraft,[35] and road traffic noise,[36] it is clear that noise generated by wind turbines has a number of unique acoustical characteristics. These comparisons reveal dissimilarities in spectral and peak levels in both the higher and lower frequency regions, including the low-frequency and infrasonic range.

Leventhall[37] was one of the first to describe how low-frequency noise is a special noise problem, particularly to sensitive people in their homes. He indicated that annoyance to low-frequency noise increases rapidly with level, often starting just above the threshold of audibility, and that about 2.5% of the population may be 12 dB more sensitive than the average person to low-frequency noise. He also noted that the World Health Organization (WHO) places a special emphasis on low-frequency noise as an environmental problem and source of sleep disturbance, even at low levels. The WHO[38] acknowledges that a noise consisting of a large proportion of low-frequency components may considerably increase AHEs and should be limited to below 40 dBA. Cummings[39] notes that sound levels of 40 dBA trigger high levels of community pushback.

Jung et al[40] experimentally identified the characteristics of acoustic emissions from large upwind wind turbines, with emphasis on ILFN. The sound spectral density showed that the blade-passage frequency component is clearly dominant, revealing up to 6-7 harmonics that generally occupy the infrasonic frequency region of 1 to 10 Hz. They voiced a concern that the low-frequency noise of the 1.5-MW and 600-kW wind turbines in the frequency range over 30 Hz would very likely lead to psychological complaints from ordinary adults.

In responding to a bylaw to restrict wind turbine infrasound in the town of Plympton-Wyoming, Ontario, Leventhall[41] declared that "Infrasound has become the Godzilla of acoustics" (p. 2). He concluded that science does not support the conditions in the bylaw, which was largely aimed at restricting blade-passing tones, because "There is no evidence that the very low level of blade passing tones affects humans, whilst there is evidence that it does not" (p. 7). Based on the kinds of evidence just discussed, we strongly disagree.

WTN has been described as having a character that makes it far more annoying and stressful than other sources of noise at the same A-weighted level, including traffic and industrial noise.[42, 43, 44, 45] Harrison[42] concluded that IWTs cause annoyance in about 20% of residents living within a distance considered acceptable by most regulatory authorities, and that for many of the 20%, the annoyance and sleep disturbance lead to AHEs. Thorne[46] has pointed out that human perception of noise is based primarily on sound character rather than sound level, and that wind turbines are unique sound sources that exhibit special audible and inaudible modulated and tonal characteristics. He states that sound levels of 32 dBA Leq outside a residence and/or above an individual's threshold of hearing inside the home are markers for serious AHEs, especially among susceptible individuals.

Structural and human responses to low-frequency noise, including noise from wind turbines, have been described by Hubbard.[47] Hubbard and Shephard[48] illustrated the special characteristics of WTN by explaining its sources, pathways, and receptors. Thorne[46, 49] described wind turbines and *wind farms* as a unique source of sound and noise, like no other noise source or set of noise sources. The sounds are often of low amplitude and shifting in character, making it difficult for people who have never been exposed to such sounds to understand the problems of those who complain about the sounds. Shepherd et al[50] have described WTN as having characteristics sufficiently different from other, more extensively studied, noise sources to justify the application of standards different from pre-existing noise standards.

The preponderance of evidence on this point leads to the conclusion that WTN has special acoustic characteristics that distinguish it from other industrial sounds. A primary feature is that it consists of measureable energy down to below 1 Hz.[24, 51, 52] Its sound pressure level decreases rapidly with increasing frequency from about 0.5-5 Hz. It varies in amplitude over time,[9, 49, 51, 53, 54, 55, 56, 57, 58] it tends to have an intermittent tonal quality,[49, 52, 59] and its characteristics vary with distance and direction.[52, 53] It can result in an impulsive sound,[21, 40, 49, 60] even at long distances.[52] According to Lee et al,[53] the swishing sounds of turbines can be perceived from all directions, but at long distances from a turbine, low-frequency amplitude-modulated sounds can be heard only in particular directions and when the SPL is sufficiently high. This effect may make the WTN seem more impulsive at long distances despite an overall SPL that is relatively low.

Furthermore, ILFN from any source, including IWTs, is well known to penetrate walls and other barriers (e.g., Minnesota Department of Health[55]); is typically more disruptive indoors than outdoors;[46, 47, 61, 62, 63] and is not easily masked by atmospheric sounds, including road traffic and other sources of infrasound.[63, 64, 65, 66] The perception of low-frequency noise depends on density level, modulations, bandwidth, purity of blade-pass tones and harmonics, discrete beating tones, or other time-varying properties, and can occur even at near-infrasonic frequencies if any of these factors is present; otherwise, it might pass unnoticed.[57, 67, 68] James[69] describes the infrasound occurring when wind turbine blades rotate past the tower as a short pressure pulse that consists of a well-defined array of tonal harmonics below 10 Hz. If the pressure peaks are received at the same time, they sum in a linear manner that significantly raises the overall SPL. Often, however, there are many wind turbines rotating at similar speeds, but not synchronized in time. This can lead to another form of modulation as the wind turbine infrasound is perceived as rising and falling, intermittent, or pulsating with variable intensity.

A common argument of wind industry proponents—one that is sometimes raised in legal proceedings—is that humans themselves generate infrasound by virtue of their own heartbeat and breathing, at levels that can be substantially higher than an external noise source such as wind turbines. In a rebuttal to a formal statement to this effect by the Association of Australian Acoustical Consultants (AAAC), Salt has provided a definitive explanation of why the two sources of infrasound (internal vs. external) cannot be equated. In a letter addressed to the AAAC,[70] Salt stated:

> "Stimulation of the ear occurs not directly by pressure (which is why deep sea divers can still hear) but by induced motions of the inner ear fluids, which in turn move sensory tissues and motion-sensitive cells….when low frequency and infrasound enters the ear via the stapes, it causes fluid movements throughout the entire ear between the stapes in the vestibule, through scala vestibuli and scala tympani to the compliant round window membrane at the base of scala tympani. It is these fluid movements that drive sensory tissue movements and cause stimulation. In contrast, pressure fluctuations generated by the body, such as by heartbeat and respiration, enter the ear via the cochlear aqueduct, not through the stapes. The cochlear aqueduct enters the ear adjacent to the round window membrane in the very basal part of scala tympani, so the fluid flows are localized in this tiny region of the ear. As the rest of the ear is bounded by a bony shell which is not compliant, fluid flows in the rest of the ear are substantially lower so that displacements of sensory tissues are negligible. Infrasound generated by the body, because it enters through the aqueduct, therefore does not cause stimulation of the ear."

Statement 3: There is no evidence that wind turbine noise, audible or inaudible, is the cause of adverse health effects in people, and there are no physiological mechanisms to explain how inaudible acoustic energy can be harmful.

In fact, there is ample evidence that noise in general, and especially low-frequency noise, has long-term consequences for human health.[71, 72] For example, long-term exposure to ordinary traffic noise has been associated in a dose-dependent manner with higher risk of myocardial infarction.[73]

Two landmark reports embodying diametrically opposing perspectives with regard to the impact of WTN on health appeared almost concurrently in 2009. One was published as a book by Dr.

Nina Pierpont,[4] a Fellow of the American Academy of Pediatrics who holds an MD degree from Johns Hopkins University School of Medicine and a PhD degree in Population Biology from Princeton University. The other report was written by a panel of seven experts (three physicians, two acousticians, an audiologist, and an audiologist/hearing scientist) commissioned by the American Wind Energy Association and the Canadian Wind Energy Association. The latter report[15] is commonly referred to as the AWEA/CanWEA report, or white paper. These respective reports, more than any others, quickly became the rallying cry for so-called anti-wind and pro-wind advocacy groups in the media, in the public discourse, and in court proceedings.

In her book, Pierpont[4] coined the term *Wind Turbine Syndrome* to describe a range of symptoms reported for 38 family members (adults and children) of 10 families who lived near wind turbines. Based on telephone interviews, she treated her observations and analyses as a case-series research design. She described the syndrome as consisting of 10 classes of symptoms (enumerated below), many of which she attributed to overstimulation of the vestibular system of the inner ear by ILFN. The wind industry, in its AWEA/CanWEA report and elsewhere, has vigorously criticized her study for being non-scientific and non-peer-reviewed. In fact, Pierpont's book was critically reviewed by far more than the usual number of reviewers for a peer-reviewed journal article. While it is true that case series are prone to selection bias, and can at best suggest hypotheses, many discoveries of new phenomena begin with a case study or case series. Furthermore, an increasing body of scientific evidence supports Pierpont's observations of a relationship between WTN and AHEs. More recent laboratory research, described later in this review, suggests that a variety of health symptoms may be due to ILFN stimulation of both vestibular and cochlear components of the inner ear.

Prior to Pierpont's book,[4] Dr. Amanda Harry[74] and Dr. Robyn Phipps and colleagues[75, 76] had documented the occurrence of ill effects from IWTs by use of questionnaire-based surveys of the health complaints of people living near wind projects in Cornwall, England, and Palmerston North, New Zealand, respectively. These authors concluded that a substantial number of people living near wind turbines suffer from health problems and that the cause of the disturbances was the complexity of the noise and vibration. Harry[74] observed that the symptoms were evident for people living within a mile from the wind development and recommended that no wind turbine should be sited closer than 1.5 mi. from the nearest residents. She noted that the guidelines used at the time to site wind turbines were developed when the turbines were 20% the size of the current ones. She concluded that annoyance from noise adversely affects human well-being, and that developers are wrong when they state that WTN is not a problem. Phipps et al[75] noted that 45% of households living within 2 km of the wind farm and 20% of households living up to 8 km away reported hearing noise from the turbines. Phipps[76] reported on the negative consequences of noise that were evident in her own survey and in the works of others, warning that residents do not readily habituate to the presence of WTN.

The AWEA/CanWEA report[15] has been widely used by the wind industry as a basis for its denial of AHEs from IWTs. However, the report is the product of a hand-picked group of experts, at least some of whom were known to hold positions favorable to the report's sponsors, it was never peer-reviewed, and it shows signs of bias, such as conclusions not supported by the research referenced in the report. That white paper concluded that sound from wind turbines, including sub-audible low-frequency sound, does not pose a risk of hearing loss or any other AHE in humans, whether those health effects are described as Wind Turbine Syndrome or otherwise. It also concluded that some people may be annoyed at the presence of sound from wind turbines, including its fluctuating nature, but described annoyance as unrelated to health. Although there is indeed no evidence that IWTs causes hearing loss, the report's conclusion that ILFN does not cause AHEs, and its dismissal of annoyance as a serious entity, have been heavily criticized as erroneous. Horner et al[77] cite many specific examples of the AWEA/CanWEA report's failure to use proper documentation, concluding that it lacks scientific merit and that it is neither authoritative nor convincing. They criticized the report's conclusion that the issue of AHEs stemming from IWTs is settled and that no more research is required, a conclusion that is rarely voiced by scientists. Horner[78] has characterized the report as offering nothing new in its treatment of annoyance, as annoyance has long been known to result from the stress effects of exposure to noise, and he criticized the report for downplaying the relationship between annoyance and health. Phillips[79] has indicated that the report mischaracterized the research designs used by epidemiologists. Despite widespread denial by wind industry advocates of a causal relationship between IWTs and AHEs, the vast majority of peer-reviewed papers have shown that IWTs significantly disturb sleep in at least some residents at distances and noise levels that are typical where IWTs are installed. Furthermore, not a single well-designed scientific study has found WTN to be harmless.[80, 81]

A panel of seven independent experts was commissioned by the Massachusetts Departments of Environmental Protection and Public Health to identify any documented or potential health impacts of risks that may be associated with exposure to IWTs and to facilitate a discussion of IWTs and public health based on scientific findings. The panel generated a report[82] concluding that scientific evidence is lacking to show that WTN leads to AHEs and that a more comprehensive assessment of WTN in populated areas is needed for establishing and refining siting guidelines and for developing best practices. Closer investigation was recommended near homes where outdoor A- and C-weighted levels differ by more than 15 dB, a strategy for detecting the presence of ILFN (e.g., Kamperman & James[83]). The Massachusetts report has been criticized as misrepresenting the evidence it cites, as well as underestimating evidence indicative of AHEs from IWTs.[84, 85] Schomer and Pamidighantam[86] have described the report as a critique of the literature relating to wind turbine acoustic emissions and health effects, and one with problems similar to those it criticizes.

Some laypersons have remarked disparagingly in the media on the factual evidence—including observations and scientific reports—that shows a relationship between IWTs and AHEs. Shahan,[87] for example, confidently states: "To date, there is no scientific evidence that anything such as 'Wind Turbine Syndrome' actually exists." A common argument of wind energy advocates is that studies show that wind turbines do not lead to AHEs, or that studies that draw such a conclusion are not sufficiently scientific to establish causation. Efforts to discredit those who take a skeptical view toward the wind industry commonly use terms such as *opponents*, *detractors*, *anti-wind activists*, or in the case of Shahan,[87] "paid anti-wind 'experts' who have a long history of directly testifying against wind energy in various court cases." Such critics casually ignore the fact that many of the industry experts, including consulting acousticians and physicians, routinely testify on behalf of the industry in such cases, sometimes for substantial fees, and those individuals are rarely described as paid pro-wind experts or activists.

Numerous researchers have reported the existence of a constellation of health symptoms, either directly mirroring or closely related to those described as Wind Turbine Syndrome by Pierpont,[4] in persons living near IWTs. Significantly, the WHO[38] states that there is sufficient evidence that nighttime noise, irrespective of its source, is related to self-reported sleep disturbance and other health problems, and that these effects can lead to a considerable burden of disease in the population.

Sleep disturbance has been identified as a major adverse impact of IWTs.[4, 18, 45, 47, 54, 57, 58, 72, 74, 76, 77, 79, 80, 81, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107] Nighttime exposure to 40-dBA low-frequency noise has been shown to affect cortisol levels, a physiological indicator of stress. Those levels, following awakening, have been found to be associated with subjective reports of lower sleep quality and mood changes.[108] Sleep is a biological necessity, and disturbed sleep is associated with a number of adverse health conditions. The WHO[71] has concluded that there is available, good-quality evidence supporting a causal association between noise and sleep disruption. Sleep disturbance has important implications for public health and may be a particular problem in children.[84, 94, 109]

Even if no other adverse effects were associated with WTN, sleep disturbance alone is a sufficient reason to site turbines at distances that do not disrupt sleep. Many rural communities have background, nighttime sound levels that do not exceed 25 dBA, and observable effects of nighttime, outdoor noise do not occur at levels of 30 dBA or lower.[71] As outdoor sound levels increase, the risk of AH1Es increases, the most vulnerable populations being the first to show their effects. Vulnerable populations include elderly persons; children, especially those younger than age six; and people with pre-existing medical conditions, especially if sleep is affected.[38, 71] According to the WHO, there is ample evidence to link AHEs with prolonged exposure to outdoor sound levels of 40 dBA or higher. It is important to note that the WHO guidelines are based largely on industrial and transportation noise research, and not on wind turbine research. Because multiple studies (covered in this review) have indicated that WTN is significantly more annoying, has higher infra- and low-frequency sound energy, and is modulating, pulsatile, and sometimes tonal, it may impact health to a greater degree than other noises. This means that noise limits in the WHO guidelines may need to be adjusted downward when applied to WTN.

Additional factors increase the probability of sleep disruption due to WTN. The noise can be heard especially well in areas with low background noise levels, which usually occur at night. Also, lower nighttime wind speeds at ground level increase the nighttime contrast between WTN and background sound levels. Using test data taken during daytime wind conditions will result in a large underestimate of nighttime WTN levels, and thus underestimate the potential for sleep disruption.[38, 58]

Researchers who have studied the impacts of ILFN in general and WTN specifically on health, including some who have reviewed and assessed the findings of other researchers, have attributed a variety of symptoms to ILFN exposure. Those symptoms have been variously described by different researchers, with varying degrees of overlap and detail. They are shown, in no particular order, in Table 1.

Clearly, in addition to annoyance, the most commonly experienced and least-contested health symptom suffered by people living near IWTs is sleep disturbance.[110] Both the United Nations Committee against Torture (CAT) and the Physicians for Human Rights[111] describe sleep deprivation as critical to human functioning. According to Physicians for Human Rights:

> "Sleep deprivation ... causes significant cognitive impairments including deficits in memory, learning, logical reasoning, complex verbal processing, and decision-making; sleep appears to play an important role in processes such as memory and insight formation" (p. 22).

Table 1. Health symptoms described by different researchers as linked to exposure to infrasound and low-frequency noise, including exposure to industrial wind turbines.

Author (Year)	Reference	Symptomatology
Pierpont (2009)	4	Sleep disturbance; headache; Visceral Vibratory Vestibular Disturbance (VVVD); dizziness, vertigo, unsteadiness; tinnitus; ear pressure or pain; external auditory canal sensation; memory and concentration deficits; irritability and anger; and fatigue and loss of motivation
Leventhall (2003) Kasprzak (2014)	12 112	Vibration of bodily structures (chest vibration), annoyance (especially in homes), perceptions of unpleasantness (pressure on the eardrum, unpleasant perception within the chest area, and a general feeling of vibration), sleep disturbance (reduced wakefulness), stress, reduced performance on demanding verbal tasks, and negative biological effects that include quantitative measurements of EEG activity, blood pressure, respiration, hormone production, and heart rate
Havas & Colling (2011)	91	Difficulty sleeping, fatigue, depression, irritability, aggressiveness, cognitive dysfunction, chest pain/pressure, headaches, joint pain, skin irritations, nausea, dizziness, tinnitus, and stress
Horner (2013) Paller et al (2013)	78 113	Headaches, nausea, tinnitus, vertigo, and worsened sleep
Jeffery et al (2013)	92	Sleep disturbance; subjective complaints such as headaches, fatigue, temporary feelings of dizziness, and nausea; objective complaints such as vomiting, insomnia, and palpitations; annoyance; and reduced quality of life (QoL)
Jeffery et al (2014)	93	Negative impacts on the physical, mental and social well-being of people
Krogh et al (2012)	96	Annoyance (regarded as an adverse health effect associated with stress), sleep disturbance, headaches, difficulty concentrating, irritability, fatigue, and a variety of more-serious ailments
Minnesota Department of Health (2009)	55	Annoyance, reduced quality of life, sleeplessness, and headache
Howe Gastmeier Chapnik Limited (2010)	114	High levels of annoyance in a non-trivial percentage of persons, with annoyance associated with sound from wind turbines expected to contribute to stress-related health impacts in some persons

Author (Year)	Reference	Symptomatology
Nissenbaum (2013)	81	Sleep disturbances/sleep deprivation and the multiple illnesses that cascade from chronic sleep disturbance, which include cardiovascular diseases mediated by chronically increased levels of stress hormones, weight changes, and metabolic disturbances (including the continuum of impaired glucose tolerance through diabetes); psychological stresses that can result in cardiovascular disease, chronic depression, anger, and other psychiatric symptomatology; headaches, auditory and vestibular system disturbances; an increased requirement for and use of prescription medication; tinnitus; and vertigo
Nissenbaum et al (2012)	97	Increased sleep disruption, reduced mental health
Thorne (2013)	49	Sleep disturbance, headache, tinnitus, ear pressure, dizziness, vertigo, nausea, visual blurring, tachycardia, irritability, problems with concentration and memory, and panic attack episodes
Pawlaczyk-Luszczyńska et al (2005)	115	Problems with vision, concentration, and continuous and selective attention (especially in persons who are highly sensitive to low-frequency noise)
Pedersen (2011)	99	Annoyance (both outdoors and indoors), statistically related to SPLs; sleep interruption, diabetes, and tinnitus (at one of three test sites); annoyance outdoors, significantly related to sleep interruption, tension, stress, irritability (at all three sites), headache (at two sites), and undue fatigue (at one site); annoyance indoors, significantly related to sleep interruption (at all three sites), and to diabetes, headache, undue fatigue, tension, stress, and irritability (at one of three sites)
Roberts & Roberts (2013)	102	Vibration or fatigue, annoyance or unpleasantness
Shepherd & Billington (2011)	103	Annoyance, which has been linked to increased levels of psychological distress, stress, difficulty falling asleep, and sleep interruption
Taylor (2013)	58	Annoyance, stress, sleep disturbance, interference with daily living, headache, irritability, difficulty concentrating, fatigue, dizziness, anxiety, and reduced QoL
Ambrose et al (2012) Rand et al (2011)	61 116	Dizziness, irritability, headache, loss of appetite, fatigue, inability to concentrate, a need to leave the home, and a preference for being outdoors (during investigations of WTN by seasoned researchers, including acousticians)
Thorne (2011)	46	Sleep disturbance, anxiety, stress, and headaches

Author (Year)	Reference	Symptomatology
Palmer (2013)	117	Negative impacts on sleep, job stability, social relationships, care giving, pursuit of hobbies, leisure, learning, and overall health (based on interviews of residents four years after living near operational wind turbines)
Castelo Branco & Alves-Pereira (2004) Castelo Branco (1999)	118 119	Vibroacoustic disease, described as occurring only after extensive exposure to high levels of infrasound

Other sources quoted by the Physicians for Human Rights[111] note that:

> "A review of the medical literature reveals numerous adverse cognitive effects of sleep deprivation including impaired language skills-communication, lack of innovation, inflexibility of thought processes, inappropriate attention to peripheral concerns or distractions, over-reliance on previous strategies, unwillingness to try out novel strategies, unreliable memory for when events occurred, change in mood including loss of empathy for colleagues, and inability to deal with surprise and the unexpected" (pp. 22-23).

Another line of reasoning is that there is a cause-effect relationship between AHEs and ILFN from wind turbines that mirrors that in motion sickness. Kennedy et al[120] made acceleration recordings during 193 standard training mission scenarios for two moving-base flight trainers. The pilots, who were of comparable age and experience in both groups, were interviewed for motion sickness symptomatology and tested for ataxia after leaving the simulators. Motion sickness incidence was high for one of the simulators, but not for the second. Ataxia scores departed slightly from expected improvements following exposure in both simulators. Spectral analyses of the motion recordings showed significant amounts of energy in the *nauseogenic range* of 0.2 Hz. The authors concluded that simulator sickness in moving-base simulations may be, at least in part, a function of exposure to infrasonic frequencies that make people seasick. Later, von Gierke and Parker[121] advanced the notion that motion sickness may involve an intermodal sensory conflict between visceral graviceptor signals and vestibular stimulation. Schomer and colleagues[52, 86] have argued that similarities with motion sickness may explain some of the health symptoms suffered by individuals living near IWTs, given that the inner ear is capable of responding to accelerations of the kind that lead to seasickness. These accelerations correspond to frequencies in the infrasonic range, around and under 1 Hz. Schomer[66] states that some persons affected by WTN may be responding directly to acoustic factors, rather than to non-acoustic factors, as argued by Leventhall.[14]

In a rare show of cooperation between the wind industry and independent acousticians, Pacific Hydro agreed to allow acoustician Steven Cooper, a consultant for The Acoustic Group,[25] unlimited access to its Cape Bridgewater wind project in SW Victoria, which had been in operation for about six years. The company allowed Cooper to make noise measurements and independently investigate the noise complaints of six affected residents at three residences located 650-1,600 m from the nearest turbines while the company controlled the on-off cycling of turbine operation. Given Cooper's credentials as an acoustician, the study was described as an acoustical study, as opposed to a medical study. Noise levels were based on A-, G-, and Z-weighted measurements, as well as 1/3-octave band and narrow-band measurements. Participants vacated their homes at night when necessary for Cooper to perform his acoustic studies, and they provided detailed diary accounts of their observations during on-off cycles. Those accounts included severity ratings of perceptions of noise impacts, vibration impacts, and other disturbances, which were collectively labelled as *sensations*. The sensations included headache; pressure in the head, ears, or chest; ringing in the ears; heart racing; or a sensation of heaviness. Synchronization of the timing of the residents' experiences with turbine operational data revealed heightened sensations inside their dwellings during turbine operation. Sensations were not dependent on the ability to hear or see the turbines, as residents were not aware of any of the turbines' operational characteristics. Cooper found that *sensation*, and not *noise disturbance*, was the major disturbance identified. Furthermore, sensations were most related to several different operating conditions of the turbines: at start-up, when there was an increase or decrease in power output of about 20%, and when the turbines were operating at maximum power and the wind speed increased above 12 m/sec.

Based on narrow-band data, Cooper identified a unique *wind turbine signature* (WTS) in which there was an energy peak at the blade-pass frequency and first five harmonics. Shutdown testing confirmed that the WTS, which included an amplitude-modulated signal, was present when the turbines were operating, but not in a natural environment during a turbine shutdown. Participants rated sensations as proportionally more severe as increases occurred in the magnitude of the low-frequency amplitude-modulated signature. The identification of infrasound components was consistent with earlier observations of Kelley et al.[19] Based on his findings, Cooper recommended that further studies be conducted to determine a threshold level of the WTS that protects against adverse impacts, and that the signature concept be used in medical studies by identifying energy from the operation of wind turbines, as the A-weighted scale inside homes is of no assistance in such studies.

In consideration of the above findings and observations, it is reasonable to conclude that IWTs cause AHEs and other unwanted disturbances. We next examine the physiological mechanisms that may explain how inaudible infrasound can be harmful.

In a recent paper, Berger et el[122] concluded that ILFN levels are insufficient to induce AHEs, given the levels of ILFN typically produced by wind turbines, and that guidelines for audible noise are sufficient to protect human health. Their conclusions were based on measurements of indoor infrasound levels and low-frequency noise levels at distances >500 m that were similar to background levels. While we believe the design and major conclusions of their study to be faulty, their conclusions are consistent with the position taken by Leventhall and other wind energy advocates over the past decade.

In her original description of Wind Turbine Syndrome, Pierpont[4] described a distinctive constellation of symptoms that she believed to be due to stimulation, or overstimulation, of the vestibular organs of balance as a consequence of ILFN from wind turbines. She termed these symptoms Visceral Vibratory Vestibular Disturbance (VVVD). In a follow-up report, Pierpont[100] suggested that the observed symptoms of Wind Turbine Syndrome are due to air-borne or body-borne low-frequency sounds that directly stimulate the inner ear, both the cochlea, or hearing organ, and the vestibular organs of balance and motion detection. As discussed below, research by Salt and associates shows that responses in the cochlea suppress the perception of low-frequency sound but still send signals to the brain, signals whose function is, at present, mostly unknown. The physiologic response of the cochlea to WTN is also a trigger for tinnitus and the brain-cell-level reorganization that tinnitus represents. Although cochlear and vestibular organs are housed within the same bony (otic) capsule, evolutionary adaptations have led to selective activation of auditory or vestibular hair cells. In the presence of certain disorders of the inner ear, however, anatomical defects in the otic capsule can alter the functional separation of auditory and vestibular stimuli, resulting in pathological activation of vestibular reflexes in response to sound.[123] The possibility that high-level ILFN can stimulate the vestibular organs lends credibility to Pierpont's suggestion and may explain the basis for symptoms that mimic other vestibular disorders. Physiologic responses from the otolith organs generate a wide range of brain responses, including dizziness and nausea, seasickness (even without bodily movement), fear and alerting responses such as startle and wakefulness, and difficulties with visually based problem-solving.[100] One candidate for the other destination of cochlear input from the outer hair cells may be the interface between the insula and the medial surface of the transverse (Heschl's) gyrus, where primary hearing is experienced but not recognized as sound; the latter involves adjacent secondary areas.[124]

WTN can increase alerting responses that disturb sleep, even when people do not recall being awakened. This effect is one that clearly disturbs sleep and mental well-being out to 1,400 m (4,600 ft.) from turbines, with diminishing effects out to 3 km (3 mi.), as shown in a cross-sectional study by Nissenbaum et al.[97]

Laboratory studies conducted by Salt and colleagues have provided evidence that clearly establishes the biological plausibility that infrasound can adversely affect health. That work shows that there are mechanisms in the inner ear that are capable of transducing infrasonic energy into a neural signal that can be transmitted to the brain, where the signals can lead to such symptoms as tinnitus, dizziness, pulsations, and sleep disturbance. Those studies by Salt and associates have involved laboratory experiments funded primarily by the National Institutes of Health and conducted mostly on guinea pigs, whose ears are very similar to human ears. Basically, electrodes were inserted into the inner ears to determine which structures respond to specific types of electroacoustic stimulation. Their findings help to explain why sound that is normally inaudible can result in the kinds of negative reactions reported by people who are exposed to wind turbine ILFN. Findings from their research indicate the following:

(1) The inner hair cells (IHCs) of the inner ear, which are primarily responsible for transmitting signals to the brain that are interpreted as sound, are velocity-sensitive, and thus unresponsive to infrasound. The outer hair cells (OHCs), on the other hand, are displacement-sensitive and respond to infrasonic frequencies at levels well below those that are heard (i.e., interpreted as sound). This suggests that most IWTs produce an unheard stimulation of OHCs;[56, 125, 126] specifically, at 5 Hz the OHCs can be stimulated at sound pressures 40 dB below those that stimulate the inner hair cells associated with conscious hearing.[126]

(2) Low frequencies, which are coded in the cochlear apex, require less low-frequency SPL to be amplitude modulated, when compared to higher frequencies, which are coded in the cochlear base. This means that amplitude modulation of audible sounds by wind turbine infrasound may be the basis for complaints of those living near wind turbines, including complaints such as annoyance or feelings of throbbing and rumbling sensations. It also means that infrasound from wind turbines need not be audible to annoy people, since infrasound can amplitude modulate sounds that are within the range of audibility.[54]

(3) There are several ways that infrasound could affect people, even though they cannot hear it: (a) causing amplitude modulation (pulsation) of heard sounds, (b) stimulating subconscious pathways, (c) causing endolymphatic hydrops, and (d) possibly potentiating, or exacerbating, noise-induced hearing loss.[127]

(4) Responses to infrasound reach the brain through pathways that do not involve conscious hearing but instead may produce sensations of fullness, pressure or tinnitus, or absence of sensation. Activation of subconscious pathways by infrasound could disturb sleep.[128]

(5) The presence of other, higher-pitched sounds (between 150-1,500 Hz) can suppress infrasound.[129, 130, 131] Because the ear is maximally sensitive to infrasound when higher frequency sounds are absent, this means that WTN is most disturbing to persons inside their homes at night, when background sound levels are low and higher-pitched sounds are attenuated by walls and other physical structures.

(6) A pathway exists, through the OHCs, for infrasound to reach the brain. There, parts of the brain other than auditory centers become active and the signals are perceived as something other than sound. This pathway to the brain, which also includes the vestibular mechanism of the inner ear, means that it is biologically plausible for infrasound to produce a variety of sensations, including pulsation, annoyance, stress, panic, ear pressure or fullness, unsteadiness, vertigo, nausea, tinnitus, general discomfort, memory loss, and disturbed sleep (with chronic sleep deprivation leading to blood pressure elevation and possibly changes in heart rate).

On the above grounds, Salt dismisses the common perception that *What we can't hear can't hurt us*, and has stated unequivocally that "Wind turbines can be hazardous to human health."[132]

Interestingly, Oohashi et al,[133]using non-invasive physiological measurements of brain responses, found evidence that sounds containing *high-frequency* components *above* the audible range, or ultrasound, significantly affect the brain activity of healthy human listeners. It should not be considered implausible, therefore, that infrasonic stimulation can also activate the brain.

Recent research supports the plausibility of such effects. Bauer et al,[134] using functional magnetic resonance imaging (fMRI), found a significant response down to the 8 Hz, the lowest frequency presented, to be localized within the auditory cortex. Using magnetoencephalography (MEG), significant brain responses could be detected down to a frequency of 20 Hz. The authors hypothesized that a somatosensory excitation of the auditory cortex possibly contributes at these frequencies. In a somewhat related study, He and Krahé[135] demonstrated a significant relationship between EEG reactions under different low-frequency noise exposures and subjective annoyance. Noise sensitivity was also found to be an important factor in most of the observations. The authors of these two studies suggested that EEG, fMRI, and MEG may serve as effective physiological measures to explain negative reactions to low-frequency noise.

Kugler et al[136] measured spontaneous otoacoustic emissions (SOAEs) before and after stimulation with perceptually unobtrusive low-frequency sound (30 Hz) and found significant changes to occur; these changes were positively correlated in frequency and level to pre-exposure status and lasted for about 2 min after stimulation. SOAEs are narrow-band acoustic signals that are spontaneously emitted by the inner ear in the absence of acoustic stimulation, and they can be recorded simply and non-invasively in the ear canal with a sensitive microphone. Otoacoustic emissions, first reported by physicist David Kemp,[137] are a by-product of active biophysical amplification by OHCs in the cochlea, persisting in relatively stable form for years under normal physiological conditions. The main task of the OHCs is to detect and mechanically amplify sound waves. In acting as a cochlear amplifier, OHCs actively generate mechanical energy, which is fed back into the cochlear travelling wave to maximize the sensitivity and dynamic range of the mammalian ear. In humans, non-invasive recordings of different classes of sound-evoked otoacoustic emissions (EOAEs) allow indirect access to OHC function, but only SOAE measurements can probe the cochlea in its natural state. The presence of OAEs signals a healthy ear, and their absence or changes in their response patterns can signal pathological function. The significance of the work by Kugler et al is that it reveals OHC function to be affected by a brief exposure to very low-frequency sound that is largely imperceptible. It also reveals that measures of perception severely underestimate OHC sensitivity. The authors concluded that direct quantifications of inner ear active amplification, as measured in their study, are well suited for assessing the risk potential of low-frequency sounds. In the present context, the study provides further support for the notion that what we can't hear can potentially affect us.

Motion sickness has been mentioned in this article as being among the variety of symptoms suffered by individuals living near IWTs. Recalling the work of Kennedy et al,[120] who found evidence of motion sickness in Navy pilots subjected to acceleration during flight simulation, Schomer et al[138] stated that it is plausible that the ear responds similarly to accelerations of a moving vehicle and acoustic pressures at infrasonic frequencies under 1 Hz, in the nauseogenic range. They suggested that the AHEs experienced as a consequence of exposure to IWTs not only bear a striking resemblance to motion sickness, but that the condition may be induced by stimulation of the otolithic organs in the vestibular system of the inner ear. That type of stimulation is purportedly worse when a person is subjected to pressure changes in a closed cavity, including inside one's home. Further, they describe the type of research needed to verify their hypothesis.

Michaud and colleagues have recently authored a series of papers[139, 140, 141, 142, 143, 144, 145] describing a cross-sectional epidemiological study conducted under the sponsorship of Health Canada, in which they investigated the prevalence of health effects or health indicators among a sample of Canadians exposed to WTN. The studies employed both self-reported and objectively measured health outcomes. The final sample, drawn from communities in Ontario and Prince Edward Island where a sufficient number of dwellings were located near wind turbine installations, included 1,238 participates (606 males, 632 females) living between 0.25 and 11.2 km from operational turbines. One participant between the ages of 18-79 years was randomly selected from each household. The reported response rate was 78.9% and did not significantly vary across sampling strata or provinces. Modelled A- and C-weighted WTN levels reached 46 dBA and 63 dBC, respectively, and the two levels were found to be highly correlated, which suggested that C-weighted values offered no additional information beyond that offered by A-weighted values. Only minor differences across strata were reported for age, employment, and type and ownership of dwelling. WTN exposure was not found to be related to hair cortisol concentrations, blood pressure, resting heart rate, or any of several measured sleep parameters (i.e., sleep latency, sleep time, rate of awakenings, sleep efficiency). Self-reported results obtained through an in-person questionnaire did not provide support for an association between increasing WTN levels and self-reported sleep disturbance, use of sleep medication, or diagnosed sleep disorders. Similarly, no significant association was found between WTN levels and self-reported migraines, tinnitus, dizziness, diabetes, hypertension, perceived stress or any measure of QoL. However, they observed statistically significant exposure-response relationships between increasing WTN levels and the prevalence of long-term high levels of annoyance toward noise, shadow-flicker, visual impacts, blinking lights, and vibrations.

The authors of the present report, along with a number of professional colleagues with acoustical or medical expertise, have carefully analyzed the reports by Michaud and colleagues and have concluded that the research protocol of the Health Canada study reflects shortcomings that severely undercut the conclusions that were drawn in the various reports. To enumerate the major flaws in the Michaud et al reports:

(1) They incorrectly concluded that AHEs were not found when sound levels were below 46 dBA by failing to benchmark their "surrogate control group" against the general population. Proper analysis, using a proper control group, would have resulted in high correlations of these symptoms with decreasing distances to, and increasing noise levels from, wind

turbines. In reports of the sound-exposure data, sound levels of 30-35 dBA were significantly associated with increases in the prevalence rates of symptoms. This indicates that the 40 dBA currently used as the permissible threshold in Ontario and other Canadian provinces is not protective of the public's health and welfare.

(2) Key health symptoms were reported primarily for non-vulnerable populations, in that younger individuals and individuals who had left their homes were excluded from participation. Those exclusions invalidate the study as a reflection of health conditions in the general population.

(3) Evidence provided by the World Health Organization[38] showing that exposure to noise from vehicles, railways, and aircraft is linked to serious physiological and psychological health effects at sound levels of 40 dBA and higher, and that lower levels are needed to protect the more vulnerable members of the population, was ignored in the Health Canada study. The finding that AHEs did not occur below 46 dBA should have been a warning sign to the researchers that their study design, their analyses, or both, were flawed.

Statement 4: Setback distances of 1,000-1,500 ft. (approximately 0.3-0.5 km) are sufficiently safe to protect humans from harm, regardless of height or other physical characteristics of the IWTs.

Many zoning ordinances that regulate IWTs specify the height of the turbine tower from its base to blade tip, plus 10% to 100%, as a setback distance that sufficiently protects residents against a catastrophic event such as a tower failure, a falling blade, or ice throw. Some ordinances specify a distance of twice the base-to-blade tip height, roughly 900 ft., while others arbitrarily specify slightly longer distances such as 1,500 ft. or 0.5 km. Most of the reported health symptoms have been observed at distances much greater than these setback distances. One can deduce, therefore, that *setbacks intended to protect physical health from mechanical or other traumatic failure of a wind turbine component are not adequate to protect general health and well-being.*

While terrain, weather patterns, number and size of turbines, and the turbine array itself can influence the ILFN emitted from IWTs, the two major factors are turbine size and distance from the receiver. Distance is the only practical means of achieving acceptable sound levels, as controlling the noise through the erection of barriers or enclosures near the source or receiver are not feasible or effective. Because infrasound is involved, closing windows, insulating buildings (including residences), and sleeping in basements are not normally helpful in attenuating the noise, and there is less likelihood that the emissions will be masked by wind at ground level.[60, 146] Noise levels must be measured by qualified personnel, and the sound level at the residence—or arguably at the property line—is the key element in protecting the health of residents.

To protect human health, a number of researchers have recommended specific distances, while others have recommended limitations on sound levels, irrespective of the distances needed to achieve those levels. Such recommendations are based on observed or reported complaints of AHEs. Though quite specific, the recommendations vary somewhat widely, as shown in Table 2.

The recommendations in Table 2 include boundaries of distance and noise levels of 0.5-2.5 mi. and 30-40 dB, respectively, that are believed by various professionals to protect human health. Although the use of maximum permissible noise levels appears to be the optimal approach for protecting the greatest number of people, the existence of multiple acoustic and environmental factors complicates our ability to recommend a single distance or noise level that protects most residents. Those factors are covered elsewhere in this review.

Table 2. Recommended minimum siting distances and maximum noise levels of industrial wind turbines, based on the protection of human health.

Author (Year)	Reference	Distance/Level
Pierpont (2009) Kamperman & James (2008)	4 83	Distance of 1.25 mi, or 2 km
Nissenbaum et al (2012)	97	Minimum distance of 0.87 mi, or 1.4 km, based on experimental conditions studied
Harry (2007)	74	Minimum distance of 1.5 km from nearest turbine
Frey & Hadden (2007)	90	2 km between family dwellings and IWTs of up to 2-MW installed capacity, with greater separation for a wind turbine greater than 2-MW installed capacity
Shepherd & Billington (2011)	103	4 km, to protect against amplitude-modulated turbine noise
Position of the National Institute of Public Health-National Institute of Hygiene on wind farms (2016)	147	A minimum distance of 2 km of wind farms from buildings
Cummings (2011)	39	Distance of ½ mi or greater; noise levels within 5-10 dB of existing background conditions; sound levels below 40 dBA, or even 30-35 dBA, as levels of 40 dBA or higher trigger large numbers of noise complaints
World Health Organization (2009)	38	Outdoor sound levels <40 dBA, with vulnerable populations expected to be most affected

Author (Year)	Reference	Distance/Level
Knopper et al (2014)	148	Sound levels <40 dBA, for non-participating receptors
Horner (2013)	78	Sound levels <30 dB
Harrison (2011)	42	Sound levels limited to 35 dBA at nighttime and 40 dBA during daytime hours; 5-dBA and 4-dBA penalties, respectively, imposed for the periodic or impulsive character of turbine noise and for uncertainty in noise prediction
Thorne (2013)	49	Sound levels <32 dB LAeq outside a residence

Statement 5: Annoyance is a nuisance, but it is not a health issue.

In the past few years, the position of the wind industry has changed from a blanket denial of any impact from noise to admitting that IWT noise is annoying to a substantial portion of exposed populations, and that annoyance from ILFN is a well-accepted phenomenon. While Bolin et al[18] and Ellenbogen et al[82] downplay the relationship between annoyance and WTN, the larger research community has documented that ILFN from wind turbines and other sources leads to annoyance.[12, 14, 15, 19, 21, 37, 38, 40, 42, 46, 49, 55, 58, 59, 63, 64, 74, 78, 80, 81, 90, 92, 94, 98, 99, 102, 118, 146, 149, 150]

Several investigators have concluded that annoyance increases in a dose-response relationship as distance from turbines is reduced.[44, 89, 146] A number of studies have concluded that noise annoyance appears to be worse when nearby residents have negative attitudes and when visual annoyance or intrusive sound characteristics are also involved.[e.g., 44, 65, 112, 146, 151] However, the annoyance from visual stimulation and the annoyance from noise may be entirely independent. The two irritants do not have to be linked. The common factor is that as one moves closer to a wind turbine, it is perceived as both larger *and* louder. One recent study,[152] which compared visual, audible noise, and combined visual-auditory representations of wind turbines, found noise sensitivity to correlate with both noise and visual annoyance. That study also demonstrated a reciprocal influence between auditory and visual stimuli, but in essentially a direction opposite that predicted by earlier studies of wind turbine visibility and noise. Interestingly, the study showed that a visual stimulus had a mitigating effect on noise annoyance, while an auditory stimulus had a disturbing effect on visual annoyance. This finding supports the idea that humans perceive the environment holistically and in context of all perceptual information. In suggesting that auditory and visual features are processed in close interaction, it forces us to question the idea that annoyance from WTN arises largely because the turbines are visible. Given our current state of knowledge, it seems reasonable to accept that people can be annoyed by auditory and visual irritants independently, even though there may be interactions between them.

Annoyance occurs in residents living near wind turbines at lower sound levels than for transportation noise, industrial noise, or other sources.[38, 42, 43, 58, 64, 93] Perception and annoyance have been found to be associated with both urbanized and rural terrains.[149] Pedersen et al,[146] in summarizing survey data on annoyance from wind turbines in the Netherlands and Sweden, found that 25% or more of all respondents were annoyed by levels of 40-45 dBA, while about 18-20% were very annoyed by those levels. A total of 18% found outdoor levels of 35-40 dBA to be rather annoying or very annoying outdoors and 8% found those levels to be rather or very annoying indoors. For outdoor levels of 40-45 dBA, 18% and 16% were rather or very annoyed outdoors and indoors, respectively. Because such surveys tend to emphasize *noise* from wind turbines, results often reflect levels of annoyance that relate more directly to audible sounds, as opposed to infrasound.

While few would argue that noise from wind turbines annoys a substantial percentage of nearby residents, there is disagreement over whether it leads to AHEs. Colby et al[15] stated that:

> "…there is no evidence for direct physiological effects from either infrasound or low frequency sound at the levels generated from wind turbines, indoors or outside" (p. 3-8).

They reasoned, therefore, that annoyance is not a pathological entity. Their basic contention was that although wind turbines produce infrasound, it is not harmful because people can't hear it. They contended that while some people may be annoyed by the sound from wind turbines — presumably audible sound—annoyance is primarily due to the fluctuating nature of the noise and personal attitudes. In their view, it is a psychological reaction, as opposed to a direct physiological reaction to sound. As noted above, however, several investigations[44, 89, 146] have found a dose-response relationship to exist between measured or estimated sound levels and annoyance. IWT noise emissions have been found to be a mediator between exposure and sleep disturbance and psychological distress,[89] and to be directly associated with stress.[e.g., 104]

The documented health symptoms from exposure to wind turbines are often stress-related and exacerbated by sleep disorders; they appear to be mediated through both direct and indirect pathways, and the result can be serious harm to human health.[92] There is an association between WTN, stress, and well-being, and this association is a potential hindrance to psycho-physiological restitution.[58, 98] The WHO has described annoyance as a critical health effect, in that in some people it is associated with stress, sleep disturbance, and interference with daily living.[38] A range of symptoms, often described as stress responses, have been associated with

WTN in people living in the vicinity of wind projects. As Pierpont[4] and others have noted, these symptoms include headache, irritability, difficulty concentrating, fatigue, dizziness, anxiety, and sleep disturbance. Regardless of whether the perceived impacts of noise from wind projects are physiological or psychological in nature, they are considered to cause AHEs through sleep disturbance, reducing the quality of life and serving as a source of annoyance that sometimes leads to stress-related symptoms.[71] The potential of environmental noises to induce stress reactions is well known. These reactions are dependent on how the noises are interpreted in the central nervous system; medical effects such as increased blood pressure, for example, are known to result from prolonged noise exposure.[153]

Generally, models that explain the relationship between noise and health fall into two broad categories, based on pathways that are *direct* or *indirect.* Figure 1, which is a modification of a figure from Shepherd et al,[50] depicts three models, one direct and two indirect, that have been described in the contemporary literature. The first (Fig. 1a) represents a direct pathological relationship between an environmental parameter (e.g., noise level) and a target organ that affects health. For example, in this model, noise can affect both cognition and sleep, and thus directly impact health. An alternative approach (Fig. 1b) distinguishes between direct health effects and psychosomatic illness. This approach suggests that any physiological illness coinciding with the onset of WTN may be caused by a negative psychological response to the noise, and not the noise *per se*. Any anxiety or anger resulting from the presence of WTN induces stress and strain that, if maintained, can eventually lead to AHEs. Another explanation that involves an indirect pathway from sound to health effects is one that is consistent with the WHO's definition of health.[38] That model (Fig. 1c) recognizes the role of environmental moderators, or mediators, in the determination of whether a sound is (unwanted) noise, and, if so, whether or not the noise

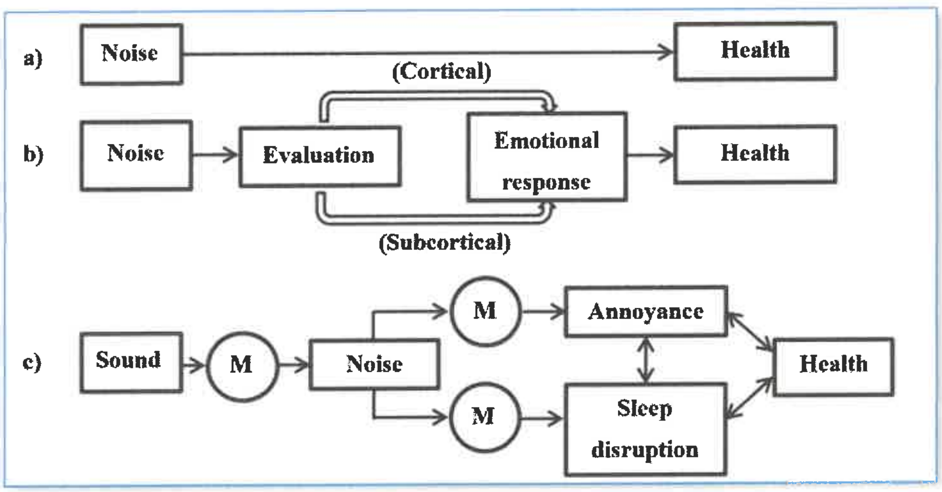

Figure 1. Three models representing the relationship between noise and health: the biomedical model (a) stipulating a direct causal relationship and indirect models (b and c) containing moderators and mediators (Adapted from original source and used with permission of first author, Daniel Shepherd).[50]

negatively impacts health. Mediators include factors such as degree of urbanization, house type, and sound level, and psychological and demographic moderators such as age, gender, education, employment status, attitudes to wind energy, noise sensitivity, and whether the individual receives a monetary return from the turbines. In this model, sleep disruption plays a major role in producing AHEs, with annoyance and sleep disruption being intervening factors between noise and AHEs for some people.

Authors of a recent study,[154] which focused on the province of Ontario, acknowledge both the link between annoyance and health and the possibility that wind projects can exacerbate psychosocial health problems through social processes such as intra-community conflict. They list socially mediated health concerns, distribution of financial benefits, lack of meaningful engagement, and failure to treat landscape concerns seriously, as the core stumbling blocks to a community's acceptance of wind energy development.

Statement 6: Noise cannot account for all of the complaints of people living in the vicinity of wind turbines; there must be another, unknown reason for the complaints.

Havas & Colling[91] have observed that wind turbines generate electromagnetic waves in the form of poor power quality (*dirty electricity*) and ground current, and speculate that these waves can adversely affect those who are electrically hypersensitive. McCallum et al[155] performed magnetic field (EMF) measurements in the proximity of 15 Vestas 1.8-MW wind turbines, two substations, various buried and overhead collector and transmission lines, and nearby homes in the vicinity of Goderich, Ontario, during high-wind, low-wind, and shut-off operational stages. They concluded that there is nothing unique to wind farms with respect to EMF emissions, finding that magnetic field levels in the vicinity of wind turbines were lower than those produced by many common household electrical devices and that levels were well within any existing regulatory guidelines with respect to human health.

Although at least a few of the health symptoms mentioned above have been self-reported by individuals who are exposed to electromagnetism, clinical trials to date suggest the link between health complaints and exposure to electromagnetism to be a purely psychological one, or a nocebo effect, in that self-described sufferers of electromagnetic hypersensitivity are unable to distinguish between exposure and non-exposure to electromagnetic fields.[156] Another review paper[157] found no convincing scientific evidence that symptoms are caused by electromagnetic fields. However, one cannot rule out that the design of the experiments upon which the review papers drew their conclusion may have missed some unique characteristic that could account for the anecdotal evidence. (See our earlier statements describing how failure to identify infrasound pulsations as a causal factor for perception at pressure levels below those needed for audibility have led some to conclude that IWT infrasound causes no harm.) When faced with health complaints from families who live near IWTs, especially when there are repeated instances of symptoms that wax and wane with alternating sequences of exposure and non-exposure, and especially when those families have taken the drastic step of abandoning their homes, it is unreasonable to argue that noise is not the cause of the complaints. Even if other factors such as electromagnetic waves are the root cause of a given complaint, it is still the placement of turbines too close to those residents that is the most likely cause of the problem.

Unfortunately, not as much is known about the effects of electromagnetism as is known about ILFN. At this point in time, therefore, it is reasonable to conclude that more people who live near wind turbines are negatively affected by ILFN than by hypersensitivity to dirty electricity or ground current, as measurable levels of ILFN from wind turbines are highly associated with individual complaints. When Stigwood et al[57] studied and analyzed complaints at over 75 wind developments in the U.K., they found that identifying the problems was straightforward, occurrence was common (i.e., some residents reported problems in all developments), all developments generated excess amplitude modulation (AM), and AM was the cause of the vast majority of the complaints. These findings have recently been reinforced by Cooper's work[25] in Australia.

Statement 7: Infrasound from wind turbines is sufficiently correlated to the A-weighted sound emissions to allow an A-weighted model to be used to predict how much infrasound is present in homes.

This statement is not typically stated explicitly, but it is one that is inherent in the positions commonly taken by wind energy advocates and regulatory bodies through their interpretations and acceptance of research on WTN, which is based largely on A-weighted levels. As noted in many previous papers, including one of our own,[101] the continued use of the A-weighting scale in sound level meters is a major basis for misunderstandings that have led to acrimony between advocates and opponents of locating wind turbines in residential areas. The dBA scale was devised as a means to incorporate into measurements of environmental and industrial SPLs the inverse of the minimum audibility curve[158] at the 40-phon level. It is typically used, though, to specify the levels of noises that are more intense, where the audibility curve becomes considerably flattened, obviating somewhat the need for A-weighting. Use of the A-weighted scale is mandated or recommended in various national and international standards for measurements that are compared to damage-risk criteria for hearing loss and other health effects resulting from occupational or environmental noise exposure. It drastically reduces sound-level readings in the lower frequencies, beginning at 1,000 Hz, and reduces sounds at 20 Hz by 50 dB. For WTN, the A-weighting scale is especially inappropriate because of its devaluation of the effects of ILFN. Many authors have commented on its inadequacy. For example, Pederson and Persson Waye[159] state:

> "There is… support both from experimental and field studies that intrusive sound characteristics not fully described by the equivalent A-weighted sound pressure level contribute to annoyance with wind turbine noise" (p. 4).

A number of researchers have recommended comparing C-weighted measurements to A-weighted measurements when considering the impact of sound from wind turbines.[10, 12, 37, 61, 67, 75, 76, 83, 101] According to these sources, the presence of infra- and low-frequency sound is generally indicated when the difference between levels on the two scales differs by 10-20 dB. When such differences are observed, the use of third-octave or linear-scale measurements is typically recommended (for example, see Shepherd et al[50]). Other weighting scales have been suggested for wind turbine applications, but at present, linear-scale or narrow-band measurements, used in conjunction with a conventional sound level meter (with low-frequency microphone) and micro barometer, offer the best potential for accurately and completely describing the soundscape in the vicinity of IWTs.

As noted above, Cooper[25] has suggested that A-weighted levels, measured inside homes, are not likely to be useful indicators of AHEs. That report concluded that A-weighted levels are not a valid index of protection from AHEs and recommended the further exploration of a newly developed *wind turbine signature* scale, based on the discovery of its capability to quantify the amplitude-modulated peak energy in the infrasonic frequency region. That scale was shown to be directly linked to a variety of adverse bodily sensations when nearby turbines were operating or undergoing transitions in operation.

Although A-weighted sound level measurements have been the *sine qua non* for specifying environmental and occupational noise levels for many decades, we must recognize the inherent inadequacies of applying the A-weighting scale to quantifying noise emitted by IWTs. Bray[160] goes even further by noting that people, and not electronic devices, are the ultimate analysts of data that affect their responses to sound, making the point that people's responses should be given the credence they deserve, and not be devalued when physical measurements fail to confirm them.

Statement 8: Wind Turbine Syndrome has not been accepted as a diagnostic entity by the medical profession, so medical professionals cannot diagnose or treat it.

Currently, Wind Turbine Syndrome is not included in the International Classification of Diseases (ICD) coding system, which is used globally for purposes of establishing categories for diagnosing diseases and other health conditions, and as a basis for reimbursing medical providers for diagnostic and treatment services. Yet, of the 10 symptom sets comprising Pierpont's Wind Turbine Syndrome,[4] at least seven are included as a category or subcategory in the newly revised (ICD-10) coding system. The fact that the syndrome itself is not included may be due to its relatively recent discovery, but is more likely due to the fact that the syndrome consists of symptoms that are highly variable from person to person and affect a minority of the exposed population.

Especially in legal proceedings, it is important to distinguish between the terms *differential diagnosis* and *causation assessment*. It is the latter that is most often the subject of such proceedings. Attorneys and expert witnesses often get the terms confused. Differential diagnosis refers to the identification of disorder(s) that may account for a particular complaint or symptom complex. It rarely deals with the external cause of the disorder. Causation assessment, on the other hand, typically requires an evaluation of whether potential causative agents have irritating properties; a determination of the approximate amount of exposure, or dose, of that agent, and the timing between exposure (and non-exposure) and the occurrence of symptoms; and an assessment of whether alternative potential causes of the disorder can be ruled out. These latter steps are not necessarily considered part of the diagnosis.

Notwithstanding the fact that Pierpont herself is a practicing pediatrician, a couple of recent developments would appear to increase the prospect that medical personnel will soon be able to establish Wind Turbine Syndrome, by that or a similar label, as a clinical entity caused by exposure to WTN. Dr. Robert McMurtry, a physician who is a special advisor to the Canadian Royal Commission on the Future of Health Care, and a long-time advocate for more effective public involvement in healthcare policy, recently published a set of highly specific criteria for establishing such a link. McMurtry[161] originally proposed a case definition that identifies first-, second-, and third-order criteria, as well as specified circumstances and symptoms that must be established before AHEs can be attributed to wind turbine exposure. According to those criteria, probable AHEs are present when:

(1) All four of the following first-order criteria are met: (a) The individual resides within 5 km of IWTs, (b) Health status is altered following the start-up of or initial exposure to, and during

the operation of, IWTs (a latent period of up to 6 months may be allowed), (c) Amelioration of symptoms occurs when more than 5 km from the environs of IWTs, and (d) Recurrence of symptoms occurs upon return to the environs of IWTs within 5 km.

(2) At least three of the following second-order criteria are met (occurring or worsening after the initiation of operation of IWTs): (a) Compromised quality of life, (b) Continuing sleep disruption, difficulty initiating sleep, and/or difficulty with sleep disruption, (c) Annoyance producing increased levels of stress and/or psychological distress, and (d) A preference to leave the residence temporarily or permanently for sleep restoration or well-being.

(3) At least three specified symptoms occur or worsen following the initiation of IWTs, those symptoms referred to as third-order criteria that fall within the following categories: (a) Otological and vestibular disorders, (b) Cognitive disorders, (c) Cardiovascular disorders, (d) Psychological disorders, (e) Regulatory disorders, or (f) Systemic disorders.

To be confirmed as AHEs from WTN exposure, McMurtry indicated that consideration should be given to other stressors present in the community, that sleep studies be carried out if at all possible, and that a licensed physician be able to rule out alternate explanations for AHEs. These alternate explanations include substantial barometric changes from prevailing winds, a stressful home environment, and psychological and/or mood disorders, all of which can normally be ruled out when symptoms subside or disappear when the individual leaves the vicinity of the wind turbines. Apart from these three factors, he indicates that there are very few, if any, other health conditions that can mimic those caused by exposure to wind turbines and at the same time meet the three orders of criteria outlined in his case definition. More recently, McMurtry and Krogh[162] published a revised case definition, in which the third-order criteria—which are commonly present—are not considered essential elements. In both papers, the authors acknowledged that the identification of IWTs as the cause of adverse health symptoms is a complex emerging issue that requires further study to validate the criteria. They proposed key elements that ought to be included in any model used to assess the validity of the case-definition criteria.

McCunney and colleagues[163] have challenged those case definitions as having poor specificity, leading to a substantial potential for false-positive assessments and missed diagnoses. A potential fallacy in this challenge is that the authors unnecessarily conflate the concept of case definition for medical practitioners with that of an epidemiologic research plan. The case definitions presented by McMurtry[161] and McMurtry and Krogh[162] represent guidelines for medical doctors whose individual patients are experiencing new or unusual symptoms. It is erroneous to purport that a physician's mental process can be encapsulated into a set of equations, especially during the earliest stages of developing a case definition. The criticisms of these early case definitions should not deter physicians from attempting to evaluate and treat patients who report AHEs after living in the vicinity of IWTs. This area may indeed benefit from further study. Our view, however, is that such criteria provide an adequate starting point for guiding medical practitioners.

Dr. Steven Rauch, an otolaryngologist at the Massachusetts Eye and Ear Infirmary and a professor at Harvard Medical School, recently declared that he believes Wind Turbine Syndrome to be a real phenomenon.[164] As reported by numerous websites and newspapers, multiple patients have sought treatment from him for AHEs stemming from consistent exposure to IWTs. Rauch compares the syndrome to migraine headaches and believes that people who suffer from migraines are among the most sensitive to the effects of WTN, and he has stated that the wind industry aims to suppress the notion of Wind Turbine Syndrome by blaming the victim.

Given these developments, it is possible that the medical profession may someday embrace Wind Turbine Syndrome—by that or another name—as a clinical entity. This prospect is encouraging, as such acceptance by the profession will facilitate efforts to protect individuals from the harmful health effects of exposure to IWTs. Even though it may be some time before such a diagnostic label is formally acknowledged as an ICD code, it is currently possible for physicians to identify many of the specific symptoms associated with wind turbine exposure and to bill for diagnosing and treating those symptoms, with or without regard for their underlying cause. Paradoxically, it is apparently the case that the most effective treatment for AHEs associated with WTN exposure is non-medical in nature; it is to recommend that patients physically remove themselves from the vicinity of IWTs.

Statement 9: Peer-reviewed epidemiological literature is the only acceptable basis for proving a causative relationship between wind turbine noise and adverse health effects.

This issue runs as a thread through virtually all the other issues addressed in this paper, as it relates to the kind of scientific evidence frequently called for, especially in legal settings, to prove that IWTs are the cause of AHEs. While personal physicians of complainants in legal cases are often considered the only expert witnesses qualified to establish *specific causation*, others can testify to *general causation*, which is the methodology by which scientists determine whether or not an agent is responsible for producing a particular disorder. In general, this requires evaluation of the scientific and medical literature to identify documented instances of health-related conditions arising from exposure to specific agents and, when available, the dose-response relationships between agents and their effects. This process is highly similar to that of *causation assessment*, as explained above, and it does not necessarily require the input of a complainant's personal physician, although such input may be helpful. In legal cases involving WTN, it is critical that expert witnesses in acoustics and health be able to reconcile their positions with the reports and standards of the WHO,[165] the International Organization of Standards (ISO),[166] and the American National Standards Institute/Acoustical Society of America (ANSI/ASA)[167] that have linked low-frequency noise to symptoms of the type involved in complaints. These acoustical documents and research reports are seldom, if ever, included in literature reviews used by the industry to deny potential health risks. If challenged on the validity of the available evidence, acousticians need to be knowledgeable of the relevant acoustical standards and make sure that they are understood by all parties. In reality, the wind industry's almost universal refusal to cooperate with researchers has made it virtually impossible to conduct proper acoustical or epidemiological studies. The industry has been largely unwilling, or claims it is unable, to shut down or modify operations of its turbines for experimental purposes. To date, such a situation has rarely occurred, most notably in the case of the Cape Bridgewater study.[25]

The veracity of Statement 9 is strongly challenged by the classic address by Sir Austin Bradford Hill,[168] Professor Emeritus of Medical Statistics, University of London, to the newly founded Section of Occupational Medicine of the Royal Society of Medicine. In his essay, Hill shared his thinking about association and causal evidence surrounding environmental disease. He posited nine elements that are critical in establishing causation:

(1) *strength* (strength of observed relationships),
(2) *consistency* (consistency, or repeatability, of relationships, based on observations by different persons, in different places, under different circumstances, and at different times),
(3) *specificity* (causation is indicated if the association is limited to specific individuals and to particular sites and types of disease and there are no associations with other factors),
(4) *temporality* (there is a clear temporal relationship between outcomes and periods of exposure and non-exposure),
(5) *biological gradient* (a dose-response relationship exists),
(6) *plausibility* (causation is more likely when certain outcomes are biologically plausible, or possible, a caveat being that plausibility depends on the biologic knowledge of the day; this element is best expressed in the statement: "When you have eliminated the impossible, whatever remains, however improbable, must be the truth" (p. 10),

(7) *coherence* (the cause-and-effect interpretation of data should not seriously conflict with generally known facts of the natural history and biology of the disease),

(8) *experiment* (experimentation or semi-experimental evidence, even if only occasional, can reveal the strongest kind of evidence for causation), and

(9) *analogy* (the recognition that similar cause-effect relationships have occurred under similar conditions).

Hill states:

> "What I do not believe (is) …that we can usefully lay down some hard-and-fast rules of evidence that must be obeyed before we can accept cause and effect. None of my nine viewpoints can bring indisputable evidence for or against the cause-and-effect hypothesis and none can be required as a *sine qua non*. What they can do, with greater or less strength, is to help us to make up our minds on the fundamental question – is there any other way of explaining the set of facts before us, is there any other answer equally, or more, likely than cause and effect?... No formal tests of significance can answer those questions. Such tests can, and should, remind us of the effects that the play of chance can create, and they will instruct us in the likely magnitude of those effects. Beyond that they contribute nothing to the 'proof' of our hypothesis" (p. 299).

Hill makes this final observation in his essay:

> "All scientific work is incomplete – whether it be observational or experimental. All scientific work is liable to be upset or modified by advancing knowledge. That does not confer upon us a freedom to ignore the knowledge we already have, or to postpone the action that it appears to demand at a given time" (p. 300).

Extrapolating from Hill's essay, the totality of our knowledge gained from the available evidence must be considered when examining the link between WTN and AHEs. Fortunately, in addition to experimentation, this evidence includes simple tools that are useful, particularly if we are willing to recognize their collective value. Those tools begin, but do not end, with adverse health reporting.

Dr. Carl Phillips, a specialist in epidemiology and science-based policy making, and a former professor of public health, has stated:[169]

> "In cases of emerging and unpredictable disease risk, adverse event reports are the cornerstone of public health research. Since it is obviously not possible to study every possible exposure-disease combination using more formalized study methods, just in case an association is stumbled on, collecting reports of disease cases apparently attributable to a particular exposure is the critical first step" (p. 304).

He gives familiar examples of hazards revealed by adverse event reporting, including infectious disease outbreaks and side effects from pharmaceuticals. He points out that:

> "Pharmaceutical regulators rely heavily on clearinghouses they create for adverse event reporting about drug side effects (and often become actively concerned and even implement policy interventions based on tens of reports)" (p. 304).

Phillips indicates that the case of wind turbines and health fits the same pattern. He describes adverse event reporting as a special type of case study—sometimes denigrated as anecdotes—that generally reports on the rapid onset of a disease that appears to be related to a particular exposure. He advocates self-reporting of adverse events as a highly useful approach in studying the health effects of wind turbines. In addition, he advocates the use of case-crossover experiments as useful and well-accepted sources of epidemiologic information, stating that they are intuitively recognized by both experts and laypersons seeking to assess whether an exposure is causing specifiable outcomes.

Other forms of evidence, all considered scientific, have been or can be used to determine the impacts of WTN on health. These include case studies, case-series studies, and other pre-experimental, quasi-experimental, true experimental, correlational analysis, and single-subject designs. Single-subject designs, like the case-crossover design used by epidemiologists, can also be applied across multiple individuals to reveal relationships between specific interventions and changes in outcomes in individuals or groups. In both designs, subjects serve as their own controls while crossing over from one treatment to another (A vs. B) during the course of the experimental trial. Both are flexible designs and useful in studying events that are infrequent or sporadic. Numerous individuals living near IWTs have experienced health symptoms that have waxed and waned during repeated cycles of exposure (A) and non-exposure (B), which indicates that the wind industry has unwittingly engaged individuals and families worldwide in a series of quasi-empirical studies for many years, without obtaining informed consent from un-enrolled subjects, typically by downplaying any concerns about potential health impacts. The outcomes from these experiments offer some of the strongest evidence available that there is a causative link between WTN and AHEs in some individuals.

According to the WHO,[170] epidemiology is "the study of the distribution and determinants of health-related states or events (including disease), and the application of this study to the control of diseases and other health problems. Although the randomized clinical trial (RCT) is generally considered the *gold standard* of designs for establishing causation, various methods can be used to carry out epidemiological investigations: surveillance and descriptive studies can be used to study distribution; analytical studies are used to study determinants." Epidemiology uses a systematic approach to study the differences in disease distribution in subgroups and allows for the study of causal and preventive factors.[171] Descriptive epidemiological studies describe the occurrence of outcomes, and analytical studies reveal associative linkages between exposure and outcomes. Descriptive studies include primarily case reports and case-series studies. Analytic designs include experimental studies such as community trials and randomized controlled clinical trials, and observational studies, in which observations can be made retrospectively, concurrently, or prospectively. Observational studies include those in which either grouped (i.e., ecologic) or individual data are collected, the latter normally favored by the scientific community. Those designs involving individual data include cross-sectional, cohort, case-control, and case-crossover studies. Although epidemiological studies rely on statistical analyses of relationships between exposure to specific agents and AHEs in relatively large samples of the population, they are not aimed at revealing the cause of a disease or disorder in specific individuals. A cogent summary of research designs used in *evidence-based medicine* can be found online.[172]

Cross-sectional studies survey exposures and disease status at a single point in time in a cross-section of the population. They measure prevalence, not incidence, of a disease process, and have the disadvantage of difficulty in establishing the temporal sequence of exposure and effect. Also, rare and quickly emerging events may be difficult to detect. Their major advantage is that data can be collected at the same time on all participants, which means the study can be completed in a relatively short time. Notably, several cross-sectional investigations of the effects of WTN exposure have been reported.[44, 97, 98, 99, 104, 149] These studies serve as major contributions to the scientific literature on the subject.

Cohort studies involve an observational design in which a sample of the population is followed to discover new events.[75] They compare individuals with a known risk factor or exposure with others without the risk factor or exposure and aim to determine whether there is a difference in the risk, or incidence, of a disease over time. They tend to be the strongest observational design, especially when the data are collected prospectively, as opposed to retrospectively. Compared to the cross-sectional design, cohort studies tend to require more time, which partially explains the paucity of such studies involving wind turbine exposure.

Case-control designs compare exposures in diseased cases vs. healthy controls from the same general population. Specific disease states must be known prior to initiation, and exposure data must be collected retrospectively. This design can be applied to cases of IWT exposure, despite the fact that it requires the cooperation of affected and unaffected segments of the same population, a circumstance made difficult by attempts on the part of energy companies to maintain confidentiality and privacy as a means to facilitate wind turbine development in areas involving both participants and non-participants.

In case-crossover studies, which are a special type of case-control design, the *case* and *control* components reside in the same individual. This design is especially useful in investigating triggers of a disease process within an individual. In the behavioral sciences, it is commonly referred to as a *single-subject design*, as already described. The case component signifies the hazard period, which is the time period before the disease or event onset (e.g., exposure to IWTs), and the control component signifies a specified time interval other than the hazard period, namely the non-exposure interval. As already mentioned, wind companies themselves have unwittingly subjected residents to the basic conditions of this design, and results clearly suggest that exposure to WTN leads to a variety of health complaints in some individuals and families. Phillips[79] argues that:

> "A case-crossover study is one of the most compelling sources of epidemiologic data. It consists of observing whether someone's outcomes change as their exposure status changes. This is often not possible because the outcomes only happen a single time as a result of long-term exposure (e.g., cancer) or the exposure cannot be changed. But the observed effects of turbine exposure lend themselves perfectly to such studies because the exposure is transient and the effects, while not instantaneous in their manifestation or dissipation, are generally transient over a period of days or weeks at most. Thus, unlike a case of a lifelong exposure or non-transient disease, where we can only make one observation about disease and outcome per person, the effects of turbines allow multiple observations by the same person, including experimental interventions" (p. 305-306).

Turning to experimental designs, the clinical trial is considered the ideal design to test hypotheses of causation. In a clinical trial, the investigator has control of the exposure to an extent similar to a laboratory experiment. The subjects generally are randomly assigned to one of at least two groups, an experimental and a control group. The experimental group receives the treatment (i.e., exposure in the case of wind turbines) and the control group does not; instead, it usually is subjected to a condition that simulates a generic treatment of some type, and the purpose and procedures of the control condition are explained only after the experiment ends.

A fully developed clinical trial of residents who live near wind turbines has never been conducted, and the reasons are fairly clear if we consider the circumstances surrounding such a trial. In a rigorous trial done to establish the link between AHEs and WTN, the investigator would randomly assign hundreds of people selected from the general population—including adults and children, elderly adults, and chronically ill adults—to either an experimental or a control group. Randomization would control for pre-experimental biases toward or against wind energy, as well as for other factors that could confound the outcome. The experimental group would be required to spend a significant period (day and night for weeks or months) in homes located between approximately 1,000 ft. and several miles from the nearest wind turbine. The control group would be required to take up residence several miles or more away from the nearest wind turbine, where they would presumably be free from any effects due to extraneous noise or infrasound. Homeowners who leave their homes, as well as research participants occupying those homes, would have to adjust to new residences and modify their work and school activities, eating patterns, and overall lifestyles. Participants in both groups and at least some of the homeowners who vacate their homes for the experiment would have to be reimbursed for their participation, as well as for the costs incurred as a result of their participation, and the research staff would also have to be paid. To maintain some control across sites, the average age and health status within each group should be equivalent, and data would have to be gathered regarding such factors as turbine size, wind speed and other weather conditions, length of time the turbines were operating, terrain, the exact distance of each participating family from the nearest turbines, and actual noise levels present outside and inside the homes. Scientifically rigorous methods for measuring low-frequency noise and infrasound would have to be agreed upon and used. Although self-report via a survey technique could be part of the experimental design, medical examinations and physiological measurements, including sleep studies, should also be incorporated into the research protocol.

While possible, it is not practical to expect such a study design, in its ideal form, to be implemented. Aside from the difficulty of recruiting and enrolling enough families in enough geographic areas to form statistically strong samples, legitimate ethical questions should be raised regarding the exposure of individuals, especially children and other vulnerable individuals, to potentially hazardous conditions. One might conjecture, however, that consent to participate in such a study could be gained from fully informed adults because the effects of WTN are widely believed to be reversible when a period of non-exposure follows a period of exposure.

Statement 10: The nocebo effect, a manifestation of psychological expectations, explains why people complain of adverse health effects when living near wind turbines.

This statement is the core position of some of the most outspoken critics of the view that IWTs cause AHEs. Any discussion of this statement should begin with an acknowledgment that human behavior and beliefs are highly variable and are often driven by psychological and emotional influences, and not just by observations, logic, intellectual knowledge, or cognitive thought processes. It is not surprising, therefore, that some have adopted the view that negative reactions to wind turbines are based primarily or solely on psychological expectations. Our analysis of the limited literature on the topic leads us to state unequivocally that it is lacking in scientific rigor. Even if the results were as described, the existing studies and observations do not support a conclusion that psychological forces are the only or even primary explanation for most of the negative reactions toward IWTs. Here, we will critically review four papers, all supporting a psychological explanation for the negative reactions.

Chapman et al[173] tested four hypotheses relevant to psychogenic explanations of the variable timing and distribution of health and noise complaints about wind farms in Australia. They obtained records from the wind companies of complaints about noise or degraded health from residents living near 51 wind projects operating between 1993 and 2013 and corroborated those records with complaints documented by three government public agencies, news media records, and court affidavits. Complaints were expressed as proportions of estimated populations residing within 5 km of a wind project. The authors concluded that historical and geographical variations in complaints were consistent with psychogenic hypotheses expressing health problems as "communicated diseases," with nocebo effects likely to play an important role in the etiology of complaints.

Nocebo effects are commonly described as being the opposite of placebo effects. While the *placebo effect* usually refers to a positive reaction to an inert substance—the placebo—the *nocebo effect* refers to a negative reaction to an inert substance—the nocebo. Both effects are psychogenic, but known to exert powerful influences on human physiology, behavior, and attitudes. Essentially, Chapman and his supporters believe that psychogenic reasons are the basis for health complaints about wind turbines, which they believe to be harmless.

Our major criticism of the work of Chapman et al is that wind companies typically engage in practices that discourage local residents to complain. These companies require participating residents to sign contracts before turbines are constructed and before the residents can receive compensation for leasing their land, and they often request non-participating residents to sign contracts prior to initiating a project. Those contracts, which are binding, often include gag clauses that effectively limit resident complaints. The contracts have often stipulated not only that residents refrain from voicing negative views of the wind project, but also that they support the development of future projects. Such conditions create an atmosphere in which is it is highly unlikely that the records of wind companies, governments, courts, or the media will sufficiently reflect all of the complaints that residents have and would voice under less-restrictive circumstances. We argue that the only way to gather accurate data on such complaints is through a survey of either an adequate sample of residents living near multiple wind projects or all such residents, where residents are free of restrictions by the wind companies. Such data would allow a valid determination of the proportion of residents who experience adverse effects. Whether that proportion is large or small, we could all act on the basis of factual evidence, as opposed to incomplete observations.

Another shortcoming of the study by Chapman et al,[173] which is less well documented but a factor observed in legal cases in which the present authors have been involved, is that residents near IWT projects tend to be delayed in their responses to AHEs. Many of them believe their health problems to be linked to other causes before suspecting that the turbines are the cause. Some or most of these individuals were supporters of wind projects prior to experiencing such problems, as Phipps et al[75] noted in New Zealand. The delay factor would mean that the types of records used by Chapman et al would not likely reflect the reactions of many affected residents.

Crichton and colleagues conducted two laboratory investigations, each of which has bolstered the argument that negative reactions to audible and inaudible WTN can be explained by psychological expectations. Crichton et al[174] conducted what they described as a sham-controlled double-blind provocation study, in which participants were exposed to 10 min of infrasound and 10 min of sham infrasound. Fifty-four participants were randomized to high- or low-expectancy groups and presented with audio-visual information, using material from the Internet that was designed to invoke either high or low expectations that exposure to infrasound causes specified symptoms. High-expectancy participants reported significant increases, from pre-exposure baseline assessment, in the number and intensity of symptoms experienced during exposure to both infrasound and sham infrasound. There were no symptomatic changes in the low-expectancy group. Healthy volunteers, when given information about the expected physiological effect of infrasound, reported symptoms that aligned with that information, during exposure to both infrasound and sham infrasound. According to the authors, results suggest that psychological expectations are sufficient to explain the link between wind turbine exposure and health complaints.

Punch[175] has criticized that study as methodologically weak, on the following grounds:

(1) Subjects were never exposed to infrasound that adequately represented that to which residents near wind turbine projects are subjected. It is extremely unlikely that the employed studio woofer was capable of producing a 5-Hz stimulus; the authors did not describe or show a graph of the output spectrum. Even if a true infrasound stimulus was produced by their equipment, 40 dB (presumably SPL) was not sufficient to represent the level of

infrasound commonly produced by IWTs. Even if a sufficient stimulus had been produced to represent wind turbine infrasound, a 10-min exposure would have been meaningless in representing the duration of exposure that is likely necessary to produce any substantial health symptoms.

(2) In effect, subjects were exposed to two sham conditions. If they had been exposed to infrasound that adequately mimicked infrasound from IWTs (preferably actual IWT infrasound), subjects in both the high- and low-expectancy groups would have had a physical stimulus (in the infrasound condition) that could have overridden, or at least moderated, their psychological reactions.

(3) The design limited the study's external validity, the ability to generalize the results to other populations and situations. Most of the individuals who have reported AHEs from WTN, some of whom have abandoned their homes, are not people who were adequately warned of potential health effects prior to their exposures. In fact, most of them were likely told by the wind company to expect no harmful effects. Again, many individuals who report AHEs were advocates of wind energy prior to being exposed. Because the major premise underlying the study is that people complain of WTN based primarily on expectancies that align with prior information, the study is based on a false premise. Also, the recruitment of university students does not represent the type of subjects who are apt to complain about WTN. This population is probably the least vulnerable to the effects of WTN in that few, if any, were very young, very old, likely to have chronic health conditions, or disabled. Also, they are more likely to exhibit a response bias because they are less likely than prospective residents of a wind project to believe that they might be harmed by participating in an experiment. Furthermore, the extensive use of pretesting introduced reactive or interactive effects that could have affected post-test behaviors and ratings. Finally, the use of a laboratory setting and short exposure times, as opposed to a real-life setting in which wind turbine blades are turning at night and the subjects are inside a home, introduced situational effects that limit the ability to generalize the data. The authors admit this shortcoming in their statement:

> "… exposure to infrasound in a listening room purpose (sic) built for sound experiments may not be directly comparable to exposure to infrasound from a wind farm" (p. 4).

(4) This was an experiment whose outcomes could have been predicted, given the conditions employed. Aside from the fact that the outcome had virtually nothing to do with the real-world conditions of exposure to infrasound from wind turbines, none of the factors that influence how expectations can affect perceptions through top-down, or cognitive- based, processing, as opposed to bottom-up, or stimulus-based, processing, were controlled or even

discussed. (Interested readers should refer to Williams[176] for examples of the effects of top-down processing and for a discussion of how such experiments might be improved.)

In a second laboratory study by Crichton and colleagues,[177] similar in design to the first, the authors investigated whether positive expectations can produce a reduction in symptoms and improvements in reported health. Sixty participants were randomized to either positive or negative expectations and subsequently exposed to audible wind turbine sound and infrasound. According to the authors,

> "Participants were … exposed to infrasound (9Hz, 50.4dB) and audible wind farm sound (43dB), which had been recorded 1 km from a wind farm, during two 7-minute listening sessions. Both groups were made aware they were listening to the sound of a wind farm, and were being exposed to sound containing both audible and sub audible components and that the sound was at the same level during both sessions" (p. 2).

Prior to exposure, negative-expectation participants watched a DVD incorporating TV footage about health effects said to be caused by infrasound produced by wind turbines. In contrast, positive-expectation participants viewed a DVD that:

> "…framed wind turbine sound as containing infrasound, sub audible sound created by natural phenomena such as ocean waves and the wind, which had been reported to have positive effects and therapeutic benefits on health" (p. 2).

The authors described the results as indicating that during exposure to audible wind turbine sound and infrasound, symptoms and mood were strongly influenced by subject expectations. Negative-expectation participants experienced a significant increase in symptoms and a significant deterioration in mood, while positive-expectation participants reported a significant decrease in symptoms and a significant improvement in mood. The authors concluded that if expectations about infrasound are framed in more neutral or benign ways, then it is likely that reports of symptoms or negative effects could be nullified.

That second investigation by Crichton and colleagues has some of the same methodological weaknesses as the first, particularly with respect to the use of what was described as experimental infrasound. Again, recordings of WTN were used, and no description of the recording instrumentation was provided, leading us to assume that the instrumentation may have been incapable of accurately reproducing infrasound, and thus its true effects. All participants were informed of the purpose of the study, which was:

> "…to investigate the effect of sound below the threshold of human hearing (infrasound) on the experience of physical sensations and mood" (p. 2).

Preferably, the purpose should have been divulged only after the data were gathered because the description of sounds as those that humans cannot hear would presumably have established a mind-set, or bias, in both groups that the sound would have little impact. That preconception could have confounded any reactions to the different DVD messages. Another criticism of the study is that wind companies frame their turbines in the best possible light, so positive expectations have already been established in the minds of most wind-project participants and non-participants. Despite neutral or positive framing that has sometimes included assurance that the turbine sounds would be no louder than that of a refrigerator (see, for example, Chen & Narins[178]), the consequences of living near IWTs are catastrophic for some residents.

Tonin et al[179] repeated the experimental work of Crichton and her colleagues by using specially modified headphones to produce infrasound, as opposed to the loudspeaker system used in the previous studies, and exposed participants to 23 min of infrasound, as opposed to the 10-min exposures in the Crichton studies. Similar results were reported, suggesting that the simulated infrasound had no statistically significant effect on the symptoms reported by volunteers, while the prior expectations the volunteers had about the effect of infrasound had a statistically significant influence on the symptoms reported, thereby supporting the nocebo effect hypothesis. Some of the same criticisms of the Crichton et al study[174] levelled by Punch[175] also apply to the Tonin et al study, as participants were not being stimulated by sufficient durations or peak levels of infrasound exposure to which residents living near IWTs are exposed, and participants were effectively exposed to two sham conditions, denying them any opportunity to experience realistic infrasonic stimuli that could have overridden or moderated their psychological reactions based on expectancy.

In a related study, Taylor et al[180] assessed the effect of negatively oriented personality (NOP) traits (Neuroticism, Negative Affectivity and Frustration Intolerance) on the relationship between both actual and perceived noise on "medically unexplained non-specific symptoms (NSS)" (p. 338), presumably their euphemism for Pierpont's Wind Turbine Syndrome.[4] Households within 500 m of 8 0.6-kW micro turbine installations and within 1 km of 4 5-kW small wind turbines in two U.K. cities were surveyed, and 138 questionnaires were completed and returned for analysis. Turbine noise level for each household was also calculated. There was no evidence for an effect of calculated noise on NSS. A statistically significant relationship was found between perceived noise and NSS for individuals high in NOP traits.

That study is similar in concept to those performed by Crichton and colleagues,[174, 177] with virtually the same conclusion—that the link between wind turbines and AHEs has a psychological origin. The study can be criticized on several grounds:

(1) Only smaller wind turbines were investigated; there is virtually no literature demonstrating that such turbines produce noise levels of any consequence to humans. The fact that no relationship was found between "calculated actual noise" from the turbines and participants' attitudes toward wind turbines was thus predictable because the noise levels were either too low to affect attitudes differentially or were completely inaudible.

(2) The authors state:

> "Actual noise turbine level for each household was also calculated" (p. 338).

Calculated levels (from noise maps) are not necessarily actual levels, so this procedure was, at a minimum, mischaracterized.

(3) It should not be surprising to find that individuals with negatively oriented personalities respond negatively to WTN, as they would likely respond negatively to almost any stimulus. However, the findings, as acknowledged by the authors, resulted from reports of participants' retrospective perceptions of noise from turbines and symptoms at the same point in time, possibly resulting in common-method variance and retrospective bias. Also, although the authors reported a statistically significant relationship between NSS and negatively oriented personality, the reported variance explained by those relationships was quite low. That finding suggests that a meaningful (i.e., clinical) significance was not established, in which case one might reasonably question whether symptom reporting in the study was actually linked to negative personality type.

(4) Among other possible confounders, individual differences are likely to have complicated the authors' analyses (see Williams[176] for an explanation).

To conclude this section, we believe that while psychological expectations conceivably can influence perceptions of the effects of WTN on health status, no scientific studies have yet convincingly shown that psychological forces are the major driver of such perceptions. Based on the bulk of literature covered in this review, those drivers are the physical stimuli themselves and the internal physiological reactions they induce.

Statement 11: Only relatively few people, if any, are adversely impacted by wind turbine noise, and the majority have no complaints.

As indicated earlier, most of the studies that have documented specified percentages of the population adversely affected by WTN have been those focusing on annoyance, as opposed to health. While the exact percentage of people whose health is affected by WTN has not been accurately determined, countless reports worldwide suggest that the acoustic energy emitted by

IWTs is harmful to the health of substantial numbers of people. As already noted, Phipps et al[75] found that 45% of households living as far away as 4 km from a wind project and 20% of households living up to 8 km away reported hearing turbine noise. Those figures take into account only the audible noise, of course, and not the inaudible infrasound, and they do not account for any documented adverse impacts.

Estimates of the percentage of people adversely affected by WTN should not be based solely on questionnaire surveys of populations known to be experiencing health problems, due to selection bias. Such surveys can be helpful in arriving at rough estimates of AHEs, however, but only if those surveys also report estimates of the total population from which the affected sample is drawn. The main value of surveys that include only affected individuals (e.g., Harry[74]; Pierpont[4]; The Acoustic Group[25]) is that they strongly suggest that substantial numbers of people living near wind turbines suffer health symptoms. For example, Harry[74] reported that 81% of her 42 survey respondents had health complaints, 76% had visited a doctor regarding those complaints, and 73% reported a reduced quality of life. In a somewhat more representative survey of residents living within 15 km of a wind turbine project—most of whom lived within 3 km—Phipps[76] found that 42 of 614 households who responded to a questionnaire (6.8%) reported occasional sleep disturbance, another 21 (3.4%) reported frequent sleep disturbance, and an additional 5 (0.8%) reported sleep disturbance most of the time due to WTN. Eleven percent of households, therefore, reported suffering at least occasional sleep disruption due to the wind turbines. Fifteen percent of respondents to that survey reported that they had suffered at least occasional reductions in their quality of life since the turbines became operational.

Despite the lack of definitive scientific evidence, we cannot ignore the numerous accounts of such effects reported worldwide on the Internet, in legal proceedings, and in news accounts. Krogh et al[96] have reviewed studies that document such incidents, many of which have involved the abandonment of homes. In a 2010 report commissioned by the Ontario Ministry of the Environment, the engineering firm of Howe Gastmeier Chapnik Limited,[112] despite its general conclusion that Ontario IWTs do not pose a risk to human health, stated:

> "The audible sound from wind turbines, at the levels experienced at typical receptor distances in Ontario, is nonetheless expected to result in a non-trivial percentage of persons being highly annoyed .... research has shown that annoyance associated with sound from wind turbines can be expected to contribute to stress related health impacts in some persons" (p. 39).

In conclusion, we should recall that Phillips[169] advocates self-reporting of adverse events as a critical element in the study of the health effects of wind turbines. As stated earlier, he has noted the importance of case-crossover experiments as useful and well-accepted sources of epidemiologic information. Numerous households around the world have been subjected to this type of quasi-experiment by the wind industry. It is unfortunate that an accurate count of these incidents has never been tallied formally and scientifically. Although that task must be left to future research, we should regard complaints of AHEs from individuals living near wind turbine installations seriously, when they occur, and the wind industry must act responsibly by siting its turbines at distances from residents that protect health and quality of life.

It is widely accepted that the industry has warned that tighter siting restrictions will destroy its prospects for growth. Such growth, however, should not continue in areas where there are probable and potential risks to human health. There are regions of the U.S. and other countries where turbines can operate safely, presumably without such risks. Some examples of those sites are illustrated in Figure 2.

Statement 12: There is no evidence in the literature to support a causative link between wind turbine noise and adverse health effects.

The above review has been aimed specifically at addressing this point, which is often cited as factual by wind industry advocates in the literature and in legal proceedings. Namely, there is an abundant literature, much of it peer-reviewed and authored by highly reputable researchers, indicating that audible and inaudible noise emitted by IWTs adversely impacts the health and well-being of substantial numbers of people who are regularly exposed to wind turbines. It is clear that the literature reviews and papers claiming no AHEs fail to include important studies, international standards, guidance from the WHO, and research conducted on wind turbine noise and other sources of infra- and low-frequency sound. Whether this is through oversight or calculation, only reports that cite scientifically credible references should be considered legitimate sources of information. Our review has shown that it is unacceptable simply to state that the literature contains little or no evidence of a causal link between WTN and AHEs. At a minimum, those effects have been shown to be regularly correlated to living in proximity to IWTs, and there is sufficient evidence that those effects are highly associated with objective measurements of audible noise and infrasound.

Although sleep disturbance and its associated impacts on health and quality of life appear to be the most salient consequences of IWT noise, varying health effects that are unrelated to sleep have also been widely and consistently reported by different investigators. While not everyone who is exposed to IWTs suffers AHEs, it is incumbent on governmental officials and the wind industry to take seriously the health implications of their decisions to locate wind turbines near residential and other populations, especially vulnerable populations, that are or likely to be negatively affected.

Figure 2. Photographic images of sites illustrating onshore landscapes where industrial wind turbines expose humans to minimal health risks due to large setback distances. Note that homes are not seen in the photos. (Source: https://images.search.yahoo.com/search/images?p=wind+turbine+images+california&fr=tightropetb&imgurl=http%3A%2F%2Fwww.freefoto.com%2Fimages%2F39%2F01%2F39_01_1---Wind-Turbine-Generators--Palm-Springs--California_web.jpg#id=36&iurl=http%3A%2F%2Fmedia-cdn.tripadvisor.com%2Fmedia%2Fphoto-s%2F01%2F70%2Ff9%2Fbb%2Ftehachepi-area-california.jpg&action=close).

Conclusion

We have discussed in this paper various elements of acoustics, sound perception, sound measurement, and psychological reactions, and the role these factors play in support of the view that a general-causative link exists between human health and ILFN emitted by IWTs. The available evidence warrants the following conclusions:

(1) Large wind turbines generate infrasound, which is not normally experienced as sound by most human listeners. Some people, however, experience it in the form of pathological

symptoms such as headache, dizziness, nausea, or motion sickness, which appear to be caused by the excitation of resonances inside closed structures and the human body itself.

(2) WTN has unique acoustic characteristics when compared to other environmental noises. These characteristics include low-amplitude, amplitude-modulated, intermittent occurrences of tones that mirror the peak energy of the blade-pass frequency and the first several harmonics. The coupling mechanisms in the inner ear prevent internally generated sound, but not externally generated sound, from being perceived, which means that perception of wind turbine infrasound is far more disturbing than infrasound generated within the human body.

(3) There is voluminous evidence, ranging from anecdotal accounts from around the world to peer-reviewed scientific research, that audible and inaudible low-frequency noise and infrasound from IWTs lead to complaints ranging from annoyance to AHEs in a substantial percentage of the population. Although sleep disturbance is the most common problem cited, a variety of other health problems has been reported by numerous reputable sources. Recent research is largely consistent with Pierpont's original description of Wind Turbine Syndrome. Research on humans and lower animals has shown that it is biologically plausible that inner ear mechanisms, in conjunction with the brain, can process acoustic energy in ways that result in pathological perceptions that are not interpreted as sound. Both balance and hearing mechanisms appear to be involved in evoking these perceptions. The findings that infrasonic stimuli can amplitude modulate higher frequencies in the audible region, and that infrasound may be more perceptible when higher frequencies are absent, are especially compelling in suggesting that what we can't hear can hurt us.

(4) To prevent AHEs, scientists have recommended that distances separating turbines and residences be 0.5-2.5 mi., and 1.25 mi. (2 km) or more has been commonly recommended. Clearly, the short siting distances used by the industry for physical safety do not protect against AHEs. Alternatively, researchers have recommended sound levels typically ranging from 30-40 dBA for safeguarding health, which is consistent with the recommendation of nighttime noise levels by the WHO.

(5) Annoyance is a health issue for many people living near IWTs, which is consistent with both the WHO's definition of health and contemporary models of the relationships among annoyance, stress, and health.

(6) The scientific evidence regarding factors other than amplitude-modulated ILFN as an explanation for most of the health complaints near IWTs, including electromagnetic fields (dirty electricity), is weak; the preponderance of research suggests that ILFN is the most viable explanation for such complaints.

(7) The A-weighted decibel scale, which effectively excludes infrasound and substantial amounts of low-frequency noise, is inadequate to predict the level of outdoor or indoor infrasound, to reveal correlations to infrasound, or to show a definitive relationship with AHEs. Achievement of these goals requires the development of new measurement methods.

(8) Even though Wind Turbine Syndrome is not currently included in the ICD coding system, that system includes most of the acknowledged symptoms of the syndrome. Medical professionals, therefore, have the necessary tools to evaluate and treat it, and that process has already begun on a limited scale.

(9) While some epidemiologically solid research has been done in the area of IWTs and AHEs, evidence from other sources cannot be ignored. Hill noted the nature of such sources in 1965, and Phillips, in 2011, described the importance of other kinds of evidence, including adverse event reports, in establishing a causative relationship. One of the strongest types of evidence is the case-crossover experimental design, which the wind industry has unwittingly imposed for years on multiple families, many of whom have abandoned their homes to escape IWT noise exposure.

(10) While psychological expectations and the power of suggestion conceivably can influence perceptions of the effects of WTN on health status, no scientifically valid studies have yet convincingly shown that psychological forces are the major driver of such perceptions.

(11) Accurate estimates of the percentage of people who are affected by IWTs exist only for annoyance, not AHEs. Multiple reports, however, emphasize the relationships that exist between annoyance, stress, health, and quality of life, and indicate that a non-trivial percentage of people who live near IWTs experience AHEs. Those reports are consistent with thousands of reports worldwide. Although it seems reasonable to conclude that noise from IWTs does not cause AHEs in the majority of exposed populations, and that accurate estimates of AHEs are yet to be established, it is also clear that considerable numbers of people are affected and that they deserve to be heard and protected from adverse health impacts.

(12) The available literature, which includes research reported by scientists and other reputable professionals in peer-reviewed journals, government documents, print and web-based media, and in scientific and professional papers presented at society meetings, is sufficient to establish a general causal link between a variety of commonly observed AHEs and noise emitted by IWTs.

Based on all the evidence presented, our fundamental view is that the controversy surrounding AHEs should not be polarized into two groups consisting of either *pro-wind* or *anti-wind* factions, but rather one in which there is room for a third, *pro-health*, perspective. Essentially, the pro-wind view is that IWTs should be installed wherever feasible, that definitive scientific research is lacking to indicate that turbines cause AHEs, and that if you can't hear it, you can't feel it. The anti-wind view is that IWTs should not be installed anywhere because wind is not an economically viable source of renewable energy, that all government subsidies and development efforts should end, and that what we can't hear can hurt us. A pro-health view is that there is enough anecdotal and scientific evidence to indicate that ILFN from IWTs causes annoyance, sleep disturbance, stress, and a variety of other AHEs to warrant siting the turbines at distances sufficient to avoid such harmful effects, which, without proper siting, occur in a substantial percentage of the population. That view holds that what we can't hear can hurt some of us, and that the precautionary principle must be followed in siting IWTs if such health risks are to be avoided. Industrial-scale wind turbines should not be located near people's homes, educational and recreational facilities, and workplaces. It is our belief that the bulk of the available evidence justifies a pro-health perspective. It is unacceptable to consider people living near wind turbines as collateral damage while this debate continues.

Further scientific investigations of the dose-response relationship between IWT noise and specific health effects in exposed individuals are sorely needed. However, people should be protected by conservative siting guidelines that recognize the concerns raised in this review. Hopefully, such research can and will be planned and executed by independent researchers with the full cooperation of the wind industry. The major objective of such research should be to reveal directions for the industry in balancing the energy needs of society with the need to protect public health.

Statement of conflict of interest: The authors declare no conflicts of interest. Mr. James is on the Board of Directors for the Society for Wind Vigilance, an international federation of physicians, acousticians, engineers, and other professionals who share scientific research on the topic of health and wind turbines.

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Setback Recommendations Per Various Studies

Name of Study	Date of Study	Author(s)	Link to Study	Author's Advised Setbacks	Notes
Wind Turbine Syndrome: A report on a natural experiment	2009	Dr. Nina Pierpont	N/A, PDF provided	Setbacks from residences should be a minimum of 2 kilometers or 1.24 miles, but 2-3 miles in hilly terrain	PDF provided to Planning Commission and BoCC
Your Guide to Wind Turboine Syndrome...a road map to a complicated subject	July 2010	Calvin Luther Martin, Phd	N/A, PDF provided	Setbacks from residences should be a minimum of 2 kilometers or 1.24 miles, but 2-3 miles in hilly terrain	This is a summary of Dr. Pierpont's book PDF provided to Planning Commission and BoCC
Health Effects of Wind Turbines: Testimony of Ben Johnson versus MidAmerican Energy (Madison County, Iowa) / Hearing before the Madison County Board of Health	August 2019	Dr. Ben Johnson, M.D.	https://www.masterresource.org/wind-turbine-noise-issues/health-effects-of-wind-turbines-testimony-of-ben-johnson-versus-mid-american-energy-project-in-madison-country-iowa/	No recommendation given for a specific distance in this hearing. Afterwards the Madison County Board of Health passed a resolution recommending that any future turbines be built at least 1.5 miles from non-participating homes	PDF provided to Planning Commission and BoCC
Wind Turbine Noise and Human Health: A Four-Decade History of Evidence that Wind Turbines Pose Risks	Ocober 2016	Professor Jerry L Punch and Professor Richard R James	https://hearinghealthmatters.org/wp-content/uploads/2023/03/16-10-21-Wind-Turbine-Noise-Post-Publication-Manuscript-HHTM-Punch-James.pdf	Setbacks from residences are recommended at 1/2 mile to 2.5 miles, 1.25 miles is most favored by scientists.	PDF provided to Planning Commission and BoCC
Infrasound from technical installations: Scientific basis for an assessment of health risks	July 2021	Dr. Werner Roos and Dr. Christian Vahl	https://www-asu--arbeitsmedizin-com.translate.goog/wissenschaft/wissenschaftliche-grundlagen-fuer-eine-bewertung-gesundheitlicher-risiken-infraschall?_x_tr_sl=de&_x_tr_tl=en&_x_tr_hl=en&_x_tr_pto=wapp	Minimum setback from residences should be 10 X turbine height as in Bavaria Germany	PDF provided to Planning Commission and BoCC
Assessing Adverse Health Effects-(Confirmed and Potential) from Industrial Wind Turbine Noise Emissions / Power point slides of presentation before the Kansas State Legislature	2022	Dr. Ben Johnson, M.D.	https://www.kslegislature.gov/li_2022/b2021_22/committees/ctte_s_utils_1/documents/testimony/20220207_01.pdf	Setbacks of 1.25 miles from residences	PDF provided to Planning Commission and BoCC
Presentation before the Kansas Senate and Utilities Committee: Effects of Wind Turbine Noise on Human Health	2022	Prof Jerry L Punch	https://www.kslegislature.gov/li_2022/b2021_22/committees/ctte_s_utils_1/documents/testimony/20220208_02.pdf	Setbacks of 1.25 miles from property lines (specifically) should be considered	PDF provided to Planning Commission and BoCC
Wind Turbines: Vacated/abandoned homes - Exploring participants' descriptions of their personal views, effects on safety, security, trust and social justice	Dec 2023	Carmen Marie Krogh, Robert Y McMurty, W Ben Johson, Jerry L Punch, Anne Dumbrille, Mariana Alves-Pereira, Debra Hughes, Linda Rogers, Robert W Rand, Lorrie Gillis	https://journals.lww.com/endi/fulltext/2023/08040/wind_turbines__vacated_abandoned_homes___exploring.2.aspx	Residents living within 10 kilometers/6.21 miles of industrial wind turbines were documented having Adverse Health Effects	See page 96 for the conclusion of the study regarding setbacks. PDF provided to Planning Commission and BoCC.
A fundamental basis for all living creatures, mechanotransduction, is significantly endangered by periodic exposure to impulsive infrasound and vibration from technical emitters - in particular cardiovascular and embryological functions	June 2025	Dr. Ursula Bellut-Staeck	https://www.scirea.org/journal/PaperInformation?PaperID=12440	Setbacks of 10 kilometers / 6.21 miles from people and animals	NOTE: The link shows the abstact and allows you to download the PDF PDF provided to Planning Commission and BoCC
Separating Myth from Fact on Wind Turbine Noise	October 2025	Prof Ken Mattsson	https://www.youtube.com/watch?v=nDwsd82SDEY	Setbacks of at least 5 to 10 kilometers (3.1 to 6.2 miles) from residences	Transcript PDF provided to Planning Commission and BoCC
Efficient finite difference modeling of infrasound propagation in realistic 3D domains: Validation with wind turbine measurements	Feb 2026	Ken Mattsson, Gustav Eriksson, Leif Persson, Jose Chilo, Kourosh Tatar	https://www.sciencedirect.com/science/article/pii/S0003682X25006280?ref=pdf_download&fr=RR-2&rr=9a872537bf69df1b	No specific distance given, see notes for conclusion of study	Conclusion of study page 14: This study also shows that modern, large-scale wind turbines generate infrasound levels substantially higher than those reported for older, smaller turbines / PDF provided to Planning Comm & BoCC

I-4

Summary: Infrasound from Technical Installations – Scientific Basis for Health Risk Assessment

(Compiled by Tom Thompson Dec 2025)

The review by Prof. W. Roos and Prof. C. Vahl (2021) argues that the health risks of technical infrasound (≤20 Hz), especially from wind turbines, are systematically underestimated. Despite official studies frequently concluding that infrasound from wind turbines is harmless, a growing body of experimental evidence from cellular, organ, animal, and human research demonstrates biologically plausible and partly proven adverse effects.

Key findings presented:

1. **Cellular level** Infrasound disrupts sensitive membrane processes (e.g., blood-retinal barrier breakdown in rats, increased erythrocyte permeability). Of particular importance is the highly significant negative inotropic effect on isolated human myocardial tissue (Chaban et al. 2020): at ≥100 dB (16 Hz), contractile force drops ~9 % per 10 dB increase after only one hour. The mechanism is likely a disturbance of electromechanical coupling via elevated diastolic Ca^{2+}. Infrasound also triggers oxidative stress and Ca^{2+}-dependent apoptosis in cardiomyocytes and neuronal cells.
2. **Cardiovascular system** Multiple studies (human and animal) show bradycardia or tachycardia, reduced cardiac output, hypertension, arrhythmias, microcirculatory disturbances, and morphological myocardial damage (swelling, hemorrhage, sarcoplasmic reticulum/mitochondrial injury). Resonance phenomena in the torso and organs (including heart rate ~1 Hz) may amplify effects when external pulse rates (e.g., ~1 Hz from three-blade turbines) coincide.
3. **Vestibular system and motion-sickness-like symptoms** Infrasound strongly stimulates otolith organs (saccule/utricle), creating a sensory conflict akin to seasickness because expected visual/proprioceptive corroboration is absent. This explains frequent reports of dizziness, nausea, and balance problems among residents near wind turbines.
4. **Brain and unconscious perception** Sub-threshold infrasound (12 Hz) activates, via fMRI, the anterior cingulate cortex (autonomic regulation), right amygdala (emotion/fear), and areas near the auditory cortex—without conscious awareness (Weichenberger et al. 2017). This offers a neurophysiological explanation for sleep disturbance, anxiety, respiratory changes, and hypertension during nighttime exposure.
5. **Critique of official wind-turbine studies** Many government-commissioned investigations are methodologically inadequate for assessing infrasound risk because they (a) use A- or C-weighted measurements that exclude <8–20 Hz, (b) average third-octave spectra that "smooth out" the characteristic steep pressure pulses of wind turbines, or (c) expose subjects only briefly to sinusoidal tones rather than real pulsed emissions. Thus, they systematically fail to detect the very parameters most likely responsible for harm.

Conclusion of the authors

Current evidence substantiates a fundamental health risk from chronic exposure to technical infrasound, particularly the pulsed, steep pressure changes emitted by wind turbines in the 1–8 Hz range. Reported resident symptoms (severe sleep disturbance, dizziness, cardiovascular complaints, anxiety) closely match experimentally documented effects on cells, heart, vestibular system, and subconscious brain centres. The authors urgently call for (1) research using real wind-turbine emission profiles, (2) establishment of dose–response relationships for cardinal symptoms, (3) mandatory unweighted measurement of the 1–8 Hz band, and (4) **precautionary setback distances from residences (e.g., ≥10 × total height, as in Bavaria) until risks are quantified. Dismissing concerns solely as nocebo effects is premature and medically unjustified given the objective biological targets identified.**

Corroborating Sources for the Study "Infrasound from Technical Installations: Scientific Basis for an Assessment of Health Risks

(This paper was compiled by Tom Thompson Dec 2025)
ASU / Journal for Medical Prevention, published in issue 07-2021
Study conducted by Prof. Dr. Emeritus W. Roos and Prof. Dr. Emeritus C. Vahl

German to English translation of study: https://www-asu--arbeitsmedizin-com.translate.goog/wissenschaft/wissenschaftliche-grundlagen-fuer-eine-bewertung-gesundheitlicher-risiken-infraschall?_x_tr_sl=de&_x_tr_tl=en&_x_tr_hl=en&_x_tr_pto=wapp

Link to German language website with article: https://www.asu-arbeitsmedizin.com/wissenschaft/wissenschaftliche-grundlagen-fuer-eine-bewertung-gesundheitlicher-risiken-infraschall

Listed below are independent studies ranging from 2009 through 2025, which confirm Profs Roos and Vahl's research. None of the studies below are referenced in the study conducted by Prof. Roos and Prof. Vahl

1) See pages pages 3-6 of Drs. Roos and Vahl study, which are validated by Dr. Ursula Bellut-Staeck's 2025 study entitled: ***A fundamental basis for all living creatures, mechanotransduction, is significantly endangered by periodic exposure to impulsive infrasound and vibration from technical emitters - in particular cardiovascular and embryological functions***. Here is the link to Dr. Bellut-Staeck's study: https://www.scirea.org/journal/PaperInformation?PaperID=12440

2) See pages pages 5-6 and 10-11 of Drs. Roos and Vahl study, which are validated by W. Ben Johnson MD in his testimony in the two following articles: a) MasterResource Blog: ***Health Effects of Wind Turbines: Testimony of Ben Johnson versus MidAmerican Energy (Madison County, Iowa),*** August 2019. Link to this article: https://www.masterresource.org/wind-turbine-noise-issues/health-effects-of-wind-turbines-testimony-of-ben-johnson-versus-mid-american-energy-project-in-madison-country-iowa/, b) Dr. Ben Johnson's presentation before the Kansas State Legislature in Feb 2022, entitled ***Assessing Adverse Health Effects (Confirmed and Potential) from Industrial Wind Turbine Noise Immissions***: https://www.kslegislature.gov/li_2022/b2021_22/committees/ctte_s_utils_1/documents/testimony/20220207_01.pdf

3) See pages 5-6 of Drs. Roos and Vahl study, which are validated by Prof Jerry L Punch and Prof Richard R James study in 2016 entitled: ***Wind Turbine Noise and Human Health: A Four-Decade History of Evidence that Wind Turbines Pose Risks***, see link at https://hearinghealthmatters.org/wp-content/uploads/2023/03/16-10-21-Wind-Turbine-Noise-Post-Publication-Manuscript-HHTM-Punch-James.pdf Also see Prof Jerry L Punch's Feb 2022 presentation before the Kansas Senate and Utilities Committee entitled ***Effects of Wind Turbine Noise on Human Health:*** https://www.kslegislature.gov/li_2022/b2021_22/committees/ctte_s_utils_1/documents/testimony/20220208_02.pdf

4) See pages 7-8, 11-14 of Drs. Roos and Vahl Study, which are validated by Dr. Nina Pierpont's 2009 study entitled ***Wind Turbine Syndrome*** and Prof Calvin Luther Martin's 2010 report entitled ***Your Guide to Wind Turbine Syndrome...a roadmap to this complicated subject***. PDFs of both have been submitted to Whitman County Planning Commission and the County Attorney Denis Tracy.

Arbeitsmedizin/Sozialmedizin/Umweltmedizin
Occupational Medicine/Social Medicine/ Environmental Medicine

July 1, 2021 | Published in Issue 07-2021 | Print Preview

Infrasound from technical installations: Scientific basis for an assessment of health risks

Background: The pathogenic potential of infrasound from technical sources is significantly underestimated by the public and politicians. Wind turbines are the most common emitters and their rapid rollout means that an increasing number of residents are affected by far reaching pressure pulses.

Methods: Research findings relating to causal mechanisms of infrasound are compiled and examined for indications of adverse effects on health.

Results: Infrasound is perceived as a stressor and is met with adaptive and defensive responses. Points of attack for toxic effects can be identified a) at cellular level, where membrane processes react with particular sensitivity. This leads to disruption of the microcirculation, muscle contraction and neuronal signal transmission. b) In the cardiovascular system, the effects mentioned in a) cause a reduction in the efficiency of the myocardial muscle coupled with centrally mediated bradycardia, hypertension and reduced cardiac output. c) The signal receptors for the balance system receive infrasound as interference and produce a clinical picture similar to motion sickness. d) In the brain, infrasound is unconsciously perceived in areas that are involved in the control of autonomic functions (incl. respiratory frequency and blood pressure) and in emotional control.

Conclusions: The findings available today substantiate a fundamental health risk for people exposed to infrasound. The steep pressure pulses of actual emissions have been disregarded by government-initiated studies of wind turbines to date. There is a need for adequate safety margins and further research in order to establish dose (energy)-response curves for the cardinal symptoms.

Keywords: infrasound – wind turbine – pressure pulse – adverse effects on health

U Arbeitsmed Sozialmed Umweltmed 2021; 56: 420–430

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(received on December 4, 2020, accepted on May 10, 2021)

Introduction

Medical aspects have so far not received due attention in the debate about the acceptance of wind turbines. This is particularly true for long-range acoustic effects, which are essentially based on infrasound, an inaudible emission from these turbines. Significant intensities of infrasound emitted by wind turbines have been measured several kilometers away (e.g., Palmer 2017; Pilger and Ceranna 2017). There has long been evidence that complaints from residents reporting severe sleep disturbances and the resulting damage during wind turbine operation are caused by the infrasound component of the emissions (e.g., Bahtarian and Beaudry 2015; Stelling 2015; Kaula 2019). On the other hand, there is no shortage of official statements that attribute only very low intensities to infrasound from wind turbines even at a distance of a few hundred meters and that negative effects on humans are not scientifically proven (e.g., LUBW 2016; UBA 2016; Maijala 2020).

This situation reflects not only a problem with wind energy, but also a lack of availability and knowledge of scientifically sound data on the effects of infrasound on biological systems. This prompts the authors of this article to compile research results on the specific effects of technical infrasound on humans and mammals and to investigate them for verifiable or at least plausible indications of health impairment. The goal is a causal analysis of infrasound effects. Can a potential stressor with defined properties (frequency, sound pressure, duration of effect) be attributed to measurable changes in a defined object (cell, tissue, organ) or at defined sites of action in the organism? Wherever possible, standards of experimental medicine and pharmacology were applied, particularly recognized and documented measurement procedures, blind and reference values, and comprehensible statistical transparency. Usable data exist for cells and tissues, the cardiovascular system and other organs, the signaling systems of the sense of hearing and balance, and selectively activatable brain areas.

This approach differs from epidemiological studies on the annoyance or acceptance of infrasound sources by residents. These, for example, look for correlations between expressed or documented complaints and the distance from wind turbines or measured sound pressure levels. However, the (presumably) involved infrasound components are usually not separated from audible sound, for example, low-frequency sound. Since infrasound is perceived via fundamentally different signaling pathways (see below) and very likely triggers different primary reactions than audible sound, specific causal statements about infrasound effects are hardly possible in this way. One example is the extensive work by Micheaud et al. (2016). The sound pressures measured there and used for a correlation analysis were C-filter weighted (dBC), meaning frequencies below 8 Hz were excluded, even though the infrasound pulses from the wind turbines investigated here are emitted in this range (➡Fig. 1). Further examples follow in the text.

Sound refers to mechanical waves in an elastic medium (solid, liquid, or gas). The inaudible frequency range below 20 Hz is called infrasound. It is characterized by long wavelengths (e.g., 343 m at 1 Hz in air at 20 °C) that can hardly be insulated by conventional building materials. In nature, such waves are emitted when parts of the Earth's crust vibrate, for example, during earthquakes and volcanic eruptions, by ocean waves, thunder, or wind in forests or meadows. Technological civilization has created numerous new sources of infrasound, including large-scale industrial facilities, road vehicles, and aircraft. While heterogeneous sources from nature generally emit low-frequency noise that is not perceived as disturbing, technical installations often emit pulsed vibrations that are suspected of causing damage to the human body upon prolonged exposure (Stelling 2015; Palmer 2017). This applies, among others, to wind turbines, the most widespread emitters of technical infrasound. The passage of the rotor blades over the mast leads to contractions of the air column between them and thus to pulses (maxima and minima) of air pressure, the frequency of which is determined by the rotational speed of the turbine. The fundamental vibration of the air column and the associated harmonics generate a typical frequency pattern that propagates at the speed of sound (see Fig. 1 at the bottom of this article from the sidebar).

As a measure of the energy transmitted by sound waves, the sound pressure is usually expressed in Pascal.

It is used and expressed in the logarithmic unit decibels (dB), with 20 μPascals as the zero point. When measuring audible sound, sound pressure levels are usually weighted to approximate human hearing (A-weighting, dBA). The inaudible frequency range below 20 Hz is filtered out. To assess infrasound, the objectively present, biophysically effective sound pressure levels in the range below 20 Hz are required. The sound pressure levels quoted below are always unweighted.

Effects of Infrasound at the Cellular Level

Disruption of Membrane Processes

The mechanical energy transported by sound waves manifests itself in alternating movements, condensations, and rarefactions of particles in the sound-carrying medium. It is therefore obvious that a critical sound pressure can trigger changes in biological structures, with membranes being particularly sensitive due to their biophysical properties. Due to the low attenuation and great penetration depth, this is particularly to be expected for infrasound.

Indeed, the gradual breakdown of the blood-retinal barrier was demonstrated in rats during the application of high infrasound pressures (8 Hz, 130 dB). This process was monitored over several days using the diffusion marker La^{3+} and increased with exposure time (Qui et al. 2002). The membrane permeability of rat erythrocytes was also increased after infrasound exposure (13–30 Hz, 114 dB) (Sharipova 2013).

Biophysical processes at membranes form the cellular basis for cardiac muscle contraction and its control. They occur at the cell membrane of cardiomyocytes and intracellularly at the sarcoplasmic reticulum and mitochondria. Periodic changes in calcium concentration play a key role: During systole, calcium is released from the sarcoplasmic reticulum and activates the cardiomyocyte contractile apparatus through electromechanical coupling. During diastole, calcium is pumped back from the intracellular space into the sarcoplasmic reticulum. An increase in the diastolic intracellular calcium level is characteristic of the end stages of certain heart diseases (dilated cardiomyopathy, heart failure).

In this context, the results of Chaban et al. (2020) are of considerable importance: A highly significant, negative inotropic effect of infrasound (from 100 dB) was demonstrated on isolated, beating human myocardial tissue. For every 10 dB increase in sound pressure level, there was a 9% reduction in contractile force. A strength of this study lies in the precisely defined experimental conditions. The infrasound-exposed cell preparation and the control cells were derived from the same human, thus eliminating individual differences as a confounding factor. In the isolated perfused preparations, the conduction pathway that precedes contraction in the intact myocardium was excluded, and endocrinological mediators were absent. Therefore, electromechanical coupling in the contractile apparatus of the cardiomyocytes must be assumed to be the target of infrasound. A diastolic increase in the intracellular Ca^{2+} concentration is likely the immediate cause of the reduction in contractile force. The fact that the observed effect occurred after just one hour of exposure indicates the high sensitivity of the contraction process to the stressor (➡Fig. 2).

Human and mammalian cell cultures offer suitable study subjects for the investigation of cellular stress management. Infrasound finds various targets there and interferes, for example, with the defense against oxidative stress (Pei et al. 2013). Changes in the intracellular Ca2+ concentration are often an indicator of interference with stress defense.

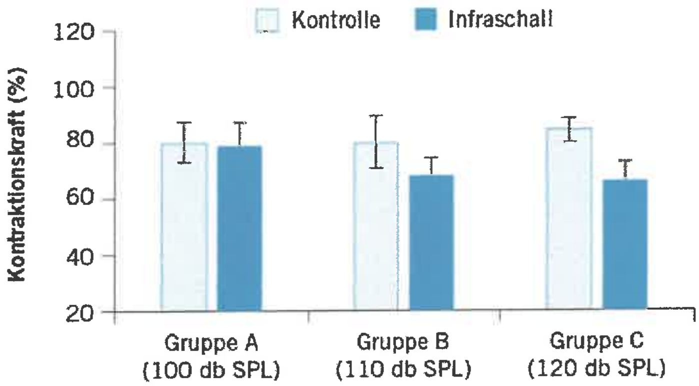

Fig. 2: Effect of infrasound on the contractile force of cardiomyocytes. Muscle preparations (3 × 0.5 × 0.5 mm) were prepared from right atrium tissue samples (waste material from bypass surgery), fixed under the microscope using microforceps, and perfused with Krebs-Henseleit buffer. After equilibration of the preparations, contractions were elicited by successive electrical pulses (4 ms each), the strength of which was measured electronically. Two samples from a total of 18 patients were examined under identical conditions. One of these samples was exposed to 16 Hz sinus infrasound via a loudspeaker for 1 h, while the other served as a control. The patients were between 18 and 90 years old and free of severe cardiomyopathies or malformations. The data show the measured contraction force before and after infrasound treatment; the differences between infrasound and control groups are significant with p = 0.0006. Details can be found in Chaban et al. (2020).

Fig. 2: Effect of infrasound on the contractile force of cardiomyocytes. Tissue samples from the right atrium (waste material from bypass operations) were used to prepare muscle specimens (3×0.5×0.5 mm) that were fixed under the microscope with micro-tweezers and perfused with Krebs-Henseleit buffer. Following sample preparation and equilibration, contractions were triggered by consecutive electrical impulses (4 ms each) whose strength was measured electronically. Two samples each from a total of 18 patients were examined under identical conditions. One was exposed to 16 Hz infrasonic sinusoidal waves through a speaker for an hour, whilst the other served as a control sample. The patients were between 18 and 90 years old and free of severe cardiomyopathies or malformations. The data show the contractile force measured before and after infrasound treatment; the differences between the infrasound group and control group are significant with p = 0.0006. Details in Chaban et al. (2020)

Apotosis (programmed cell death)

Increases in cytoplasmic Ca2+ are an early signal in the initiation of the apotosis process (Orrenius et al. 2003), through which irreversibly damaged cells or those that have lost their function in the organism are degraded in a controlled manner. The irreversible phase of this process begins with the expression of cytotoxic caspase-type proteases. Increased expression of these enzymes (caspases 3, 8, and 9) and the required transcription factors Bax and Fas was observed in neonatal rat cardiomyocytes during multi-day infrasound exposure (5 Hz, 130 dB) (Pei et al. 2011). At the same time, proteins that protect against apoptosis were downregulated.

Infrasound also leads to increased apoptosis in neuronal cells of the brain, as shown in the rat hippocampus (8 Hz, 110 dB; Zhang et al. 2016; Cai et al. 2014). From today's perspective, the hypothesis of Liu et al.

appears to be plausible. (2010, 2012) justified the idea that the additional outflow of calcium from mitochondria and endoplasmic reticulum into the cytosol caused by infrasound initiates the Ca2+-dependent apoptosis pathway and thus triggers long-term cytotoxic effects.

The evidence of a cytotoxic effect of infrasound has led to research into the medical application of infrasound for tumor therapy. One starting point was the observed inhibition of colorectal tumors in mice after a single exposure to infrasound (Zhang et al. 2013).

Interactions of infrasound with the cardiovascular system

Adverse effects of infrasound exposure have been described for various organs, including the liver and lungs (Nekhoroshev et al. 1991; Svigovyi and Glinchikov 1987), but the vast majority of data are available for the cardiovascular system. Harmful are 1982; Babisch 2011; Cai et al 2017, Millar and Steeels 1990; Søren sen et al. 2011). In the threshold range to infrasound, the regulatory function of the outer hair cells in the inner ear takes effect: Through their contraction (see below), these cells can transform an inaudible infrasound signal into an audible signal by lowering the hearing threshold. Consequently, the cardiovascular risks associated with audible noise sources must also be considered with regard to infrasound (Babisch et al. 2011; Cai et al. 2017).

Findings in Test Subjects

In an important pioneering study, the research group of Karpova et al. (1979) found reduced heart rate and arrhythmias in healthy 19- to 29-year-old subjects after exposure to infrasound (1–12 Hz, 110–132 dB). Using an older technique ("seismic cardiograph"), they observed a reduction in cardiac muscle strength, most pronounced at frequencies around 10 Hz. This reduction in heart rate was confirmed in 1980 by Wysocki et al. (e.g., at 8 Hz, 75 dB, and exposure times of up to 2 hours). Additionally, the authors demonstrated a reduction in peripheral vascular conductivity, skin temperature, and performance in choice response tasks. They hypothesized that the pressure fluctuations are detected via mechanoreceptors in the skin and lead to cerebrally triggered autonomic responses in the heart. In a more recent publication, the central finding was also recorded for low-frequency audible sound: Walker et al. (2016) found a 32% reduction in heart rate variability in healthy subjects.

Findings in Experimental Animals

Effects on the Intact Myocardium

Campbell et al. (1998) placed a small balloon in the left ventricle of rabbits and inflated and deflated it using low-frequency sound or infrasound. Vibrating the balloon in the heart resulted in a force reduction of approximately 10–20%. The authors believe that the cause of this effect is not the contraction process of the heart muscle, but rather a disruption of the preceding conduction pathway, which is linked to functional membrane structures.

Exposure of rats to infrasound (5 Hz, 130 dB) led to an increase in heart rate and blood pressure, while cardiac output decreased (Pei et al. 2007). Normally, contractile force increases with heart rate as an adaptation to increased oxygen demand (positive force-frequency relationship). The reduction in stroke volume suggests damage to this important regulatory mechanism, presumably diastolic dysfunction (Pei et al. 2009). At the morphological level (post-mortem examination), the authors observed changes in myocardial ultrastructure, including the sarcoplasmic reticulum, hemodynamic indices, and intracellular calcium concentrations. Alterations in L-type Ca2+ channels were also detected, with negative effects on electromechanical coupling. In addition, platelet aggregation in the intercellular space was observed. The results confirm earlier findings by Gordeladze et al. (1986): after 3 hours of exposure to infrasound (8 Hz, 120 dB), swelling of the walls of both ventricles and punctate hemorrhages into the pericardium occurred. In the cardiomyocytes, increasing damage to the membranes of the sarcoplasmic reticulum and mitochondria was observed, as well as fragmentation of the myofibrils. In addition, changes in chromatin and other nuclear structures occurred. After discontinuing infrasound exposure, a substantial recovery occurred.

Microcirculation Disturbances

The changes induced by infrasound are similar to the stress effects of prolonged (multi-day) exposure to audible noise: The latter leads to an increase in blood pressure and cellular Ca2+ concentration in the vascular muscles, along with increased activation of neutrophil cells (Tiefenbacher et al. 2000; Millar et al. 1990; Altura et al. 1992). It is therefore not unreasonable to expect this activation to occur with infrasound as well. High neutrophil cell activity leads to a reduction in microcirculation in the surrounding tissue and thus to a reduced oxygen and substrate supply. This often results in uncontrolled death (necrosis) of undersupplied cells. Released cellular components trigger nonspecific inflammatory reactions, and in the longer term, destroyed cells are replaced by connective tissue (sclerosis or fibrosis). Such changes have been observed repeatedly in rats exposed to infrasound. Gordelaze et al. (1986) already observed severe microcirculatory disturbances, and Sharipova (2013) reported nonspecific inflammatory processes triggered by infrasound (13–30 Hz at 114 dB), followed by perivascular coronary sclerosis. These results have been confirmed by more recent studies even at lower sound pressures (90 dB and above; Lousinha et al. 2018).

On the generalizability of data from animal experiments

The previously published data and evidence presented for the effects of infrasound on cells, tissue, and organs derive largely from experiments on mammals. The sound pressure levels used (e.g., by Pei et al. 2009 and Gordeladze et al. 1986) are often higher than those expected under real-life conditions, such as in the vicinity of modern wind turbines. In some tests, they exceed the formal human pain threshold of 120 dB at 20 Hz. Such studies were mostly conducted on the effects of infrasound from high-emitting industrial facilities such as jet engines, motors, etc. Due to different analytical methods, a comparison of sound pressure levels is only possible to a limited extent. As will be shown later, it is not the absolute level of sound pressure that determines a biological effect, but rather the extent of short-term changes.

In addition, there are differences in sensitivity and adaptability between experimental animals and humans. As described above, for example, test subjects responded to infrasound with a reduction in heart rate, while rats responded with an increase. This indicates that the balance between parasympathetic and sympathetic modulation of heart rate is regulated differently in humans and rodents. Importantly, however, clear responses to infrasound exposure were measurable in all cited animal experiments.

Nevertheless, the observed damage to animal specimens, even at high infrasound pressures, provides valuable information on the susceptibility of underlying cell structures and organs to disruption. This facilitates the comparative identification of targets for elementary building blocks and signaling mechanisms, as they evolved from common precursors in mammalian evolution.

Resonance Phenomena

Resonance phenomena can be assumed for the cardiovascular system, including the lungs. This means that vibration of cell and tissue clusters due to the effects of airborne infrasound or corresponding structure-borne sound can be amplified in this way (Vinokur 2004). It has long been known that the upper human torso can develop resonances at frequencies between 5 and 250 Hz (Smith 2002; Randall et al. 1997). Most body organs can now be assigned individual resonance frequencies, which often lie in the infrasound range (RKI 2007). This played an important role, for example, in the design of mechanical heart valves, as it is important to prevent organs of the human body from being set into resonant vibrations by the rhythm of the valve.

Interference between the fundamental vibration determined by the heartbeat and externally applied infrasound pulses has been little studied. The consequences of such interactions – attenuation and amplification – are worth considering because, for example, the pulses emitted by wind turbines (a three-blade turbine generates a fundamental vibration of 1 Hz at 20 rpm) are in the same frequency range as the human pulse (resting pulse of 60 = 1 Hz).

The Effect of Infrasound on the Hearing and Vestibular Systems

Perception in the Cochlea

In the inner ear, audible sound events are perceived in the cochlea's organ of Corti by locally causing the basilar membrane, which is filled with inner hair cells, to resonate. For most people, this occurs at frequencies above approximately 50 Hz. Slower, i.e., low-frequency vibrations, including infrasound, cannot produce a tonal auditory impression because the inner hair cells are surrounded by a fluid (endolymph), which dampens their movements. However, low-frequency audible sound and infrasound are capable of stimulating the outer hair cells, which protrude from the lymph fluid and are therefore more sensitive (Salt and Hullar 2010; Salt and Kaltenbach 2011).

It has long been known that stimulation of the outer hair cells leads to changes in their length. This process can be induced and observed experimentally in isolated hair cells of humans and various rodents (Brownell et al. 1985; Ashmore 2008). Since the outer hair cells are fused not only to the basilar membrane but also to the overlying tectorial membrane, the gap between the two membranes is reduced when these cells contract and increased when they expand. This leads to an increase or decrease in the sound pressure in the cochlea. Low-intensity external sounds are therefore perceived with increased sensitivity. The change in the length of the outer hair cells generates vibrations in the inner ear that can be measured for diagnostic purposes. This "otoacoustic emission" can be triggered by both low-frequency audible sound and infrasound. (Hensel et al. 2007). This makes the outer hair cells a target for the perception of infrasound, with a modulating effect on the hearing threshold. Their excitation may explain why sensitive individuals experience an increased perception of soft audible sounds when exposed to infrasound (Kaltenbach and Godfrey 2008).

Perception in the Vestibular System

The human vestibular system responds to vibrations and long-wave pressure oscillations whose frequencies lie below the range of tonal perception in the cochlea. This occurs in the inner ear in the saccule and utricle organs, which detect linear accelerations, including the effects of gravity, and in the semicircular canals, where rotational accelerations in all directions of space are registered. Signal conversion in these organs also occurs at hair cells, but with the help of the inertia of $CaCO_3$ crystals, the otoliths. These sensors are also activated by infrasound or low-frequency audible sound, as demonstrated in test subjects and mammals such as mice (Jones et al. 2010). They react with high sensitivity: the human vestibular system detects accelerations even below 1 thousandth of a g (Todd et al. 2008).

Elements of the vestibular system developed during the evolution of vertebrates (Fay and Popper 2000), with the principle of otolithic sensors being conserved. Otolith organs, which can detect low-frequency pressure waves, are already present in fish, thus predating the development of the cochlea (Popper and Lu 2000). This provides infrasound access to a basic signaling system of all vertebrates.

During the perception of movement and balance control, the information coming from the vestibular apparatus is compared in the cerebrum with position signals from the eyes and stretch receptors in the body. This creates a precise perception in the brain, even of complex movements (Cullen 2019; Gu 2018). When the vestibular system is activated by infrasound, the accompanying information from the body's organs is missing, leading to a perceptual conflict. This conflict is similar to kinetosis, such as seasickness (Dooley and Morris 2014; Macefield and Walton 2015; Schomer and Erdreich 2015). Residents of wind turbines have repeatedly reported such attacks of dizziness; if such a perceptual conflict persists chronically, other symptoms such as severe sleep deprivation, tinnitus, and anxiety reactions also seem plausible.

The activation of distinct brain regions by infrasound

The compilation of potential sites of action of infrasound raises the question of how the resulting signals are reflected and processed in the brain. Modern imaging techniques such as functional magnetic resonance imaging (fMRI) enable the visualization of neuronal activity and connectivity in the brain, thus providing new insights into the perception of auditory and infrasound. The analytical method of "regional homogeneity" can reveal improved communication between neurons within a defined region. In a groundbreaking fMRI study, three regions were identified in the brains of test subjects that showed increased neuronal activity after exposure to infrasound (12 Hz) at intensities below the hearing threshold (Weichenberger et al. 2017; ➡Fig. 3). These regions are:

- a region near the auditory cortex (rSTG),
- the anterior cingulate cortex (ACC),
- the right amygdala (rAmyg).

Activation of these regions did not occur when infrasound was applied at an intensity above the individual's hearing threshold. Apparently, infrasound subconsciously alters the activity patterns in defined brain regions, i.e., in the absence of conscious perception. This signal transfer is presumably suppressed when audible sound pressures are perceived.

The regions activated by infrasound have been well studied with regard to their functions for the organism. While the rSTG region is indirectly involved in the processing of sound events, the ACC contains several centers of autonomic control, including those of respiratory rate and blood pressure (Critchley et al. 2003). Their activation has been demonstrated in certain contexts, for example, when engaging in a cognitively demanding task (Thomason et al. 2011). Recent studies suggest that a connection between unconscious perception and conscious recognition occurs in the ACC (Meneguzzo et al. 2014). The amaygdala is known for its involvement in the control of emotional reactions. fMRI studies attribute the role of a detector for the intensity of excitations (Bonnet et al. 2015).

The work of Weichenberger et al. (2017) provided the first concrete evidence suggests the involvement of specific brain areas in the perception of infrasound. This suggests an unconscious processing of infrasound-triggered signals in regulatory centers of the brain. Such signaling pathways could originate, among other things, from the outer hair cells (see above). It is known that these – unlike the inner hair cells – are also connected to nerve pathways that terminate in non-auditory centers of the brain (Weisz 2009). Other candidates include the otoliths of the vestibular system and the pressure receptors of the skin, such as the

Pacini corpuscle (sensitive in the range 10–300 Hz), the Merkel cell (0.3–3 Hz), and the Krause end bulb (3–40 Hz).

The presented data allow us to assume that the findings in respiratory rate and blood pressure recorded in patients after exposure to infrasound (e.g., from the vicinity of wind turbines) are caused by excitation of the ACC region. The anxiety also reported by residents suggests a possible involvement of the amygdala. However, since the infrasound used in the experiment differed from the characteristic infrasound pulses from wind turbines, no direct connection can be established between the changes in neuronal activity found in these test subjects and the findings in residents or patients. However, if one assumes that infrasound pulses from wind turbines (in the range of 1 to approximately 8 Hz) are received in the same or closely adjacent brain areas as the signals used in the test (12 Hz), this raises the suspicion of health risks from the subconscious perception of infrasound—and provides a starting point for further research.

Infrasound appears to have other, previously unknown effects during waking hours: Exposure to short episodes of a few seconds each led to the expected activation of the primary auditory cortex and tended to improve working memory (Weichenberger et al. 2015).

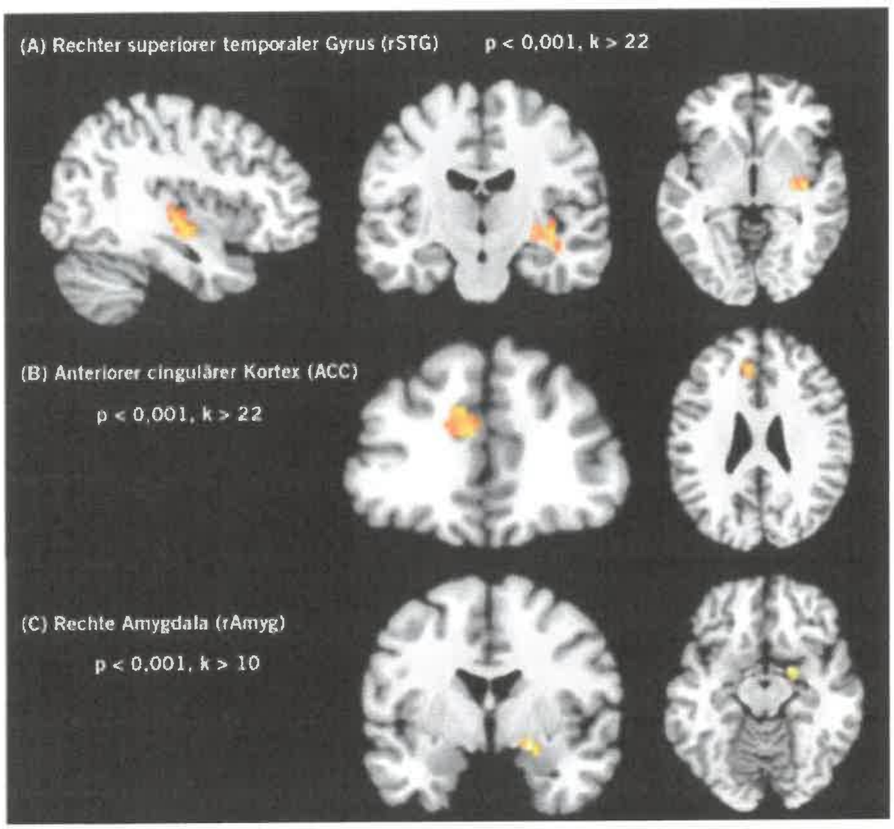

Fig. 3: fMRI maps of the brains of test subjects with areas of increased regional homogeneity (connectivity) during exposure to infrasound below the hearing threshold. The virtual slice planes are sagittal (left, only in A), frontal (middle), and transverse (right). Regions with differences compared to the control group (without sound exposure) are marked in color. 14 test subjects were treated with infrasound of 12 Hz sine for 200 s in a resting state. The intensity was set 2 dB below the (previously determined) individual hearing threshold. During this time, fMRI measurements were taken and then examined for areas of higher neuronal activity using regional homogeneity analysis (see above), compared to no sound exposure. The regions found are marked in color. The marked changes did not occur when the sound was exposed at the same frequency but at an intensity that the test subject could hear. This intensity was not perceived as painful (determined

individually in a preliminary test). Source: Weichenberger et al. 2017 Fig. 3: fMRI maps of the brain of test subjects with areas of higher regional homogeneity (connectivity) during exposure to infrasound below the hearing threshold level. The virtual planes are sagittal (left, A only), frontal (center) and transverse (right). Regions with differences to the control group (without sound exposure) are marked in color. 14 test subjects were treated in a state of rest with 12 Hz infrasonic waves for 200 s. The intensity was set 2 dB below their individual hearing threshold (as determined previously). fMRI measurements were taken during this time and the regional homogeneity analysis (see above) was then used to examine them for areas of higher neuronal activity in comparison with the absence of exposure to sound. The regions found during this process are marked in color. The marked changes did not occur during exposure to sound at the same frequency but at an intensity that was audible to the test subject. This intensity was not perceived as painful (individually ascertained in a preliminary trial). Source: Weichenberger et al. 2017
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Conclusion and Conclusions

Points of Attack for Infrasound

The available scientific data indicate that infrasound is assessed as a stressor in humans as well as in mammals (test animals). The organism responds with adaptive and defensive reactions, the basic elements of which are also known for other stressors. The effects known today include:

- direct damage to cells and organs and
- disruption of signaling chains whose information is evaluated in the brain.

Targets for the damaging effects of infrasound have been found at all levels of the mammalian organism.

- At the cellular level, disruption of membrane processes has been demonstrated. This not only impairs the function of individual cells, but also their interactions within tissue, such as microcirculation, muscle contraction, or neuronal signal transmission. Corresponding evidence comes almost exclusively from animal experiments. The high degree of similarity between the subcellular mechanisms conserved in mammalian evolution makes similar damage likely in human cells as well.

- The cardiovascular system reacts to infrasound on two levels: Disruptions to the membrane processes required for contraction and microcirculation in the myocardial tissue occur, resulting in reduced blood flow and efficiency of the heart muscle. In addition, there is the centrally coordinated stress defense (see above), which causes a drop in heart rate with rising blood pressure and reduced cardiac output. The result is the appearance of incipient heart failure.

- Infrasound acts as a disruptive signal on the signaling systems in the inner ear, especially the vestibular system and outer hair cells, and is not coordinated with the control and compensatory mechanisms that typically accompany physical movements (such as visual perception and the pressure receptors of muscles and other organs). This results in a clinical picture similar to kinetosis.

- In the brain, infrasound is perceived in defined areas that are involved in the control of autonomic functions (including respiratory rate and blood pressure) and emotional control. The activation of these areas occurs without conscious perception. This may explain why exposure to infrasound during sleep leads to a variety of stress-like symptoms. It is still unclear which specific peripheral receptors and signaling pathways provide the information for the activation of these brain areas.

Wind turbines: real dangers and study subjects

There are obvious connections between the results presented here on test subjects or laboratory animals and the frequently reported real illnesses that occur in the vicinity of infrasound generators, but often no complete causal chain. This is especially true for wind turbines, the number of which has increased dramatically in recent years. Based on their own diagnoses, general practitioners estimate a minimum of approximately 180,000 people affected in the vicinity of these turbines (Kaula 2019). At the same time, several epidemiological studies have been published in recent years that essentially find no negative effects of the infrasound emitted by wind turbines on residents. There are clear reasons for these discrepancies.

Studies with test subjects lack Often relevant to health risk factors

Current studies commissioned by governments and planning authorities reveal significant limitations of experimental or statistical approaches in the critical frequency range. For example, known, potentially harmful parameters of the infrasound emitted by wind turbines are excluded from application or analysis:

- Epidemiological studies from Denmark (Poulsen et al., several publications in 2018 and 2019) found no statistical correlation between sound emissions from wind turbines and certain diseases (cardiovascular damage, diabetes, hypertension, and miscarriages) among residents. The collected health data were compared with the sound pressure levels measured at the respective locations. These reference points were measured according to the so-called A-weighting, i.e., in the range above 20 Hz. The infrasound from the wind turbines (and thus also the peaks between 1 and 8 Hz, see Fig. 1) was therefore generally not recorded, and the health risks it may have caused were therefore not part of the analysis.

- A scientific consortium commissioned by the Finnish government concluded that the infrasound emitted by wind turbines was not the cause of the health problems reported by residents of several wind farms within a radius of approximately 2.5 km (Maijala et al. 2020). In this study, infrasound frequencies below 8 Hz were also recorded, but in the form of third-octave spectra. The latter consist of average sound pressure values over defined frequency ranges, each with a third-octave range. By averaging, the steep sound pressure peaks emanating from wind turbines, which occur at characteristic frequencies dependent on speed (see Fig. 1), have only a minor impact on the measurement result. This "smoothed out" the signature most likely responsible for health impairments. As expected, residents did not exhibit any significant complaints, even when exposed to the recorded sound for a few minutes in a blind test.

- An experimental study was conducted in Germany on behalf of the Federal Environment Agency (UBA 2020) in which test subjects were exposed to infrasound (3–18 Hz) in the form of sine waves. This "pure"—i.e., artificially produced and simplified—infrasound, according to the authors, rarely occurs in practice, so no conclusions can be drawn about the effects of infrasound from real sources, such as the pulsating emissions of wind turbines. Nevertheless, all test subjects found the sinusoidal infrasound, which was only exposed for 30 minutes, to be bothersome in a blind test, without this being reflected in physiological data (blood pressure, pulse, EEG).

This last case also provides an example of the limited validity of studies that use narrowly defined exposure times. As a result, effects that actually occur with longer or chronic exposure remain undetected. A harmful agent develops a pathophysiological effect many times greater with chronic exposure than with short-term exposure. Adaptive responses are usually only successful if sufficient recovery periods are provided. Therefore, chronic exposure to infrasound during sleep is considered particularly problematic.

The particular health risk of infrasound emitted by wind turbines

Since the vast majority of data from people exposed to infrasound is available for wind turbines, they have become a suitable study object for investigating the effects of infrasound from modern sources (overview in Roos 2019).

The starting point is known complaints from residents, which have been increasingly voiced in recent years. Starting with the primary symptom of severe sleep disturbance, dizziness, anxiety, reduced respiratory rate, depression, and hypertension develop (Kaula 2019; Stelling 2015). One consequence of sleep deprivation is an increase in the stress hormone cortisol (Minkel et al. 2014). Due to the low specificity of individual symptoms and individual differences in sensitivity, infrasound from wind turbines is often not readily identifiable as the cause (e.g., Kamp and Berg 2018), so that an estimate of the prevalence (see above) is likely too low.

Comparative studies, for example, between rotating and switched-off turbines or between exposed and non-exposed residences, have led to the conclusion that rapid changes in sound pressure represent the actual hazard potential, rather than its absolute values. While pulse-free infrasound noise (from natural sources or the background after switching off emitting systems) is not annoying, fluctuating, abrupt pressure changes are very likely to trigger the complaints of residents mentioned above.

(Stelling 2015; Dooley and Metelka 2014; Palmer 2017). Therefore, when assessing a health hazard, the often considerable sound pressure caused by the wind itself (which is measurable when the turbine is stationary) must be distinguished from the pulsatile emissions of the rotating turbine (see caption Fig. 1).

The illnesses reported by residents of wind turbines indicate physical damage and reactions that occur in dangerous proximity to the aforementioned, experimentally determined effects of infrasound:

- Dizziness and the impression of kinetosis (seasickness or motion sickness) can be explained by irritation of the otolith cells of the vestibular system.
- Severe sleep deprivation and the stress effects on autonomic functions (increased blood pressure, respiratory depression) and emotional control (anxiety, depression, irritability) are compatible with the activation of distinct brain areas in the subconscious.
- The frequently reported cardiovascular problems are very likely caused by the aforementioned stress reactions. The experimentally observed reduction in the contractile force of the heart muscle should be considered as a further risk factor, even if evidence in patients is still pending.

Need for Research and Regulation

From a medical perspective, the aforementioned targets and effects on various biological systems constitute a substantial health risk for individuals exposed to infrasound. Nevertheless, obvious causal relationships are partly incomplete and can only be concluded through further research. However, it would be negligent to interpret the ongoing lack of suitable research as an indication of a low or nonexistent risk potential of infrasound from wind turbines, as is unfortunately often the case (LUBW 2016; UBA 2016, 2020). The overall picture of currently established knowledge – including the still incomplete data – justifies concerns about serious health risks. One of the principles of preventive medicine is to identify and address health threats as they arise, before negative effects escalate.

Urgent research goals include:

- the effects of real emissions from infrasound sources on test subjects and laboratory animals, including the potential danger of steep pressure pulses from wind turbines;
- the creation of quantifiable cause-and-effect relationships, i.e., sound-pressure-effect curves for key criteria such as sleep quality, blood pressure, activation of specific brain areas, etc.

In addition to infrasound, which can be measured several kilometers away, wind turbines also emit emissions at close range (a few hundred meters), primarily audible sound and the shadow cast by rotor blades. These stress factors are known to also lead to psychological and physical reactions in residents. The question of the extent to which these infrasound-induced reactions are amplified or modified remains unanswered.

As long as the potentially negative effects of wind turbines on humans cannot be quantified, the safety distance from residential areas of 10 times the height of the turbine, which is applicable in Bavaria, is a reasonable lower limit for planning. The decline of the main symptom of "severe sleep disturbance" with distance from wind turbines has been documented for years (Paller 2016). Occasional statements that the noise from a wind turbine and the nuisance to residents do not depend significantly on distance (e.g., Baumgart 2020) are not substantiated.

A prerequisite for a proper assessment of the health risk is the acquisition of sufficient data. To date, this has been hampered by the measurement regulations of the TA Lärm (Technical Instructions on Noise), which exclude the particularly critical range between 1 and 8 Hz. In the upcoming revision, measurements in this frequency range should be made mandatory.

The assessment of infrasound effects must be carried out independently of the human hearing or perception threshold. The latter are defined as sound levels that 50% or 90% of people can no longer hear, respectively, and reflect the sensitivity of perception in the cochlea. As shown here, infrasound-induced damage and stress responses occur via fundamentally different structures and mechanisms. The fact that infrasound emissions from wind turbines are usually well below the human perception threshold does not make them any less problematic, partly due to the high sensitivity of the vestibular system (see above).

In the discussion about the acceptance of wind turbines, it is occasionally claimed that the stress reactions of some residents are based on a nocebo effect, i.e., a negative expectation (bias) towards wind turbines, rather than on the physical effects of sound exposure (Farboud et al. 2013; Crichton et al. 2014, 2015). These statements are based on evidence from Test subjects who experience greater annoyance from wind turbines when their expectations are negative (asked or experimentally provoked) than when their attitudes are positive. Psychogenic changes may play a role in residents' exposure to wind turbines, which are also visually intrusive, and modify physical damage. They do not explain the illnesses or risks emanating from objectively identified points of attack in the vestibular system, brain, and heart of test subjects and laboratory animals. Stress and avoidance reactions of wild animals to wind turbines (Agnew et al. 2016; Lopucki et al. 2018) also contradict this assumption. As long as no dose (energy)-response curves are available for experimentally documented effects and the illnesses reported by residents, it is too early to determine the extent of the nocebo effect.

Finally, it should be remembered that a stressor that can be controlled briefly can become highly dangerous through repeated application: A drop of water falling on a person's forehead is a trivial matter in itself. However, if a drop of water falls on a person's forehead every 30 seconds, it can be considered a form of torture.

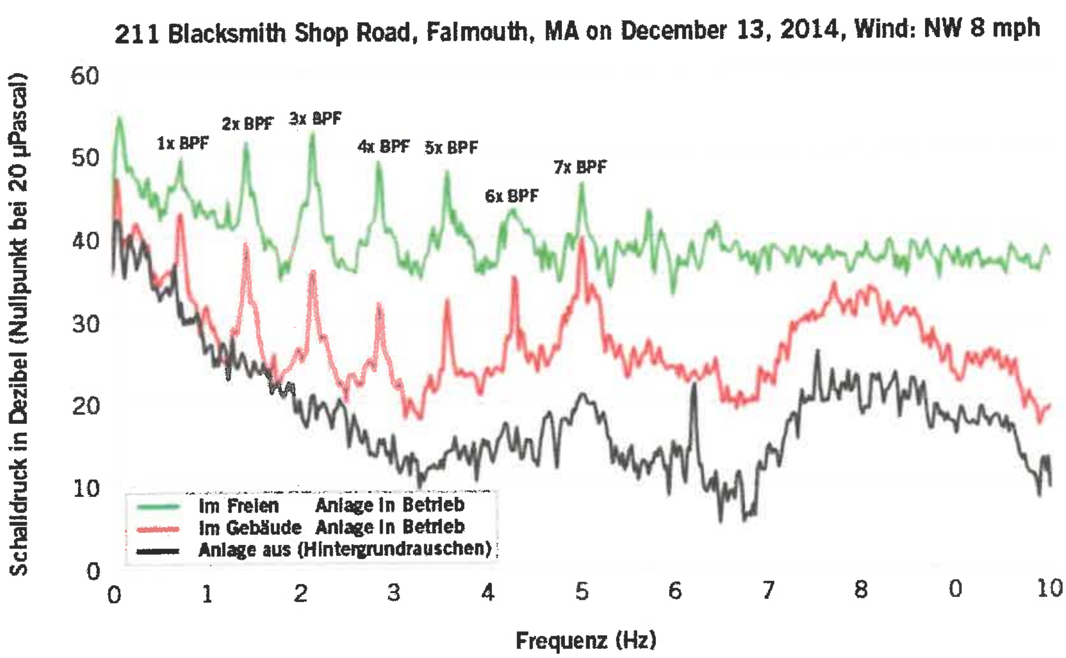

Fig. 1: Frequency pattern of infrasound from two wind turbines. Green line: outside the building. The fundamental rotation frequency at approximately 0.7 Hz (1x BPF) and six harmonic peaks (2x BPF ... 7x BPF) are visible. Red line: Inside the building, the total sound pressure is significantly lower, but the frequency and amplitude of the infrasound peaks mentioned remain unchanged. The sound pressure caused by the wind itself is reduced inside the building, but not the pulses emitted by the turbine. Black line: background noise when the turbine is switched off. Wind turbines: Vestas, 1.65 MW, distances 421 m and 792 m. BPF: blade pass

frequency (frequency of blade passage on the mast). Source: M. Bahtiarian, A. Beaudry, Noise Control Engineering, Billerica, USA 2015

Acknowledgements: The authors thank Dr. L. Ascone and Prof. Dr. S. Kühn, University Medical Center Hamburg-Eppendorf, Department of Psychiatry and Psychotherapy, for their critical review of the manuscript.

Conflict of interest: Both authors declare that they have no conflicts of interest.

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Setback Recommendations Per Various Studies

Name of Study	Date of Study	Author(s)	Link to Study	Author's Advised Setbacks	Notes
Wind Turbine Syndrome: A report on a natural experiment	**2009**	Dr. Nina Pierpont	N/A, PDF provided	**Setbacks from residences should be a minimum of 2 kilometers or 1.24 miles, but 2-3 miles in hilly terrain**	PDF provided to Planning Commission and BoCC
Your Guide to Wind Turboine Syndrome...a road map to a complicated subject	**July 2010**	Calvin Luther Martin, Phd	N/A, PDF provided	**Setbacks from residences should be a minimum of 2 kilometers or 1.24 miles, but 2-3 miles in hilly terrain**	This is a summary of Dr. Pierpont's book PDF provided to Planning Commission and BoCC
Health Effects of Wind Turbines: Testimony of Ben Johnson versus MidAmerican Energy (Madison County, Iowa) / Hearing before the Madison County Board of Health	**August 2019**	Dr. Ben Johnson, M.D.	https://www.masterresource.org/wind-turbine-noise-issues/health-effects-of-wind-turbines-testimony-of-ben-johnson-versus-mid-american-energy-project-in-madison-country-iowa/	**No recommendation given for a specific distance in this hearing. Afterwards the Madison County Board of Health passed a resolution recommending that any future turbines be built at least 1.5 miles from non-participating homes**	PDF provided to Planning Commission and BoCC
Wind Turbine Noise and Human Health: A Four-Decade History of Evidence that Wind Turbines Pose Risks	**Ocober 2016**	Professor Jerry L Punch and Professor Richard R James	https://hearinghealthmatters.org/wp-content/uploads/2023/03/16-10-21-Wind-Turbine-Noise-Post-Publication-Manuscript-HHTM-Punch-James.pdf	**Setbacks from residences are recommended at 1/2 mile to 2.5 miles, 1.25 miles is most favored by scientists.**	PDF provided to Planning Commission and BoCC
Infrasound from technical installations: Scientific basis for an assessment of health risks	**July 2021**	Dr. Werner Roos and Dr. Christian Vahl	https://www-asu--arbeitsmedizin-com.translate.goog/wissenschaft/wissenschaftliche-grundlagen-fuer-eine-bewertung-gesundheitlicher-risiken-infraschall?_x_tr_sl=de&_x_tr_tl=en&_x_tr_hl=en&_x_tr_pto=wapp	**Minimum setback from residences should be 10 X turbine height as in Bavaria Germany**	PDF provided to Planning Commission and BoCC
Assessing Adverse Health Effects-(Confirmed and Potential) from Industrial Wind Turbine Noise Emissions / Power point slides of presentation before the Kansas State Legislature	**2022**	Dr. Ben Johnson, M.D.	https://www.kslegislature.gov/li_2022/b2021_22/committees/ctte_s_utils_1/documents/testimony/20220207_01.pdf	**Setbacks of 1.25 miles from residences**	PDF provided to Planning Commission and BoCC
Presentation before the Kansas Senate and Utilities Committee: Effects of Wind Turbine Noise on Human Health	**2022**	Prof Jerry L Punch	https://www.kslegislature.gov/li_2022/b2021_22/committees/ctte_s_utils_1/documents/testimony/20220208_02.pdf	**Setbacks of 1.25 miles from property lines (specifically) should be considered**	PDF provided to Planning Commission and BoCC
Wind Turbines: Vacated/abandoned homes - Exploring participants' descriptions of their personal views, effects on safety, security, trust and social justice	**Dec 2023**	Carmen Marie Krogh, Robert Y McMurty, W Ben Johson, Jerry L Punch, Anne Dumbrille, Mariana Alves-Pereira, Debra Hughes, Linda Rogers, Robert W Rand, Lorrie Gillis	https://journals.lww.com/endi/fulltext/2023/08040/wind_turbines__vacated_abandoned_homes___exploring.2.aspx	**Residents living within 10 kilometers/6.21 miles of industrial wind turbines were documented having Adverse Health Effects**	See page 96 for the conclusion of the study regarding setbacks. PDF provided to Planning Commission and BoCC.
A fundamental basis for all living creatures, mechanotransduction, is significantly endangered by periodic exposure to impulsive infrasound and vibration from technical emitters - in particular cardiovascular and embryological functions	**June 2025**	Dr. Ursula Bellut-Staeck	https://www.scirea.org/journal/PaperInformation?PaperID=12440	**Setbacks of 10 kilometers / 6.21 miles from people and animals**	NOTE: The link shows the abstact and allows you to download the PDF PDF provided to Planning Commission and BoCC
Separating Myth from Fact on Wind Turbine Noise	**October 2025**	Prof Ken Mattsson	https://www.youtube.com/watch?v=nDwsd32SDEY	**Setbacks of at least 5 to 10 kilometers (3.1 to 6.2 miles) from residences**	Transcript PDF provided to Planning Commission and BoCC
Efficient finite difference modeling of infrasound propagation in realistic 3D domains: Validation with wind turbine measurements	**Feb 2026**	Ken Mattsson, Gustav Eriksson, Leif Persson, Jose Chilo, Kourosh Tatar	https://www.sciencedirect.com/science/article/pii/S0003682X25006280?ref=pdf_download&fr=RR-2&rr=9a872537bf69df1b	**No specific distance given, see notes for conclusion of study**	Conclusion of study page 14: This study also shows that modern, large-scale wind turbines generate infrasound levels substantially higher than those reported for older, smaller turbines / PDF provided to Planning Comm & BoCC

I-5

Assessing Adverse Health Effects– (Confirmed and Potential) from Industrial Wind Turbine Noise Immissions

- Assessing Risk in the Absence of Proven Health Safety

- W. Ben Johnson, M.D.

In the beginning…

- Prior Career, Now retired
  - Cardiologist specialized in Cardiac Electrophysiology
  - Patient Care and Clinical Research
- My presentation:
  - Based on very current scientific data (<4 years)
  - Reflects 40 years of DIRECT patient care experience
  - Supports the individual's right to make informed decisions about their hea
  - Reflects "our" duty to protect the **Health**, **Safety** and **Welfare** of our comm
- My initial assumptions about wind turbines
  - Quiet
  - Good for the world
  - And I **assumed** they were "safe"

In the last 3 years, I have witnessed the "good, the bad and the ug intrusions onto rural communities

Disclosures:

- The topic is massive, emotions are high and distortion and corruptior is "in play"
- I will try to present information everyone should know
- This material is basic and complex and obvious and non-intuitive
- I would ask that you steadfastly retain human health as your priority
- I believe property rights considerations are important for regulating noise "pollution"
- If you believe that "renewables" are the "only pathway forward", I would ask you to reconsider
- I have no hidden agenda. I dove into this area to simply "find the truth." I am receiving no compensation for this talk.
- I am biased because "I care about people"

I am an Environmentalist; I do care very much about the future

- We must not succumb to media and political hysteria framing renewab
as the only "viable energy going forward"
- **Ignored** are the concerns of
  - Intermittency of Wind and Solar and subsequent unreliability and insecurity
  - The need to create "parallel" backup energy systems to supplement inevit
likely frequent) renewable energy shortfalls. Backup systems are very expe
being fossil-fuel sourced, will likely never achieve net carbon reduction targ
gm/KWH.
  - To eliminate "backup systems", we will need cost-effect, safe and reliable
storage systems. That technology does not currently exist at that scale (TM
  - Expanding toward "100% renewables" is absurd and will increase cost/kwh
likely rendering a significant portion of the population unable to afford it ar
country becoming non-competitive on world markets
  - We need to replace current electrical needs and also take-on future transp
electrification. Renewables will not "deliver" for the world
  - There are much better and less expensive options (nuclear) available into
need to venture. We are wasting time and money we don't have

Assumptions, Realities & Deception

- Two events that happened in Madison County
- The U.S. Environmental Protection Agency
  - ONAC and the Quiet Communities Act
- A conversation with a County Supervisor
- A phone conversation with MAE's Biologist
- Safe: We must stick to the definition:
  - Protected from or not exposed to danger or risk
  - Free from harm of risk and secure from threat of danger, harm or loss

So are IWTs "safe"?

- They have **never** been shown to be "free of danger, harm or RISK"
- IWTs have never undergone comprehensive scientific and medical studies
- There is no ongoing, **unbiased** safety-monitoring entity charged with certifying that IWTs were **once** health safe, **are currently** health safe and will be **monitored for any future** safety concerns.
- A "Safe" (health) designation, like respect, has to be earned and then granted

How the EPA defines "Risk"

- Risk is the chance of harmful effects to human health or t ecological systems resulting from exposure to an environmental stressor.
- A STRESSOR is any physical, chemical or biological entity that can induce an adverse effect in humans and ecosystems.
- When an assessor measures risk, a key part of all good risk assessments is a fair and open presentation of the uncertainties, including data gaps and limitations of models used to estimate exposure and effects.
- E.P.A. Assessors use **Health Protective Assumptions,** and recognize that risk assessment often is an ongoing proces

E.P.A.- Commissioned (1970) Columbia Univ. Law Review (to review noise pollution as an introduction and outline for future legal research. Over 50 years ago they noted

- First line: "Noise is one of the scourges of the modern world… and has become an increasingly dangerous and disturbing environmental pollutant".
- Noise may affect one's health in subtle ways – both psychologically and physiologically
- They noted the "problem of noise as 'serious' in 1970 and if social and legal measures were not taken to prevent it, and for the failure to act in time, the public authorities would bear major responsibility"
- "a direct cause and effect relationship between excessive noise and death cannot yet be shown. However, the bell that is tolling is a loud one and is getting louder". (we NOW KNOW that environment noise can cause death)

With Uncanny Insight, they noted:

- The inadequacies of existing legal remedies, municipal noise ordinances as being insufficient to protect rights, health and safety.
- The relationship between exposure to excessive noise over a period of time and the incidence of heart disease, cardiovascular dysfunction, migraine headaches as well as endocrine and metabolic effects.
- That one of the most disruptive effects of noise pollution, both physically and mentally, **is loss of sleep.**
- That infrasound (is a) "sound that may damage the body and mind even though it cannot be heard"

Directives from Congress to the E.P.A

- Through the Noise Control Act of 1972, Congress directed the E.P.A. to publish scientific information about the kind and extent of all identifiable effects of different qualities and quantities of noise.
- The E.P.A. was also directed to define acceptable levels under various conditions which would protect public health and welfare with an **adequate margin of safety**.

In a 1978 SUMMARY of Federal Noise Research in Noise Effects where ONAC categorized and prioritize research efforts:

- They noted "noise can disrupt sleep by causing individuals to awaken or it can degrade the quality of sleep by causing them to shift into a lighter stage of sleep".
- They actively sought-out a very broad source of research expertise – not only the E.P.A. resources but the Departments of Defense, Consumer Product Safety, Energy Research and Development, the National Academy of Sciences, NASA, the National Science Foundation and many others.

Where did the "standard 1500-foot setback" recommendation by Wind Energy originate?

- In the U.K., legislated noise regulation exists as the British Sta
BS4142 which is **based on the likelihood of complaints**

- That regulatory limit was felt by the British Wind Industry to b
restrictive for IWTs as they knew the **only noise control optio**
IWTs is greater distancing. The writing group included acou
attorneys, contractors and businessmen and governmenta
business developers. There were no independent medical

- The Energy Technology Support Unit (ETSU-R-97) was develo
a "guideline" and was **never approved as "regulation"**

Origins of the 1500 feet setback (2)

- It was described by world acoustical experts as "developed specifically to circumvent more science-based and health-protective U.K. regulations". There was **no medical or scientific evaluations** of turbine noise nor health safety.
- When this became implemented, the world came to consider residents living near IWTs as "acceptable collateral damage". It initiated the "practice" of uncompensated noise **trespassing** inside rather than at the property line where other pollution regulation and enforcement occurs.

Terms of "Condition of Coverage" of My Umbrella Insurance Policy

- **Pollutant (defined)**: Electrical or magnetic emissions, electromagnetic particles or fields, whether visible or invisible, and sound or **NOISE**
- Insurance will **not cover injury arising** out of or resulting **from pollution**
  - Including **any actual, alleged or threatened**:
    - Dispersal, release, escape, **EMISSIONS**, seepage, **TRESPASS,.....**
    - Ingestion, inhalation or **ABSORPTION** of **ANY POLLUTANT** from any source

This includes any cost or expense to:

Abate, test for, monitor, clean up, remove, contain, treat, ...

In any way respond to, or assess the effects of any pollutant

from any source

The insurance company will not cover punitive , statutorily imposed or court-ordered damages

In talking with the Insurance Company Underwriter:

- When I asked them whether their "protracted description" of a "pollutant" included industrial wind turbines, they said "absolutely"
- When I asked why they just didn't say "industrial wind turbines" they said it would take too long to get the State Insurance Board to permit that wordage
- When I asked them, "why don't you insure industrial wind turbines", they said that they have not been evaluated as safe and there are lots of risks that remain undefined.
- So if IWTs emits "pollutants" without being designated as safe or with defined risks, why would you permit them to be placed in the State and threaten citizens?

Health – defined

- Includes a **broad composite** of not only physical and mental health but also represents a "POSITIVE" living condition
- Encompasses the "WHOLE" of the individual and their interactions with their living environment and supporting social structures
- The World Health Organization (WHO) defines health as a state of COMPLETE physical, mental and social WELL-BEING
- **Well-being** is defined as "the state of being comfortable, healthy or happy"
- Mental and physical health are inextricably connected, thus highlighting that **"annoyance" AT ANY LEVEL can contribute to adverse health effects.**

Annoyance – An Adverse Health Effect

- Annoyance could be considered as a feeling of displeasure reacted with varying degrees of resistance or active coping of audible or visual clues or recalled situational conflicts
- Greater levels of perceived annoyance generally produce greater "stress" that is actively felt or can be internalized but not eliminated
- Several studies have concluded that individuals do not "get used to" annoyance over time; even if they become indifferent they are still affected
- The WHO in 2011 declared that high levels of annoyance caused by environmental noise should be considered as an environmental health burden with costs to people and society

Unavoidable Perception and Reaction…Is the **Nocebo effect** really a conscious choice?

- Nocebo Effect: Used by wind energy proponents to justify their view that negative reactions to wind turbines are based primarily or solely on psychological expectations
- This is the central argument necessary for Wind Energy to claim an absence of "**DIRECT**" harm
- Pro-wind factions seek to deny complaints as "not counting", outcomes as "not real" or are the victims' "own fault"
- Pro-Wind: "Antagonism to a wind turbine development often comes from two directions
  - 1) inadequate communication by the developer and
  - 2) excessive communication from objector groups
- Reflects Wind Energy's willingness to allow harm. (Leventhal): "In my opinion, the Kent Breeze Wind Farm will **not cause serious harm** to human health of a participating receptor". (but mild or moderate?)

Sleep Disruption(taken from 2018 WHO Environmen Noise Guidelines… (Basner and Maguire)

- “Sleep is a **biological imperative** and a **very active process** that serv **vital functions**. Undisturbed sleep of sufficient length **is essential** for c alertness and performance, **quality of life and health**. Noise has bee **fragment sleep**, **reduce sleep continuity** and **reduce total sleep time** Numerous experimental studies have demonstrated that **sleep restri causes**, among others, **changes in glucose metabolism** and **appetit regulation**, an **attenuated immune response** to vaccination, **impaire** consolidation and **dysfunction of blood vessels**. **These are precursor manifest diseases like obesity, diabetes, high blood pressure, and pr dementia.** The epidemiologic evidence that chronically disturbed o sleep is associated with the negative health outcomes mentioned a **overwhelming**. For these reasons, **noise-induced sleep disturbance i considered one of the most important non-auditory effects** of enviro noise exposure

WItNESS Study, 2019, Michael Smith, M.D.

- Sleep is disrupted through both unconscious arousals and with frank awakenings – both disrupting the otherwise healthy (thus required) progressions through both non-REM and REM sleep periods.
- Dr. Smith confirmed via sleep study analysis of subjects exposed to reproduced IWT noise at an "interior home noise level" of 32 dBA that REM sleep was statistically shortened.
- In addition, self-reported responses in 14 of 17 questionnaire items **indicated worse sleep quality** and **less restorative sleep** when compared to the quiet control night.

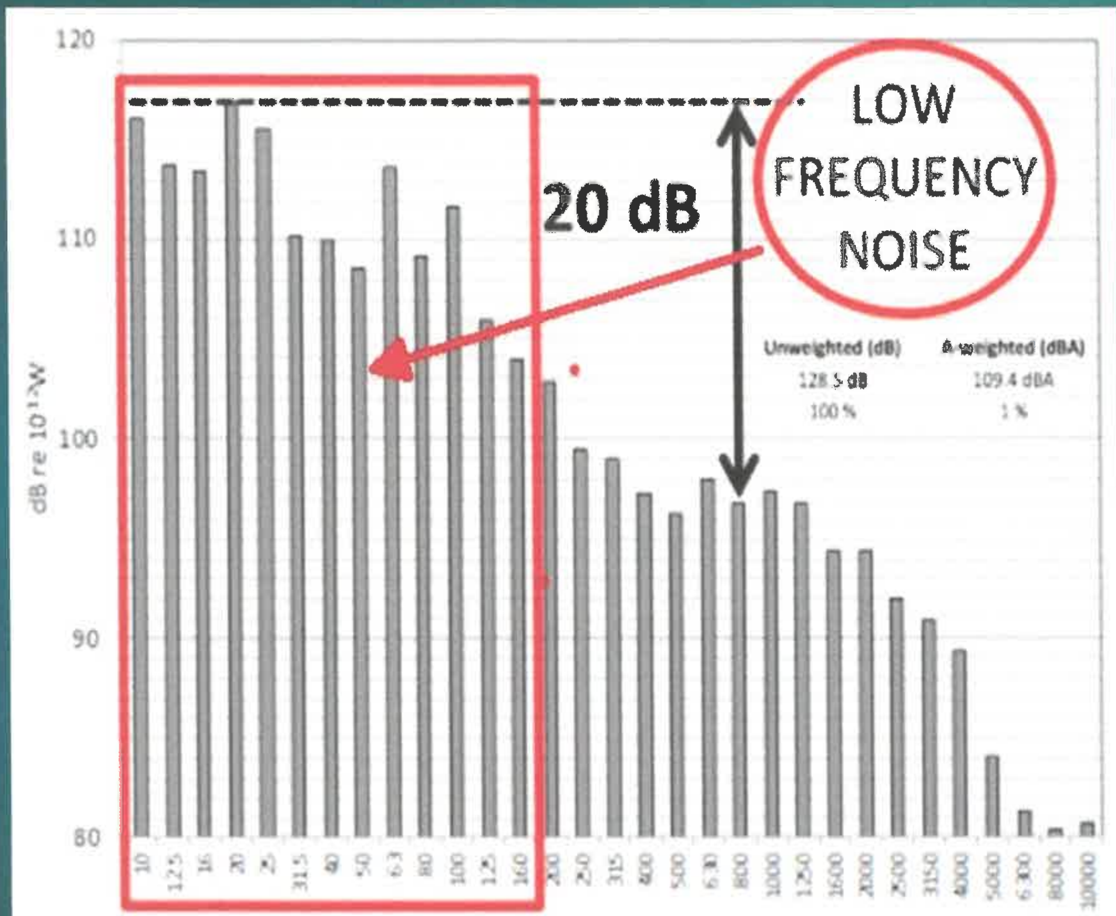
Emerging Concept: "Transportation noise impairs cardiovascular function without altering sleep: The importance of autonomic arousals" (Thiesse L., Rudzik F., et.al. Environ Res. 2020 Mar)

- Response to Stressors includes two pathways: : Cortical Arousal and Autonomic Arousal –the later being relatively more affected by highly intermittent noise
- Under controlled lab conditions, **highly intermittent** nocturnal road noise exposure at 45 dB increased the cumulative duration of **autonomic** arousals during sleep and next-day cortisol levels
- Surprisingly, the performed classical sleep study and scoring did not significantly impact sleep macrostructure, blood pressure , nocturnal catecholamine levels and morning cytokine levels (typical of Cortical Pathway)
- This suggests that <u>nocturnal noise can have adverse biological consequences without necessarily disrupting classically scored sleep micro- and macrostructure</u> (previously expected to be seen on "sleep studies")

Infrasound and ILFN

- During MidAmerican Energy's community presentation, a resident aske
  about infrasound… isn't that a problem?" The project manager laugh
  then only responded with "what you can't hear, won't hurt you"
- Indeed that meme is a "myth" Wind Energy industry continues to prop
  because they know it is essential for their business plan.
- ILFN (infrasound low frequency noise) encapsulates frequencies betwe
  and 200 Hz. At those low frequencies, noise "travels" roughly twice as f
  higher (audible) frequencies. After about a half mile from the turbine,
  what is perceived is ILFN. Amplitude modulation of those lower frequen
  source for the majority of sleep disturbance complaints
- Wind Energy downplays the relative amount of ILFN in the entire wind t
  noise spectrum and the adverse health impacts originating from ILFN. W
  Energy recognizes, that to adequately limit the adverse health of IWT n
  turbine siting must be MUCH greater than 1500 feet from where people
- The necessary setback distance, if infrasound is considered is about 1.2
  (2km)

Sound Power Spectrum of V-112 3MW



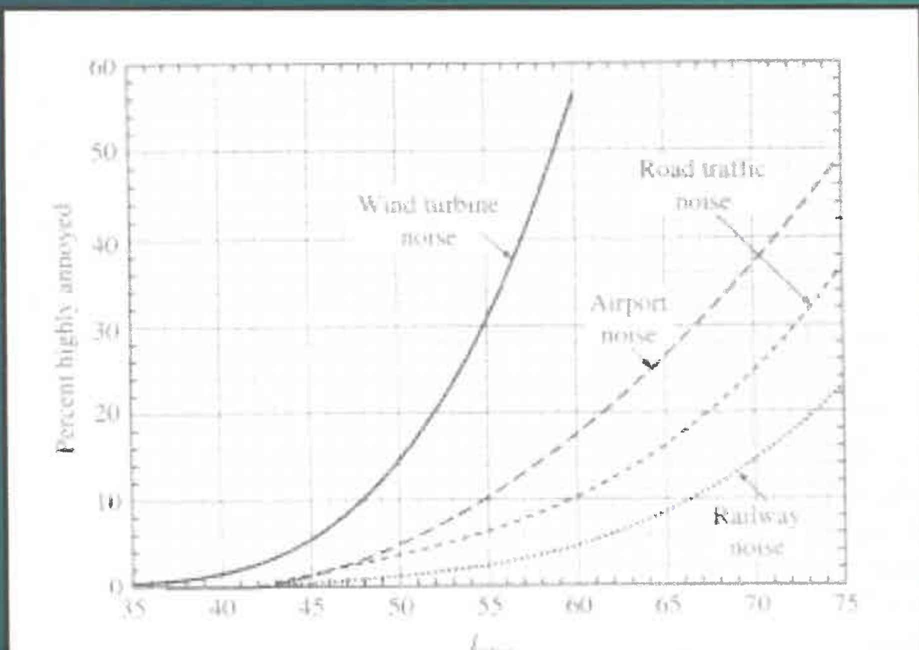
Wind Turbines Emit Primarily Infra- and Low Frequency Noise (ILFN) From 0.5 to 200 Hz)

Dose - Response Functions for High Annoyance: IWT Noise vs Transportation Noise

Wind Farm Noise (text) – Hansen, Doolan, Hansen, 2017

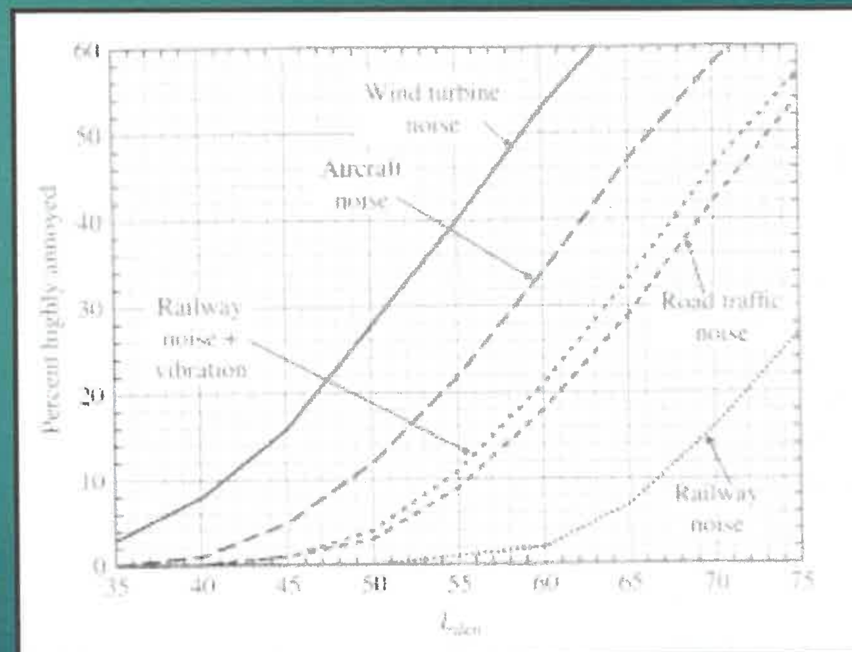
Miedema Oudshoorn (transp 2001)

Janssen, et. al., (IWT Noise 2008)



Health Canada Study

Michaud et al., 2016



Is it "Fair" to compare IWT vs RTN in terms of cardiovascular disease risk?

- When WTN is more annoying than RTN at all perceived Lden and Leq noise levels?
- When RTN and Cardiovascular Disease Association are now statistically plotted?

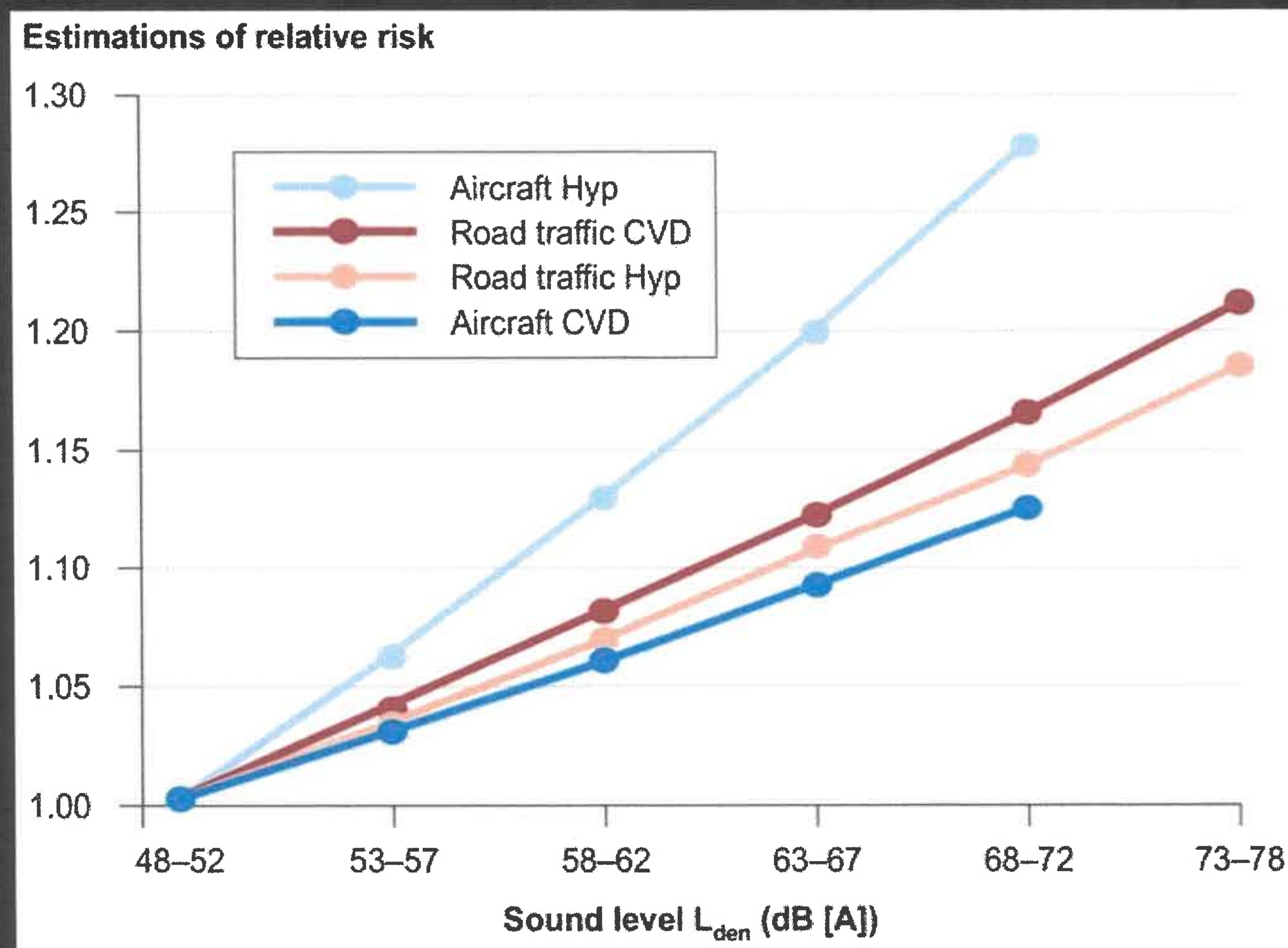
- No,
- BUT it does raise <u>significant</u> concerns of RISK that IWT noise causes cardiovascular disease

Cardiovascular Effects of Noise

(Wolfgang Babisch; Noise Health, 2011 Ed

- It is well known that noise levels below the hearing damagi criterion cause annoyance, sleep disturbance, cognitive impairment, physiological stress reactions, endocrine imbal and cardiovascular disorders
- …"The question is no longer whether noise causes cardiova effects, it is rather: what is the magnitude of the effect in te the exposure-response relationship (slope) and the onset or threshold (intercept) of the increase in risk"?

Dose Response Relationship for Noise and Cardiovascular Disease (Muenzel: CV Effects of Noise, 2019



Atherosclerosis: the consequence of traditional and non-traditional risk factors

- **Traditional**: tobacco use, hypertension, diabetes, hyperlipidemia, obesity, physical inactivity (modifiable), and family history (non-modifiable)
- **Non-traditional**: sleep problems, substantial life stresses, inflammatory autoimmune diseases
- Recent, **Non-traditional** surprising and NON-intuitive additional risk factors were high consumption of refined sugars, PTSD, Obstructive sleep apnea, mild depression, certain 2.5 micron particulate air pollution **and environmental noises** – road traffic, air traffic are all associated with higher rates of ischemic disease (due to obstructive atherosclerotic disease).

Cardiovascular Health in Rural America

- Cardiovascular disease remains the leading cause of death in the U.S.
- In recent years, declines in cardiovascular mortality have stalled with st heart failure showing increasing death rates which have been worse fo living in rural counties.
- Over the last 3 decades, health outcomes are significantly worse in rura areas
- Life expectancy now >3 years shorter in rural areas (2014)
- 2017 CDC data show a 40% higher prevalence of heart disease among residents – a gap growing over the last decade
- Rural areas have higher rates of uncontrolled traditional risk factors

Meta analysis Review of Subjective and Objective Sleep Duration and Sleep Quality on Sub-Clinical Cardiovascular disease

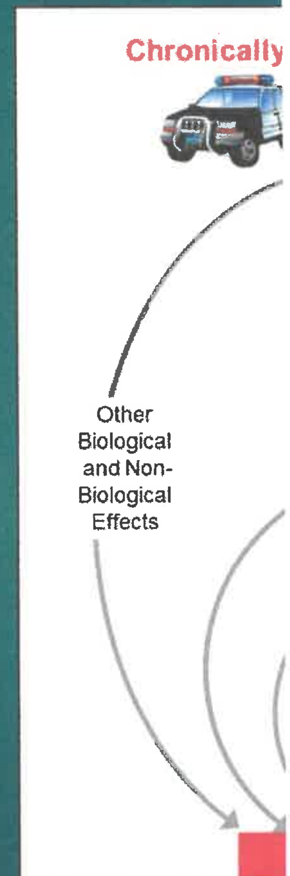
J. Atheroscler Thromb, 2017

- Combined 32 studies, used non-invasive techniques to defin
"burden" that potentially lead to clinical cardiovascular eve
- They concluded, "based on our systemic review**, individuals**
sleep disturbances, both qualitative and quantitative, have
accelerated subclinical CVD burden in the form of augmen
Coronary Artery Calcium, increased Carotid Intima Media
Thickness, impaired endothelial function, and augmented ar
stiffness.
- These findings suggest that **association between sleep distur**
and increased CVD risk is exemplified by early changes in subclinical CVD status. **<u>(Subclinical disease needs to be recognized in the "big picture")</u>**

Direct Chronic Noise to Amygdala producing Autonomic Sympathetic Activation

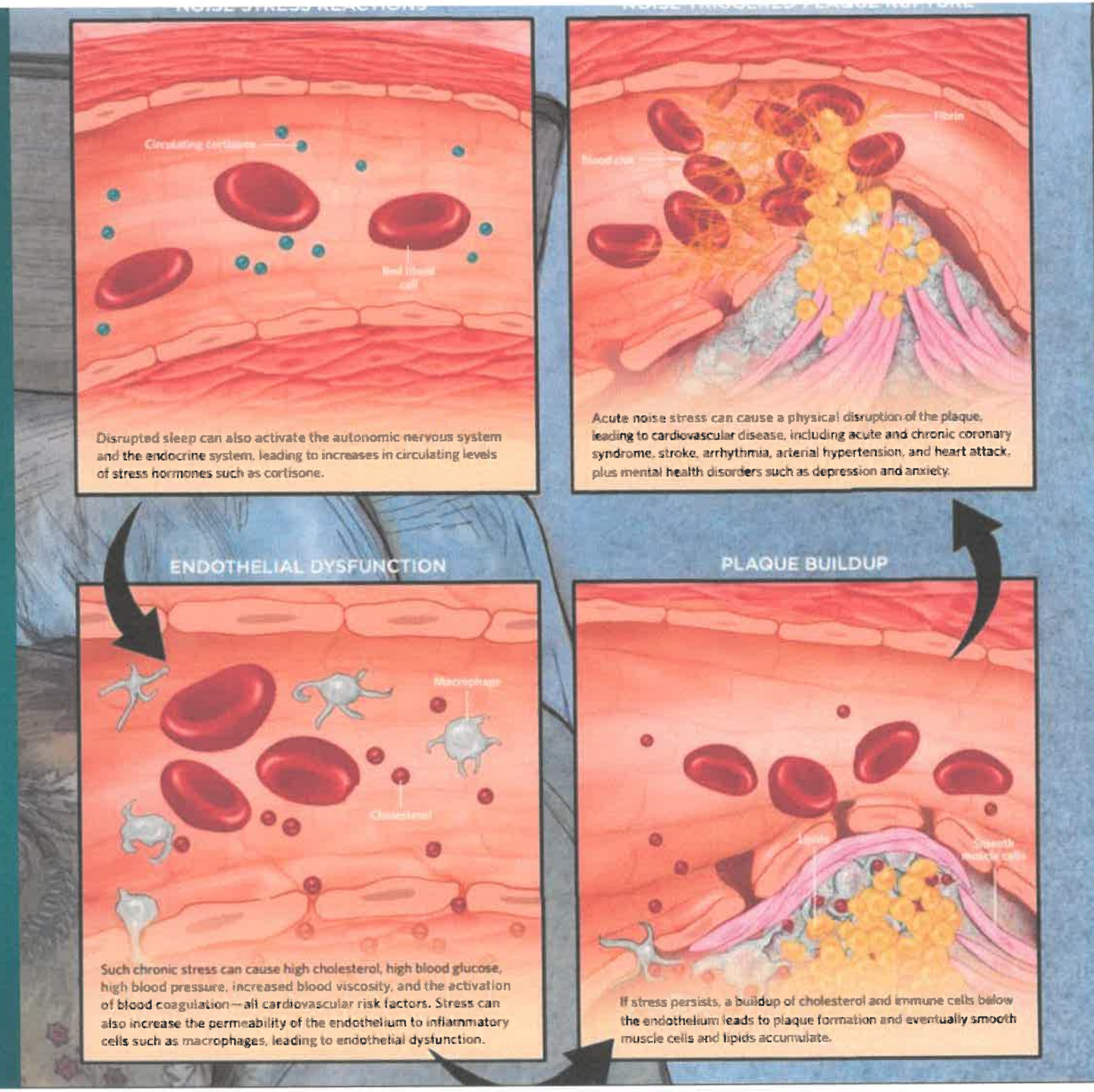
This can cause Systemic Inflammation that may lead to Atherosclerosis

- "A neurobiological mechanism linking transportation noise to cardiovascular disease in humans"
- Taken from Osborne, Radfar, Hassan, et.al., European heart Journal; 2020 Feb 1; 41(6): 772-782



Pathways and Mechanisms of Atherosclerosis

- Demonstrated in hypertension, ischemic cardiovascular disease, associated with traditional risk factors
- Confirmed that pathways and mechanisms are the same with non-traditional risk factors as noise and air pollution-induced hypertension, ischemic cardiovascular disease
- Pathways include:
  - Systemic Inflammation
  - Oxidation stress
  - Endothelial dysfunction
  - Sympathetic activation (from ANS)


Circulating cortisone
Red blood cell
Disrupted sleep can also activate the autonomic nervous system and the endocrine system, leading to increases in circulating levels of stress hormones such as cortisone.
Fibrin
Blood clot
Acute noise stress can cause a physical disruption of the plaque, leading to cardiovascular disease, including acute and chronic coronary syndrome, stroke, arrhythmia, arterial hypertension, and heart attack, plus mental health disorders such as depression and anxiety.
ENDOTHELIAL DYSFUNCTION
Macrophage
Cholesterol
Such chronic stress can cause high cholesterol, high blood glucose, high blood pressure, increased blood viscosity, and the activation of blood coagulation—all cardiovascular risk factors. Stress can also increase the permeability of the endothelium to inflammatory cells such as macrophages, leading to endothelial dysfunction.
PLAQUE BUILDUP
Lipids
Smooth muscle cells
If stress persists, a buildup of cholesterol and immune cells below the endothelium leads to plaque formation and eventually smooth muscle cells and lipids accumulate.

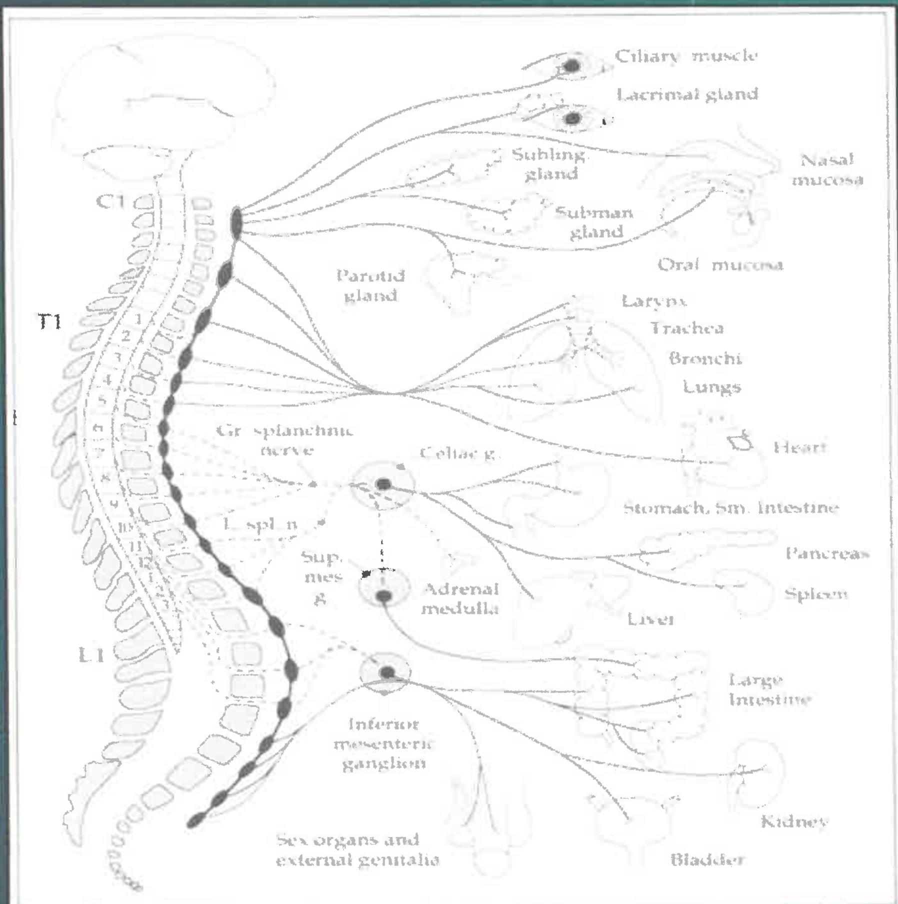
Autonomic Nervous System

- Man evolved in a "natural environment" where survival was dependen unique capabilities of hearing, vision and retaining some "awareness" sleep
- The brain became the "central processor" of the "input" from our tradi senses relating the external world and from various "perceptions" of ou "being"
- The autonomic nervous system (ANS), in working with the central nervo has a dominant role in integrating the various local and reflex mechan best serve the needs of the entire organism
- Simplistically, the ANS, is a "control system" that acts largely unconscio regulate bodily function such as heart rate, blood pressure, digestion, r and many others. Through its activation, it facilitates and enhances "in cells to organ system" function to improve survival

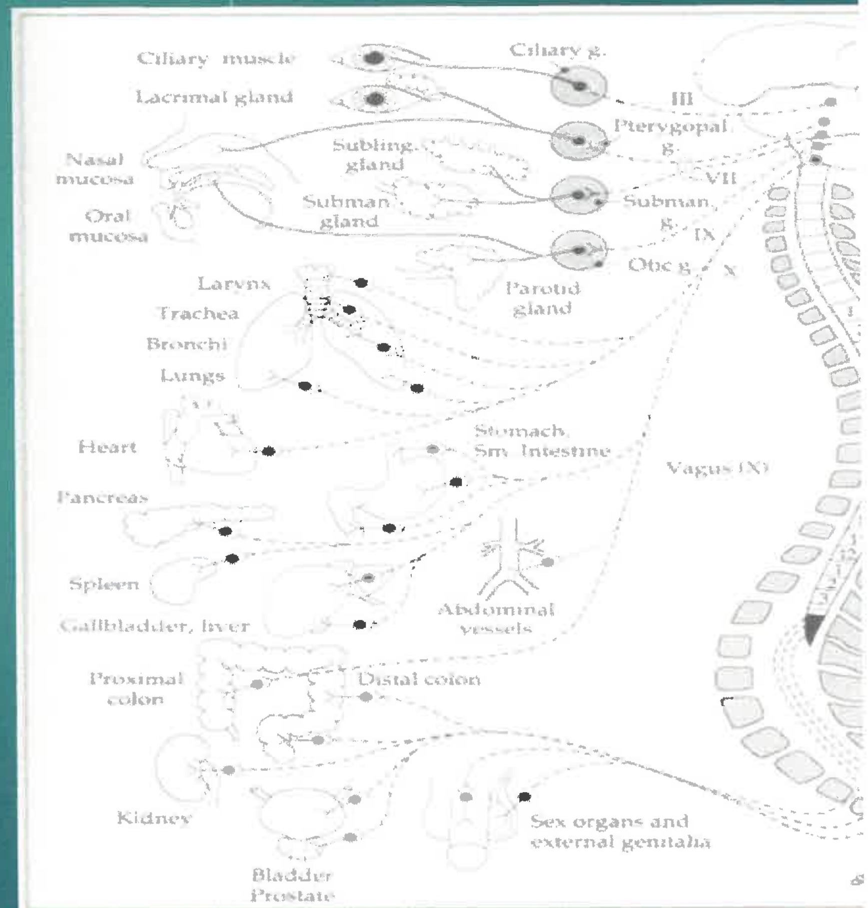
Peripheral Autonomic Nervous System

(Wiring diagram: Ganglia and Cranial Nerves to Organs)

Sympathetic NS



Parasympathetic NS



The ANS "balance"

- Anatomically and physiologically, there are two major branch
  - Sympathetic "fight or flight"
  - Parasympathetic "sleep or eat"
- In many cases, these systems have "opposite actions" where
system activate a physiologic response and the other inhibits
- In practicality there is an "undulating balance" or responsive
that can "tweak" the system within seconds as a momentary
or can persistently "tilt" toward one side or the other.
- Stress or chronic disease is associated with chronic elevated sympathetic tone.

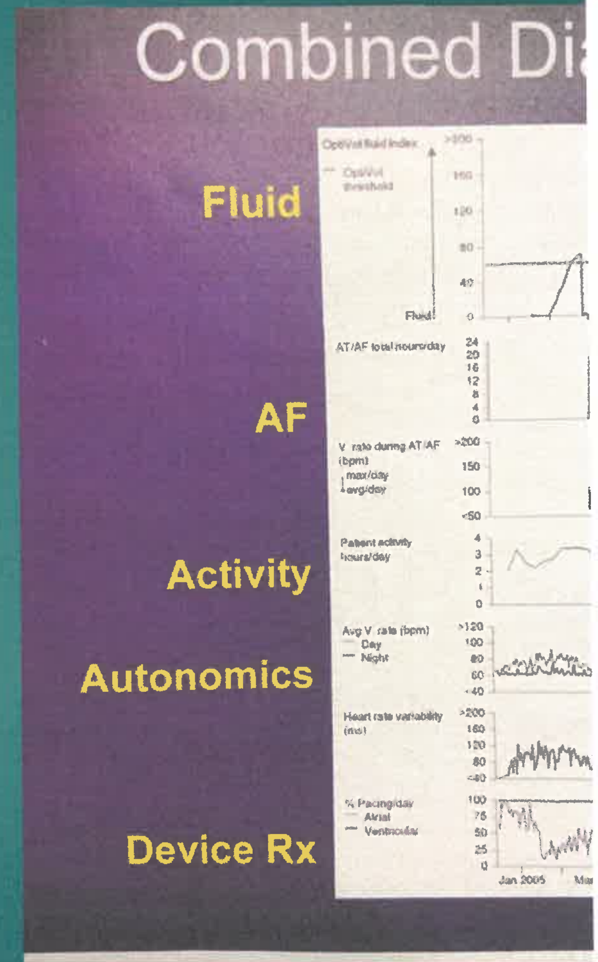
Heart Rate Variability

- HRV is the variation over time of the period between adjacent heartbeats
- Reflects ongoing balance between sympathetic and parasympathetic limbs of the ANS
- A reduced HRV reflects enhanced sympathetic activity
- Low frequency (31-125 Hz) noise exposure produces a greater reduction in HRV (reflective of greater sympathetic stress) than higher frequency (500-2000 Hz) noise and tend to persist longer. (Walker, Brammer, et.al. Environmental Res. 2017)
- Studies reflect sympathetic activation for LFN (20-200 Hz) **during brief and close IWT exposure** – noting significant, proportional HRV reduction with increasing noise levels. (Chiu, et al, 2021) **This raises the concern that unrecognized low-frequency noise may be triggering autonomically driven inflammatory cardiovascular disease. This is a MAJOR unknown IWT Risk for CVD**

Implantable Cardiac Devices – Pacemaker, Defibrillators Resynchronization Devices

Continuous Diagnostics:

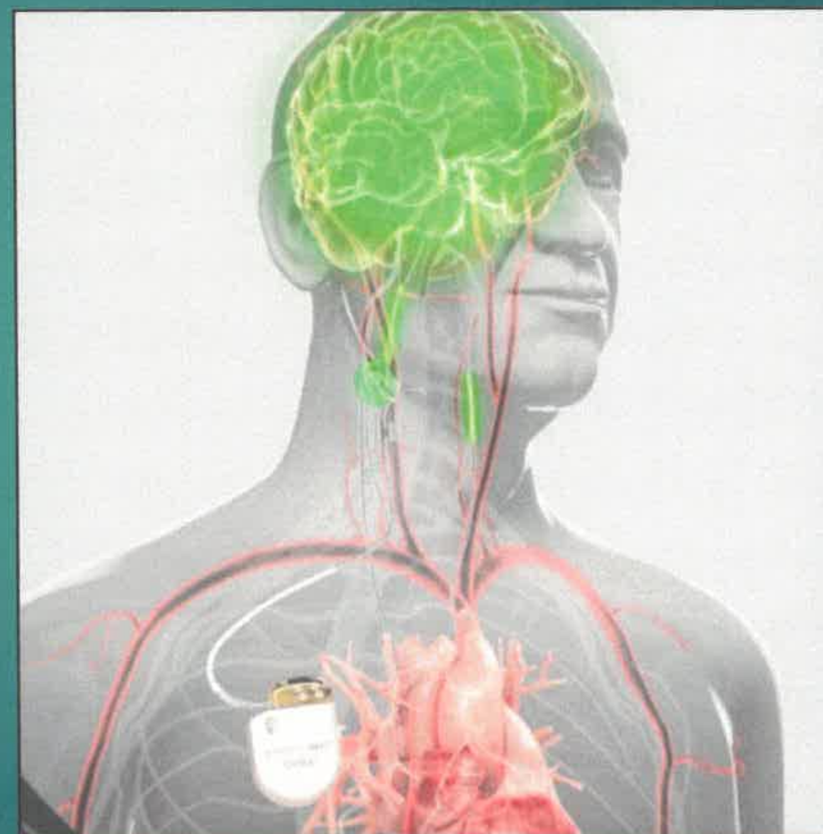
- May see ongoing surrogate of autonomic nervous system "balance" as computed and displayed "heart rate variability"
- When atrial rhythm is "not-paced" or is Atrial Fibrillation

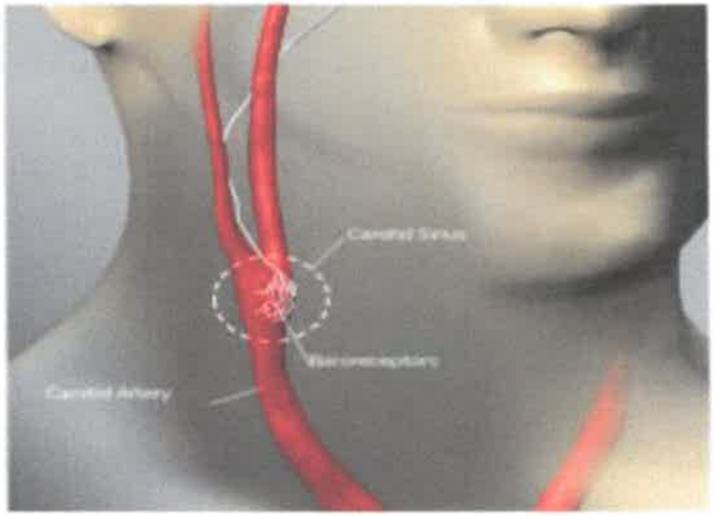


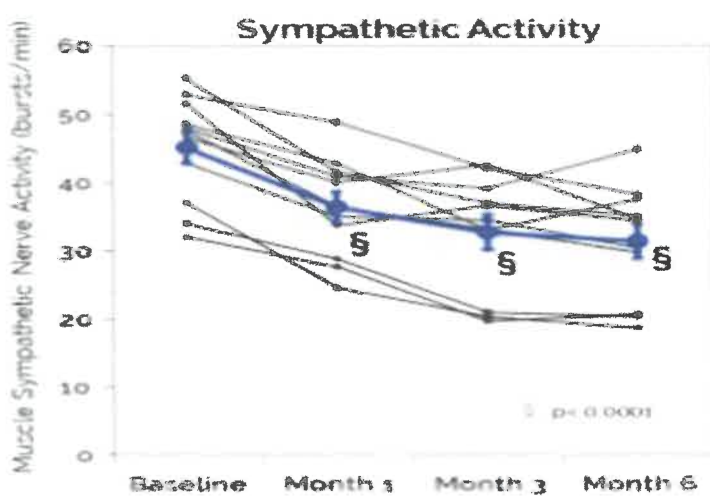
Implantable Baroreceptor Stimulation Device Therapy Neuromodulation: Evidence of the Importance of the Autonomic Nervous System in Cardiovascular disease

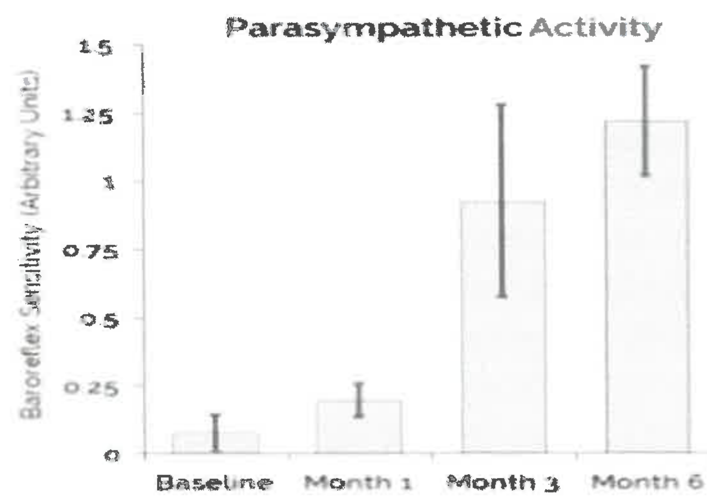
Converting afferent (incoming) high ambient sympathetic tone to more "healthy" efferent (outgoing) autonomic balance

(Currently approved only for indications of resistant hypertension and certain forms of advanced heart failure – NOT for adverse health effect from wind turbine emissions)









Gronda et al. EJHF 2014

“Words” chosen by Survivors; Interviews of those who had or contemplated vacating their homes having lived within 10 km of Wind Energy Facilities. (Krogh, et. al., Scientific Res, 2021)

- Used rigorous qualitative data collection research to explore **“deeper” personal and social impacts** of attempted living close to wind turbines
- 67 interviewees – 28 permanently abandoned, 31 contemplated home abandonment, 4 pre-emptively left
- Questioned along themes and subthemes… their words:
- “My belief is that this turbine issue is going to take a long time for all of the effects to become known… I do think they already are known to some degree but to get the majority of people to understand and to relate to them, I think it’s going to take time. I have concerns so that they will always think that this has to do with the greater good… that people **have to suffer** for the greater good”.
- … the noise varied, one time when the Ministry official was here he said, 'I can’t hear the vibration because of the noise of the blades’
- “we’re exposing our children… they’re being harmed

Sir Austin Bradford Hill: Biological Plausibility

(Pertinent to epidemiology to establish a causal link between WTN and AHEs)

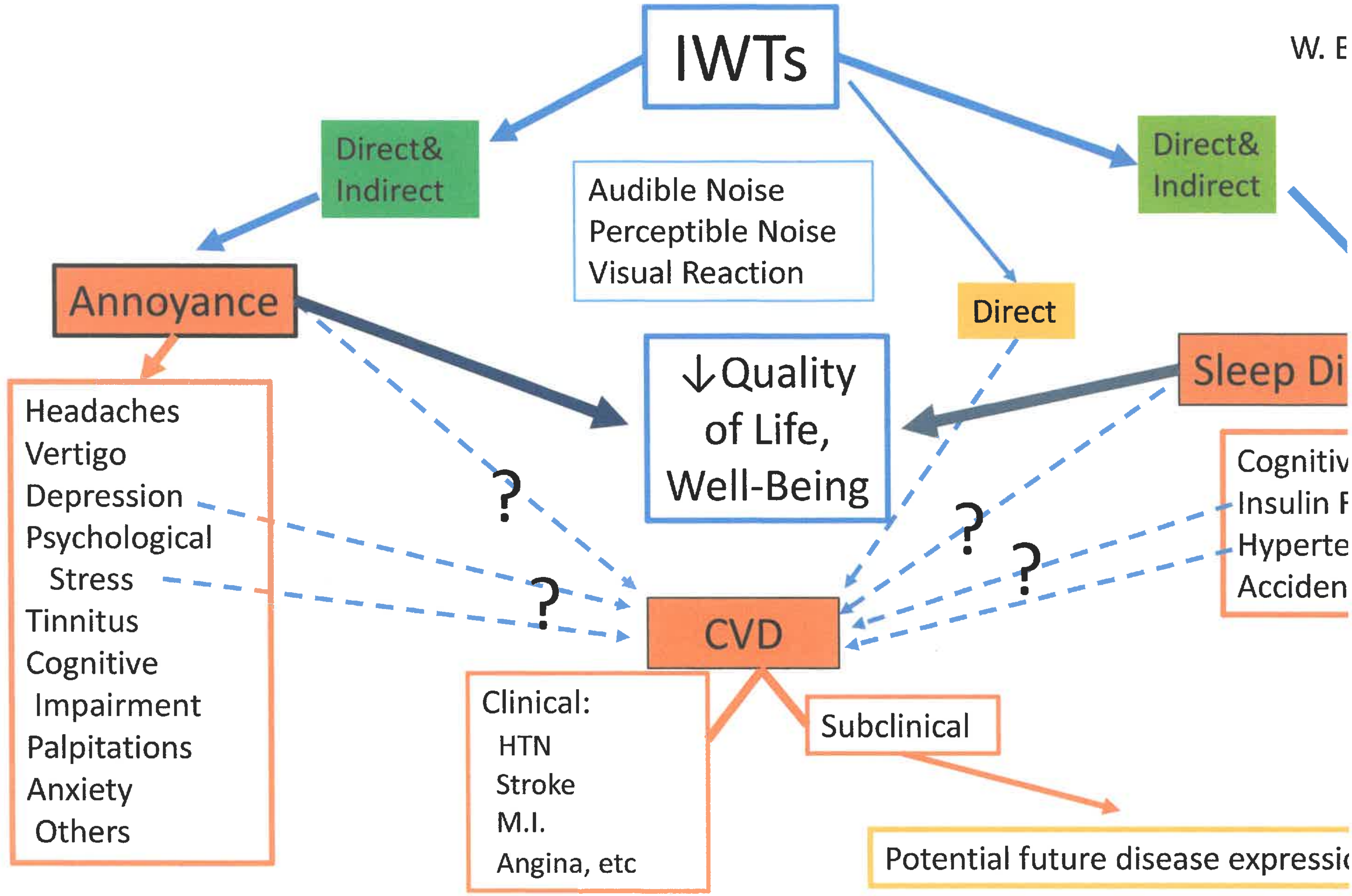
- **Strength** (widespread reports of complaints)
- **Consistency** (consistency of reported symptoms)
- **Specificity** (concurrence of symptoms with IWT operation)
- **Temporality** (concurrency of symptoms with IWT operation)
- **Biological Gradient** (a dose response relationship between exposure levels (or distance) and symptoms)
- **Plausibility** (the role of disturbances of the hearing and balance mechanisms of the inner ear in causing identified symp
- **Coherence** (coherence with WHO, federal and some state noise guideline
- **Experiment** (cross-sectional studies, also fact that symptoms decline or dis when receptors leave the area and recur upon return)
- **Analogy** (noise-induced Sick Building Syndrome)

Do IWTs Cause Adverse Health Effects?

- Annoyance – Yes,
- Sleep Disturbance –Yes
  - Most common complaint; clinically undeniable
- Cardiovascular disease - Increasing evidence to support
  - Confirmation with traffic **noise**
  - Confirmation with aircraft **noise**
  - Very likely association with rail traffic
  - Autonomic Nervous System "activation" to LFN
  - Recognition of sleep disturbance from traffic noise, OSA causing subclinical CV disease

  Lessons from baroreceptor stimulation and neuromodulation

Industrial Wind Turbines – Adverse Health Effects – Proposed Intera



Why Assessing IWT Heath Effects is so Difficult

- There are far fewer exposed patients (compared to traffic, airplane traffic)
- Varying individual "noise sensitivity"
- Exposure quantification is difficult to assess
  - Distance to turbine/turbines
  - Intermittency and variability of noise affecting noise levels
  - Windows open/closed, bedroom exposure to noise
  - Construction of home: insulation type, quantity
  - Varying weather affecting amplitude modulation
  - Time spent at residence
  - Long term monitoring/testing to demonstrate subclinical disease

Mathias Basner, MD, PhD Associate Professor of Sleep and Chronobiology in Psychiatry. University of Pennsylvania

- President of the International Commission of Biological Effects of Environmental Noise
- Personally reviewed and helped to summarize the data for the Oct, 2018 WHO Environmental Noise Report
- He stressed that **NONE** of the **wind noise guideline data** from the 2018 WHO report **found "an absence of risk**" (Which is needed to declare health safety – my comment)
- Finished his 2019 editorial with "the fact that more studies are needed should not lead us to postpone the urgently needed protection of the population from noise. <u>The knowledge we have acquired so far (about environmental noise) **IS SUFFICIENT** to take preventative action and substantiate them with respective legal noise regulation</u>

From the 2017 textbook "Wind Farm Noise – Measurement, Assessment and Control" (Hansen, Doolan, Hansen)

- It is time to stop debating whether or not a (health) problem exists. It is well known that wind farm noise DOES result in **sleep disturbance and adverse health effects** for some people and the time has come to decide what to do about it.
- The fact remains that some people are so affected by wind farm noise that their **health suffers** and some are forced to leave their home in order to achieve an acceptable **quality of life**.

Board of Health "E-mail Header" Mission Statement – Page County, Iowa

- Prevent, Promote, Protect

Prevent adverse health events

Promote health and well-being

Protection of all citizens

- IWTs are Permitted and Sited without these Public Health Goals

My original assumption about Industrial Wind Turbines

- I thought they were "quiet"
- Believed that they were "good for the world"
- And assumed they were "safe"

I now absolutely know that **NONE** of those assumptions are true.

Setback Recommendations Per Various Studies

Name of Study	Date of Study	Author(s)	Link to Study	Author's Advised Setbacks	Notes
Wind Turbine Syndrome: A report on a natural experiment	**2009**	Dr. Nina Pierpont	N/A, PDF provided	**Setbacks from residences should be a minimum of 2 kilometers or 1.24 miles, but 2-3 miles in hilly terrain**	PDF provided to Planning Commission and BoCC
Your Guide to Wind Turboine Syndrome...a road map to a complicated subject	**July 2010**	Calvin Luther Martin, Phd	N/A, PDF provided	**Setbacks from residences should be a minimum of 2 kilometers or 1.24 miles, but 2-3 miles in hilly terrain**	This is a summary of Dr. Pierpont's book PDF provided to Planning Commission and BoCC
Health Effects of Wind Turbines: Testimony of Ben Johnson versus MidAmerican Energy (Madison County, Iowa) / Hearing before the Madison County Board of Health	**August 2019**	Dr. Ben Johnson, M.D.	https://www.masterresource.org/wind-turbine-noise-issues/health-effects-of-wind-turbines-testimony-of-ben-johnson-versus-mid-american-energy-project-in-madison-country-iowa/	**No recommendation given for a specific distance in this hearing. Afterwards the Madison County Board of Health passed a resolution recommending that any future turbines be built at least 1.5 miles from non-participating homes**	PDF provided to Planning Commission and BoCC
Wind Turbine Noise and Human Health: A Four-Decade History of Evidence that Wind Turbines Pose Risks	**Ocober 2016**	Professor Jerry L Punch and Professor Richard R James	https://hearinghealthmatters.org/wp-content/uploads/2023/03/16-10-21-Wind-Turbine-Noise-Post-Publication-Manuscript-HHTM-Punch-James.pdf	**Setbacks from residences are recommended at 1/2 mile to 2.5 miles, 1.25 miles is most favored by scientists.**	PDF provided to Planning Commission and BoCC
Infrasound from technical installations: Scientific basis for an assessment of health risks	**July 2021**	Dr. Werner Roos and Dr. Christian Vahl	https://www-asu--arbeitsmedizin-com.translate.goog/wissenschaft/wissenschaftliche-grundlagen-fuer-eine-bewertung-gesundheitlicher-risiken-infraschall?_x_tr_sl=de&_x_tr_tl=en&_x_tr_hl=en&_x_tr_pto=wapp	**Minimum setback from residences should be 10 X turbine height as in Bavaria Germany**	PDF provided to Planning Commission and BoCC
Assessing Adverse Health Effects-(Confirmed and Potential) from Industrial Wind Turbine Noise Emissions / Power point slides of presentation before the Kansas State Legislature	**2022**	Dr. Ben Johnson, M.D.	https://www.kslegislature.gov/li_2022/b2021_22/committees/ctte_s_utils_1/documents/testimony/20220207_01.pdf	**Setbacks of 1.25 miles from residences**	PDF provided to Planning Commission and BoCC
Presentation before the Kansas Senate and Utilities Committee: Effects of Wind Turbine Noise on Human Health	**2022**	Prof Jerry L Punch	https://www.kslegislature.gov/li_2022/b2021_22/committees/ctte_s_utils_1/documents/testimony/20220208_02.pdf	**Setbacks of 1.25 miles from property lines (specifically) should be considered**	PDF provided to Planning Commission and BoCC
Wind Turbines: Vacated/abandoned homes - Exploring participants' descriptions of their personal views, effects on safety, security, trust and social justice	**Dec 2023**	Carmen Marie Krogh, Robert Y McMurty, W Ben Johson, Jerry L Punch, Anne Dumbrille, Mariana Alves-Pereira, Debra Hughes, Linda Rogers, Robert W Rand, Lorrie Gillis	https://journals.lww.com/endi/fulltext/2023/08040/wind_turbines__vacated_abandoned_homes___exploring.2.aspx	**Residents living within 10 kilometers/6.21 miles of industrial wind turbines were documented having Adverse Health Effects**	See page 96 for the conclusion of the study regarding setbacks. PDF provided to Planning Commission and BoCC.
A fundamental basis for all living creatures, mechanotransduction, is significantly endangered by periodic exposure to impulsive infrasound and vibration from technical emitters - in particular cardiovascular and embryological functions	**June 2025**	Dr. Ursula Bellut-Staeck	https://www.scirea.org/journal/PaperInformation?PaperID=12440	**Setbacks of 10 kilometers / 6.21 miles from people and animals**	NOTE: The link shows the abstact and allows you to download the PDF PDF provided to Planning Commission and BoCC
Separating Myth from Fact on Wind Turbine Noise	**October 2025**	Prof Ken Mattsson	https://www.youtube.com/watch?v=nDwsd32SDEY	**Setbacks of at least 5 to 10 kilometers (3.1 to 6.2 miles) from residences**	Transcript PDF provided to Planning Commission and BoCC
Efficient finite difference modeling of infrasound propagation in realistic 3D domains: Validation with wind turbine measurements	**Feb 2026**	Ken Mattsson, Gustav Eriksson, Leif Persson, Jose Chilo, Kourosh Tatar	https://www.sciencedirect.com/science/article/pii/S0003682X25006280?ref=pdf_download&fr=RR-2&rr=9a872537bf69df1b	**No specific distance given, see notes for conclusion of study**	Conclusion of study page 14: This study also shows that modern, large-scale wind turbines generate infrasound levels substantially higher than those reported for older, smaller turbines / PDF provided to Planning Comm & BoCC

I-6

Effects of Wind Turbine Noise on Human Health

Jerry Punch, Ph.D., Professor Emeritus
Michigan State University
East Lansing, MI 48824

Kansas Senate Hearing, Utilities Committee
February 8, 2022

Huron County, Michigan (2009): First Wind Turbine Experience

- Multiple turbines surrounded residence; nearest was ~1,300 feet
- Family of four was leaving home at night to sleep in motel when turbines were operating
- Heard periodic whooshing sounds from several nearby turbines
- Felt momentary, mild sensations when turbines were operating
- Observed water rippling inside a bowl in the kitchen when turbines operated (apparently due to infrasound and low-frequency noise, or ILFN)

- Left the home feeling skeptical that wind turbines could cause serious sleep disturbance

Follow-Up to Huron County Experience

- Following literature review, co-authored an article in *Audiology Today*, an invited three-part blog, and a comprehensive review article (Punch & James, 2016), each on the effects of wind turbine noise (WTN) on health
- Chaired Michigan Wind and Health Technical Work Group to revise siting guidelines for onshore wind turbines in the state
- Served as expert witness in legal actions in multiple states, several of which involved interviewing affected residents
- Viewpoint: Noise from large wind turbines causes annoyance, a variety of unpleasant sensations, and adverse health effects (AHEs) in a substantial number of exposed people; view best described *not* as pro-wind or anti-wind, but as pro-health

Punch and James (2016)

Punch, J.L. & James, R.R. (2016), Wind turbine noise and human health: a four-decade history of evidence that wind turbines pose risks

Available at:

http://hearinghealthmatters.org/journalresearchposters/files/2016/09/16-10-21-Wind-Turbine-Noise-Post-Publication-Manuscript-HHTM-Punch-James.pdf

Wind Industry Talking Points Refuted by Punch and James (2016)

"Our review is organized by summarizing the past and present literature that addresses each of 12 selected statements, listed below, that encapsulate specific claims, or positions, commonly taken by advocates for the wind industry:

1. Infrasound is not an issue, as infrasound generated by wind turbines is not perceptible to humans.
2. There is nothing unique about wind turbine noise, as infrasound and low-frequency noise are commonly produced by the body and by many environmental sources.
3. There is no evidence that wind turbine noise, audible or inaudible, is the cause of adverse health effects in people, and there are no physiological mechanisms to explain how inaudible acoustic energy can be harmful.
4. Setback distances of 1,000-1,500 ft. (approximately 0.3-0.5 km) are sufficiently safe to protect humans from harm, regardless of height or other physical characteristics of the IWTs.
5. Annoyance is a nuisance, but it is not a health issue.
6. Noise cannot account for all of the complaints of people living in the vicinity of wind turbines; there must be another, unknown reason for the complaints.

Wind Industry Talking Points Refuted by Punch and James (2016, Cont.)

7. Infrasound from wind turbines is sufficiently correlated to the A-weighted sound emissions to allow an A-weighted model to be used to predict how much infrasound is present in homes.
8. Wind Turbine Syndrome has not been accepted as a diagnostic entity by the medical profession, so medical professionals cannot diagnose or treat it.
9. Peer-reviewed epidemiological literature is the only acceptable basis for proving a causative relationship between wind turbine noise and adverse health effects.
10. The nocebo effect, a manifestation of psychological expectations, explains why people complain of adverse health effects when living near wind turbines.
11. Only relatively few people, if any, are adversely impacted by wind turbine noise, and the majority have no complaints.
12. There is no evidence in the literature to support a causative link between wind turbine noise and adverse effects."

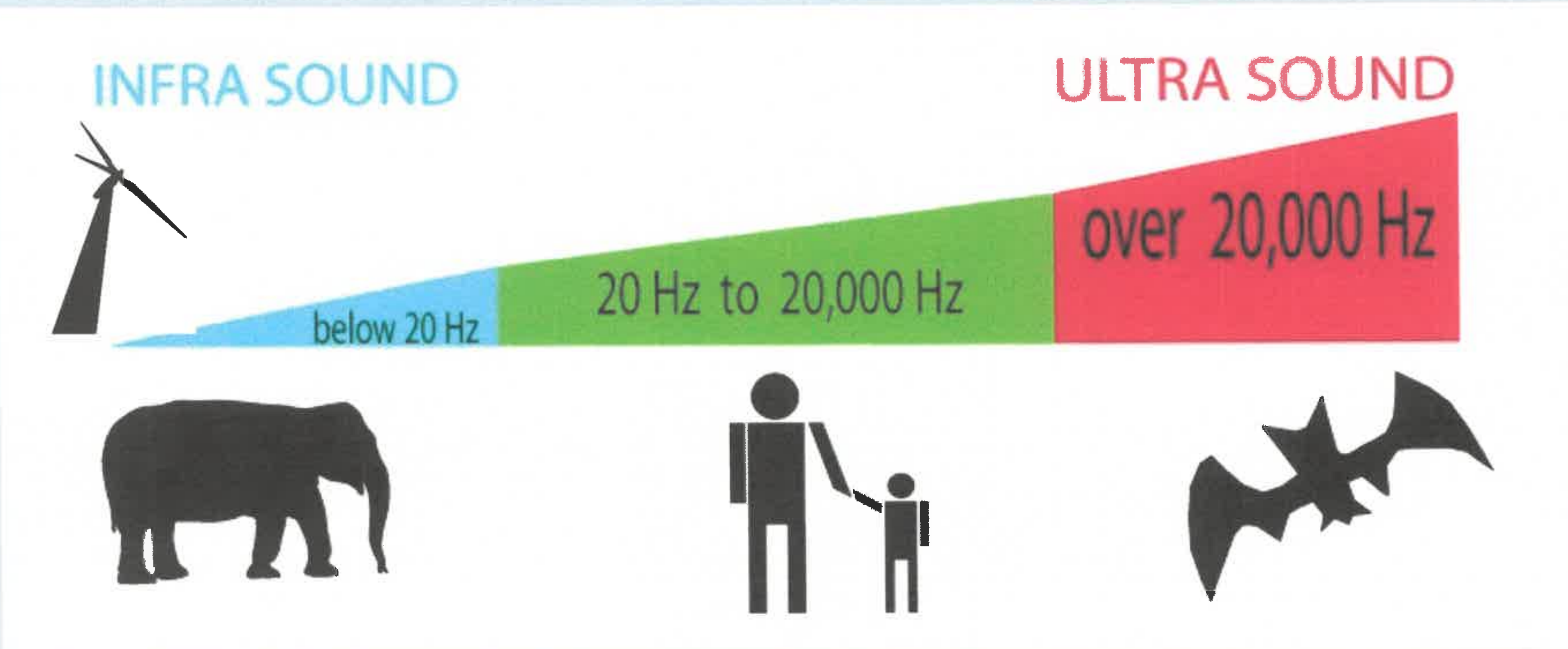
Assertion 1

Wind turbine noise is unique among industrial noises that are known to lead to high annoyance and AHEs.

- Amplitude-modulated ("whooshing noise")
- Impulsive (pressure pulses)
- Tones from blades, drive train and support equipment
- Perception varies with distance, terrain, wind direction
- Unpredictable (intermittent)
- Uncontrollable by receptors
- Occurs most often against low background noise levels in rural areas at night, disturbing sleep
- ILFN easily crosses property boundaries and penetrates homes and barriers

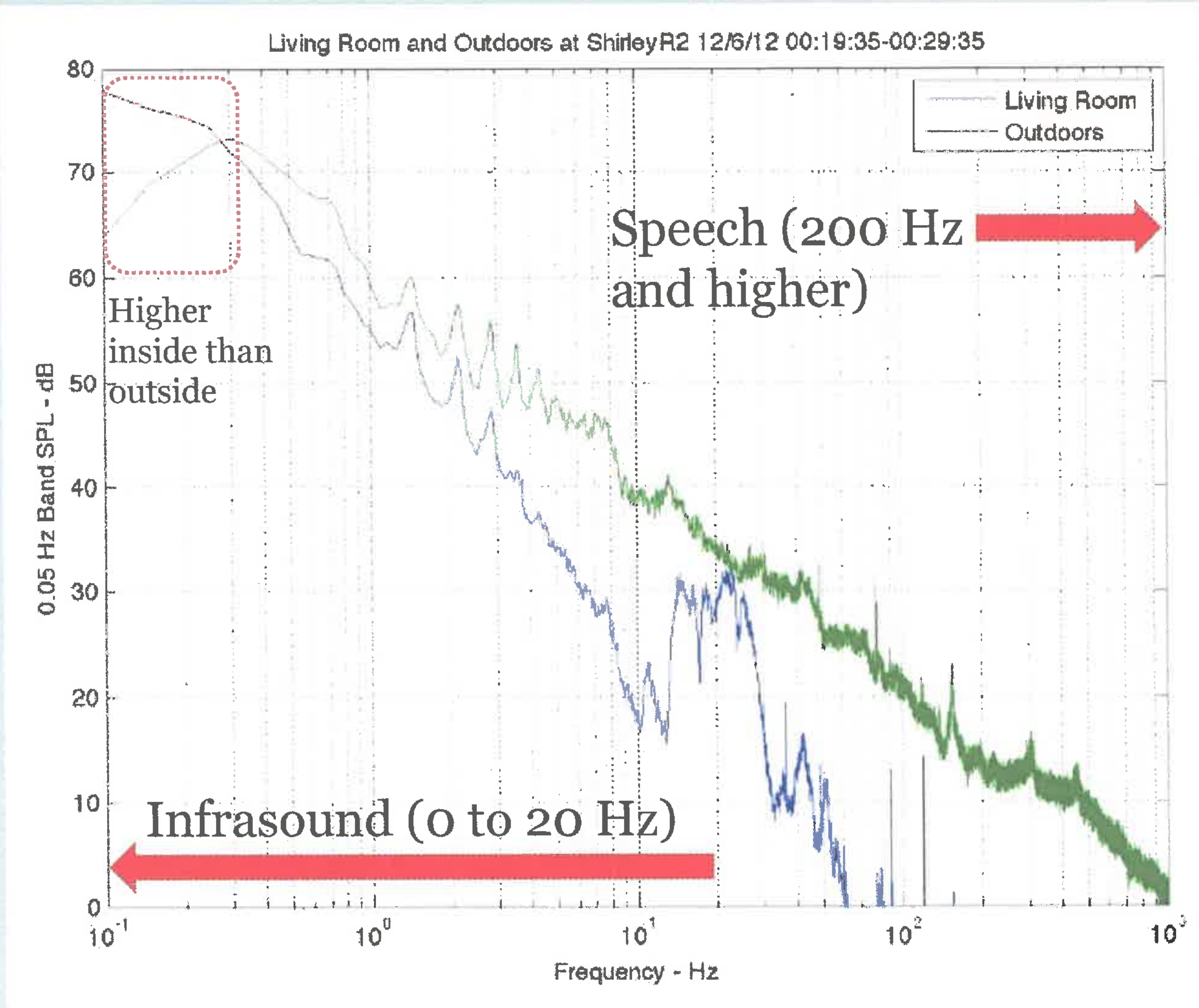
Taken together, these characteristics make WTN unique among transportation and other industrial noises.

Range of Human Hearing (20-20,000 Hz)



WTN contains both audible sound and infrasound. Infrasound can't be heard by most humans, but it can be perceived as abnormal (felt) sensations due to vibrations to bodily organs and tissues. It can become intensified inside closed spaces like homes.

Spectrum of Wind Turbine Noise: Outside vs. Inside



Assertion 2

Annoyance is an adverse health effect.

- WHO 1999 – current
  - (Berglund et al., Guidelines for Community Noise. World Health Organization, April 1999, 19-20)
- EPA (1972 – current)
  - (Noise Control Act of 1972 and others)
- Health Canada (current)
  - Considers high annoyance to be an (indirect) adverse health effect

Assertion 3

Many AHEs have been associated with audible and inaudible wind turbine noise, sleep disturbance being the most common complaint. Pressure pulses at infrasonic rates have been linked *directly* to negative sensations and AHEs.

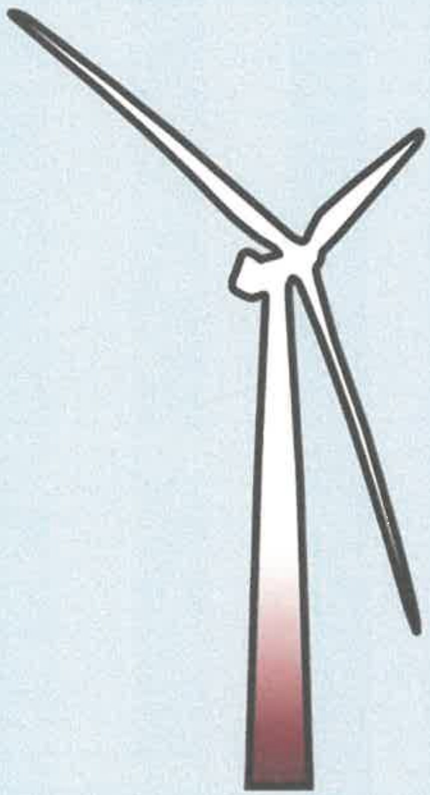
These effects, alone or in a variety of combinations, can occur in exposed individuals.

- Annoyance
- Sleep disturbance
- Headache
- Dizziness
- Vertigo
- Nausea (and other unpleasant bodily sensations)
- Motion sickness
- Tinnitus (ringing in ear)
- Fatigue
- Stress
- Depression
- Memory deficits
- Inability to concentrate
- Reduced quality of life
- Blurred vision (?)

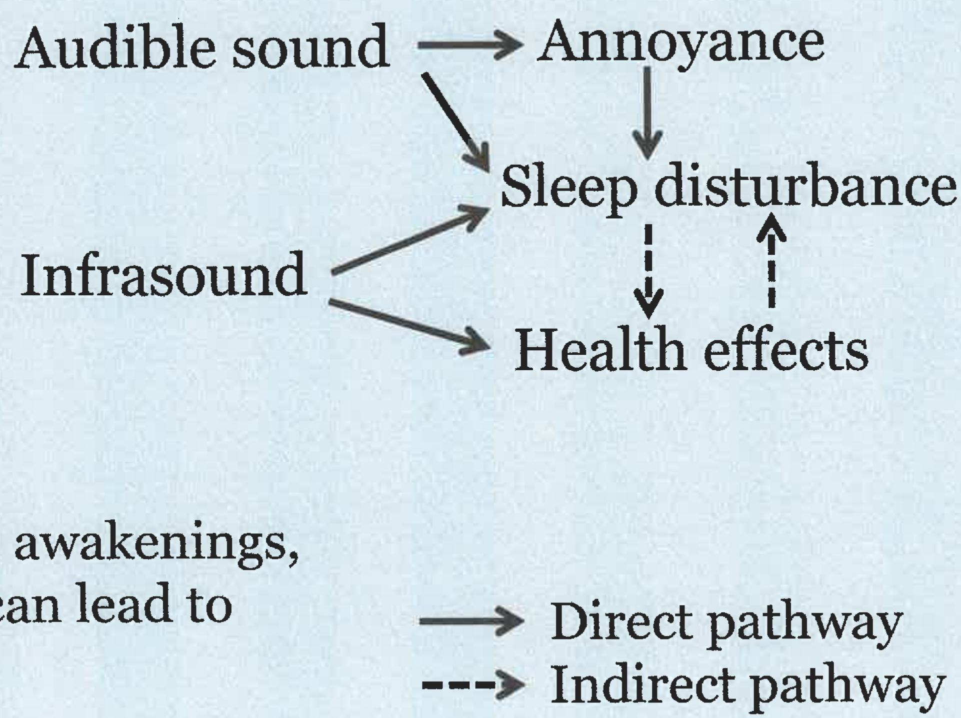
Medical Recognition of Health Impact of Infrasound

- The wind industry argues that medical professionals cannot diagnose or treat *Wind Turbine Syndrome* (Pierpoint, 2009) because it has not been accepted as a diagnostic entity by the medical profession.
- Virtually every human disease is associated worldwide with an ICD (International Classification of Diseases) diagnostic code for purposes of tracking medical conditions of individuals and populations.
- Although there is no ICD code specifically for "Wind Turbine Syndrome," codes exist for 8 of the 10 conditions identified by Pierpont.
- Recently, a new ICD code, *2022 ICD-10-CM Diagnosis Code T75.23XD*, was added to identify vertigo from infrasound.

Effects of Audible Noise and Infrasound on Health: Schomer (Modified)



Stress is often a mediator between stimulus and response.



Example: WTN can cause awakenings, and chronic awakenings can lead to AHEs.

Observations from Personal Interviews: Individual Resident, Site A

Comparison with Pierpont's Wind Turbine Syndrome Criteria

Symptom	*Adult Male*
Sleep disturbance	✓
Headache	✓
Visceral Vibratory Vestibular Disturbance (VVVD)	✓
Dizziness, vertigo, unsteadiness	✓
Tinnitus	
Ear pressure or pain	
External auditory canal sensation	
Memory and concentration deficits	✓
Irritability, anger	✓
Fatigue, loss of motivation	✓

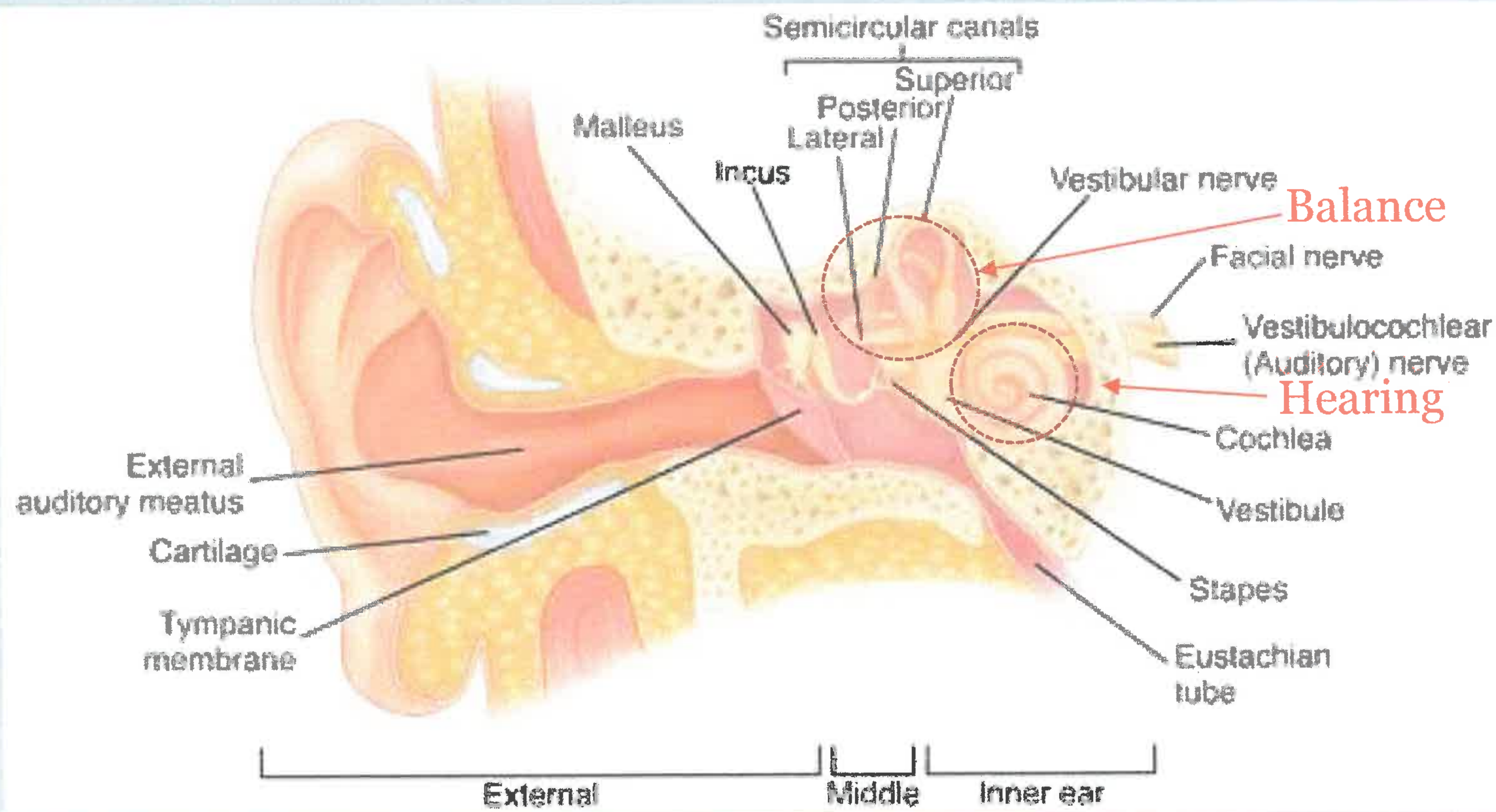
Observations from Personal Interviews: Family, Site B

Comparison with Pierpont's Wind Turbine Syndrome Criteria

Symptom	*Mother*	*Father*	*Son*
Sleep disturbance	✓	✓	✓
Headache			✓
Visceral Vibratory Vestibular Disturbance (VVVD)	✓		✓
Dizziness, vertigo, unsteadiness	✓		
Tinnitus		✓	
Ear pressure or pain	✓	✓	✓
External auditory canal sensation	✓	✓	
Memory and concentration deficits	✓		✓
Irritability, anger	✓	✓	
Fatigue, loss of motivation	✓	✓	✓

Assertion 4

Among other bodily organs responsible for negative reactions to wind turbine noise, both the cochlear and vestibular portions of the inner ear play major roles.



Motion Sickness

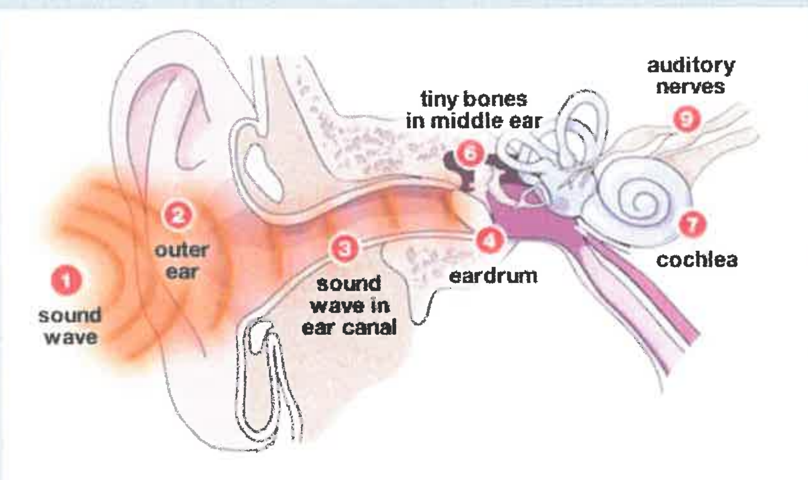
- Motion sickness can occur with wind turbine noise exposure because the infrasound and low-frequency noise can stimulate the fluid in the vestibular sense of balance, in much the same way as turbine noise can cause ripples in a container of water.
- Motion sickness occurs when stimulation to the inner ear's *vestibular system*, *visual system*, and *muscle stretch receptors* are in conflict.

Motion Sickness: Example

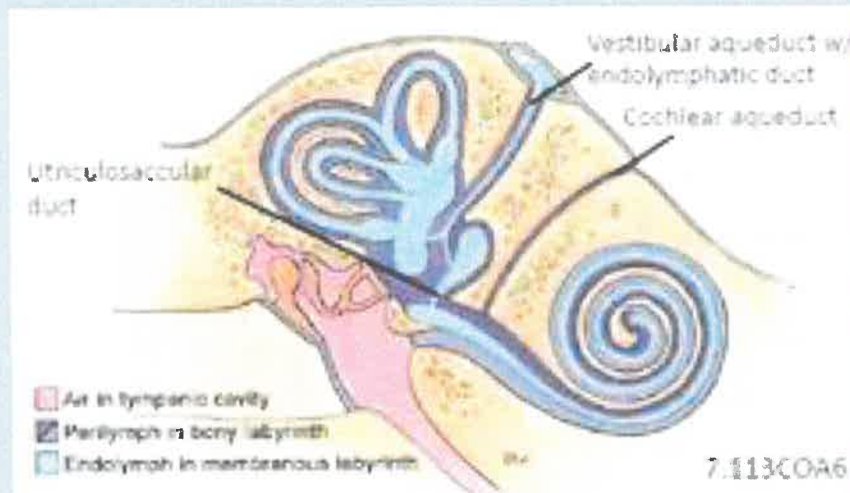
A person standing on a moving ferry boat and looking at structures inside the boat, such as the floor, cannot see any movement, and may feel minimal muscular stimulation, but the fluids in the vestibular system are being stimulated by the boat's slow, rocking movement in the water—resulting in motion sickness due to sensory conflict.

Assertion 5

Infrasound from external sources like IWTs is not processed in the same way as internally generated sounds like heartbeats.



Pathway of external sounds



Pathway of external sounds

Source: Salt, A.N. (September 18, 2013). Letter to Chairman of Association of Australian Acoustical Consultants. Available from: https://s3.amazonaws.com/windaction/attachments/1998/Warpenius.pdf.

Perception of Wind Turbine Infrasound (Cooper, 2014)

Australian acoustician Steven Cooper conducted a controlled, visually blinded, field study in cooperation with the wind company, Cape Bridgewater.

(1) WTN has a distinctive "signature" that is unlike a natural environment,

(2) Inaudible pressure pulsations from wind turbines, occurring at infrasonic rates, caused unpleasant perceptible "sensations" that were synchronized with wind turbine operations (on, ramping up-and-down), and

(3) Sensations included headache; pressure in the head, ears, or chest; ringing in the ears; heart racing; or a sensation of heaviness.

Perception of Wind Turbine Infrasound (Cooper & Chan, 2017)

In a separate laboratory experiment, Cooper and Chan showed that persons who experienced these "sensations" (and thus sensitized to low-frequency noise) were able to perceive WTN when exposed to it in a laboratory setting.

(1) Sensations were strongest when the entire body was exposed to WTN delivered through stereophonic loudspeakers (mimicking real life) when compared to hearing under headphones, and

(2) Results refute alternative explanations of AHEs, such as the so-called *nocebo effect*, by establishing a direct cause-effect relationship between infrasound and these negative effects.

Assertion 6

To protect health, limiting noise levels is more effective than establishing setbacks, especially the relatively short setbacks typically used.

- A 1.25-mile (2 km) setback has most often been recommended to minimize annoyance and AHEs. Some scientists and regulatory bodies are now recommending even longer setbacks to reduce health risks, especially given the increasing rated capacity of IWTs.
- The 1-mile setback proposed in the current Senate Bill 353 is reasonable, and worthy of support, especially when coupled with its requirement to limit WTN to 35 dB LAF(max).
- Limiting maximum noise levels is critically important during nighttime hours, as it protects the greatest number of residents from sleep disturbance.

Assertion 7

To protect health, nighttime wind turbine noise levels must be limited to no more than 10 dB above background levels.

- Background levels should be defined as those present during the quietest nighttime periods, with intermittent sounds such as traffic and wildlife noises excluded. Noise monitoring should be accompanied by sound recordings that allow identification and exclusion of those extraneous sounds from analysis. Rural areas have background sound levels of 20-25 dBA. This has been proven many times.
- The NY Department of Environmental Conservation (Table B) has determined that noise levels that exceed background levels by more than 10 dB will be associated with substantial resident complaints and increased AHEs.

Table B

HUMAN REACTION TO INCREASES IN SOUND PRESSURE LEVEL

Increase in Sound Pressure (dB)	Human Reaction
Under 5	Unnoticed to tolerable
5 - 10	Intrusive
10 - 15	Very noticeable
15 - 20	Objectionable
Over 20	Very objectionable to intolerable

(Down and Stocks - 1978)

Assertion 8

The wind industry wants regulations that use averaged noise levels (dBA Leq) to specify the amplitude of wind turbine noise, but Leq levels do not protect from exposure to sudden spikes in WTN (often 10-12 dB higher than the average level), which lead to high annoyance, sleep disturbance, and other AHEs.

- dBA Leq filters out *substantial* amounts of ILFN (50+ dB below 20 Hz).
- Leq measurements have most often been applied to transportation noise and industrial noises whose characteristics are different from IWTs.
- If averaged levels are used to limit nighttime noise, the most authoritative sources of noise guidelines recommend limiting the levels to 36-40 dB Laeq; those limits are preferably applied at property lines.
- Dr. Paul Schomer, Director Emeritus of the Standards Division of the Acoustical Society of America, has suggested that when dBA Leq is used to limit wind turbine noise, it is based on a goal of limiting *high annoyance* to 10% in the affected population. It does not limit pressure pulses to protect those who are sensitive.

Assertion 9

LAF(max), as opposed to the long-term average noise levels commonly advocated by the wind industry, is recommended to minimize sleep disturbance.

- The use of LAF(max) provides reasonable assurance that the levels of short-term, pulsating, nighttime wind turbine noise are sufficiently low to prevent serious AHEs.

dB LAF(max)

- Because energy peaks in noise are the major cause of sleep disturbance, the WHO has proposed that LAmax be used as an effective metric to minimize sleep disruption.
- WHO (Berglund et al., 1999; community noise)
  - Special attention should be given to noise when background noise is low, when noise is combined with vibrations, and when noise consists of low-frequency components.
- WHO (2009; nighttime transportation noise)
  - Nighttime noise(inside) should be limited to 42 dB LAmax.
- Required maximum levels should be lower to account for the unique characteristics of WTN, which include high levels of ILFN.

Assertion 10

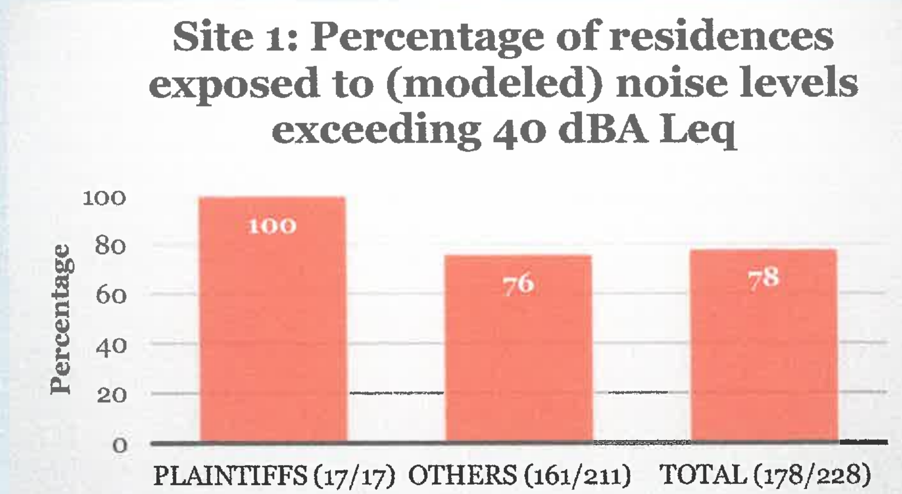
Although peer-reviewed epidemiological research is highly desirable in establishing a causative relationship between wind turbine noise and adverse health effects, it is not the only type of information that is helpful.

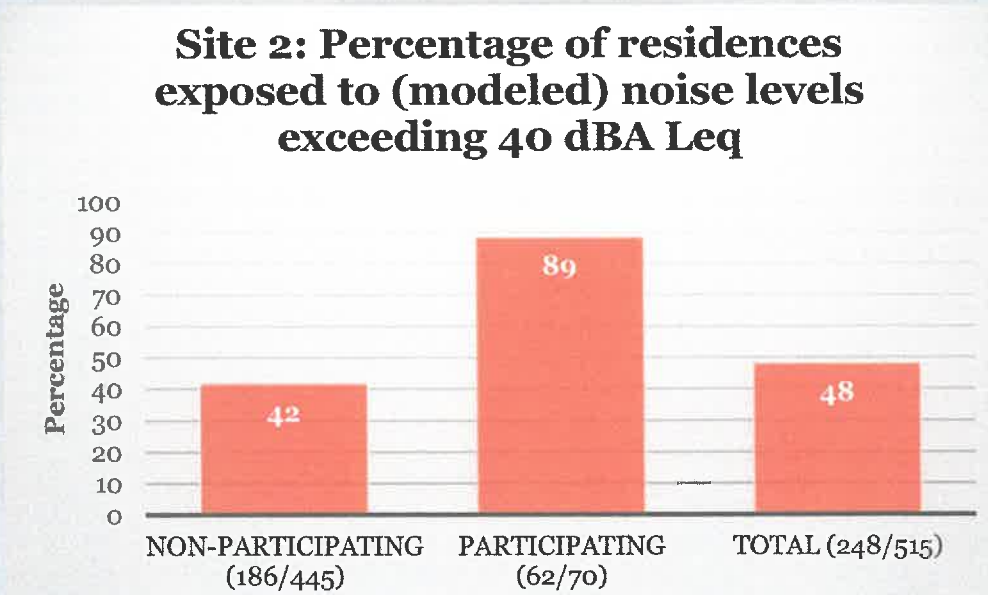
- Other types of helpful information include:
  - Anecdotal reports
  - News accounts (print and web-based media)
  - Documentary films
  - Legal proceedings
  - Reports by other scientists and professionals in peer-reviewed journals and at professional and society meetings, government reports, and internet postings
- (Refer to 1965 "Bradford Hill criteria" for determining causation.)

Recommended Setbacks and Noise Levels

- Setback Distance: Minimum distances ranging from 0.5-2.5 miles are often recommended to protect health. Setbacks recommended most often by researchers is 1.25 mi (2 km), but some now recommend longer setbacks. Property lines, not residences, should be used as targets for setbacks.
- Noise levels: When using A-weighting, recommendations include maximum levels ranging from 35-40 dBA. Some local zoning ordinances require noise levels be limited to 5-10 dB above prevailing background noise levels, with emphasis on nighttime levels, and some now include LAF(max).
- Case in point: Prompted by input from cardiologist Dr. Ben Johnson, the Madison County, Iowa, Board of Health recently incorporated 1.5-mile setbacks from property lines AND noise limits of 40 dBA Lmax and 60 dBC Lmax into its wind ordinance, which is currently being litigated.

Noise Analyses





If IWTs Don't Harm People, Why Are Some Residents Abandoning Their Homes?

- There are numerous anecdotal reports worldwide.
- Carmen Krogh and colleagues currently are systematically studying motivations for home abandonment by families who lived near wind turbine facilities in Ontario, Canada, between 2006 and 2016.
- The research team acquired government records documenting that neighbors living near IWT facilities filed 4,574 noise complaints and/or incident reports related to the turbines.
- The team interviewed a sample of 67 participants, all reporting AHEs or potential for AHEs when living within 10 km (6.2 miles) of a wind project.

If IWTs Don't Harm People, Why Are Some Residents Abandoning Their Homes? (Cont.)

- Some temporarily left during the day and/or night to alleviate effects. At the time of the interviews, 4 (6%) had preemptively vacated their homes, 28 (42%) had permanently vacated, 31 (46%) were contemplating vacating, and only 4 (6%) intended to remain in their homes.

C. M. Krogh *et al.*

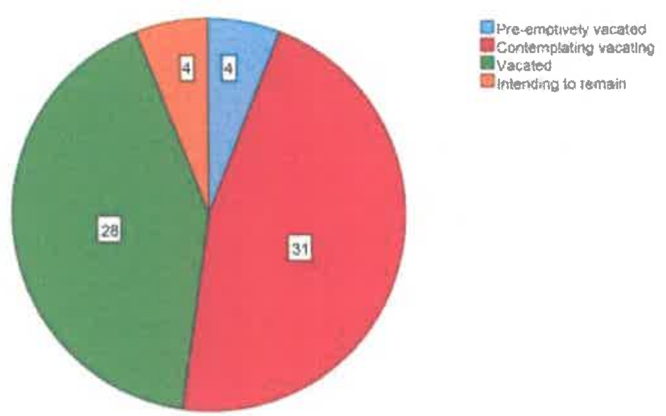


Figure 1. Home status at the time of interview.

Krogh, C.M, McMurtry, R.Y., Dumbrille, A., Hughes, D., & Gillis, L. (2020). Preliminary results: exploring why some families living in proximity to wind turbine facilities contemplate vacating their homes—a community-based study. Open Access Library Journal, 7, doi: 10.4236/oalib.1106118.

- Decisions to abandon reflected concerns with physical, psychological, and social well-being; electrical fields; wind turbine noise, vibration, atmospherics, and wind conditions; pets and animals; well water disruption; and personal viewpoints, social justice, safety, and security.

Conclusions: Summary of Assertions

1. Wind turbine noise is unique among industrial noises that are known to lead to high annoyance and AHEs.
2. Annoyance is an adverse health effect.
3. Many AHEs have been associated with audible and inaudible wind turbine noise, sleep disturbance being the most common complaint. Pressure pulses at infrasonic rates have been linked *directly* to negative sensations and AHEs.
4. Among other bodily organs responsible for negative reactions to wind turbine noise, both the cochlear and vestibular portions of the inner ear play major roles.

Conclusions: Summary of Assertions (Cont.)

5. Infrasound from external sources like IWTs is not processed in the same way as internally generated sounds like heartbeats.
6. To protect health, limiting noise levels is more effective than establishing setbacks, especially the relatively short setbacks typically used.
7. To protect health, nighttime wind turbine noise levels must be limited to no more than 10 dB above background levels.

Conclusions: Summary of Assertions (Cont.)

8. The wind industry wants regulations that use averaged noise levels (dBA Leq) to specify the amplitude of wind turbine noise, but Leq levels do not protect from exposure to sudden spikes in WTN (often 10-12 dB higher than the average level), which lead to high annoyance, sleep disturbance, and other AHEs.
9. LAF(max), as opposed to the long-term average noise levels commonly advocated by the wind industry, is recommended to minimize sleep disturbance.
10. Although peer-reviewed epidemiological literature is highly desirable in establishing a causative relationship between wind turbine noise and adverse health effects, it is not the only type of information that is helpful.

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For more information, see:

Punch, J.L. & James, R.R. (2016), Wind turbine noise and human health: a four-decade history of evidence that wind turbines pose risks, available at: *http://hearinghealthmatters.org/journalresearchposters/files/2016/09/16-10-21-Wind-Turbine-Noise-Post-Publication-Manuscript-HHTM-Punch-James.pdf*

Setback Recommendations Per Various Studies

Name of Study	Date of Study	Author(s)	Link to Study	Author's Advised Setbacks	Notes
Wind Turbine Syndrome: A report on a natural experiment	**2009**	Dr. Nina Pierpont	N/A, PDF provided	**Setbacks from residences should be a minimum of 2 kilometers or 1.24 miles, but 2-3 miles in hilly terrain**	PDF provided to Planning Commission and BoCC
Your Guide to Wind Turboine Syndrome...a road map to a complicated subject	**July 2010**	Calvin Luther Martin, Phd	N/A, PDF provided	**Setbacks from residences should be a minimum of 2 kilometers or 1.24 miles, but 2-3 miles in hilly terrain**	This is a summary of Dr. Pierpont's book PDF provided to Planning Commission and BoCC
Health Effects of Wind Turbines: Testimony of Ben Johnson versus MidAmerican Energy (Madison County, Iowa) / Hearing before the Madison County Board of Health	**August 2019**	Dr. Ben Johnson, M.D.	https://www.masterresource.org/wind-turbine-noise-issues/health-effects-of-wind-turbines-testimony-of-ben-johnson-versus-mid-american-energy-project-in-madison-country-iowa/	**No recommendation given for a specific distance in this hearing. Afterwards the Madison County Board of Health passed a resolution recommending that any future turbines be built at least 1.5 miles from non-participating homes**	PDF provided to Planning Commission and BoCC
Wind Turbine Noise and Human Health: A Four-Decade History of Evidence that Wind Turbines Pose Risks	**Ocober 2016**	Professor Jerry L Punch and Professor Richard R James	https://hearinghealthmatters.org/wp-content/uploads/2023/03/16-10-21-Wind-Turbine-Noise-Post-Publication-Manuscript-HHTM-Punch-James.pdf	**Setbacks from residences are recommended at 1/2 mile to 2.5 miles, 1.25 miles is most favored by scientists.**	PDF provided to Planning Commission and BoCC
Infrasound from technical installations: Scientific basis for an assessment of health risks	**July 2021**	Dr. Werner Roos and Dr. Christian Vahl	https://www-asu--arbeitsmedizin-com.translate.goog/wissenschaft/wissenschaftliche-grundlagen-fuer-eine-bewertung-gesundheitlicher-risiken-infraschall?_x_tr_sl=de&_x_tr_tl=en&_x_tr_hl=en&_x_tr_pto=wapp	**Minimum setback from residences should be 10 X turbine height as in Bavaria Germany**	PDF provided to Planning Commission and BoCC
Assessing Adverse Health Effects-(Confirmed and Potential) from Industrial Wind Turbine Noise Emissions / Power point slides of presentation before the Kansas State Legislature	**2022**	Dr. Ben Johnson, M.D.	https://www.kslegislature.gov/li_2022/b2021_22/committees/ctte_s_utils_1/documents/testimony/20220207_01.pdf	**Setbacks of 1.25 miles from residences**	PDF provided to Planning Commission and BoCC
Presentation before the Kansas Senate and Utilities Committee: Effects of Wind Turbine Noise on Human Health	**2022**	Prof Jerry L Punch	https://www.kslegislature.gov/li_2022/b2021_22/committees/ctte_s_utils_1/documents/testimony/20220208_02.pdf	**Setbacks of 1.25 miles from property lines (specifically) should be considered**	PDF provided to Planning Commission and BoCC
Wind Turbines: Vacated/abandoned homes - Exploring participants' descriptions of their personal views, effects on safety, security, trust and social justice	**Dec 2023**	Carmen Marie Krogh, Robert Y McMurty, W Ben Johson, Jerry L Punch, Anne Dumbrille, Mariana Alves-Pereira, Debra Hughes, Linda Rogers, Robert W Rand, Lorrie Gillis	https://journals.lww.com/endi/fulltext/2023/08040/wind_turbines__vacated_abandoned_homes__exploring.2.aspx	**Residents living within 10 kilometers/6.21 miles of industrial wind turbines were documented having Adverse Health Effects**	See page 96 for the conclusion of the study regarding setbacks. PDF provided to Planning Commission and BoCC.
A fundamental basis for all living creatures, mechanotransduction, is significantly endangered by periodic exposure to impulsive infrasound and vibration from technical emitters - in particular cardiovascular and embryological functions	**June 2025**	Dr. Ursula Bellut-Staeck	https://www.scirea.org/journal/PaperInformation?PaperID=12440	**Setbacks of 10 kilometers / 6.21 miles from people and animals**	NOTE: The link shows the abstact and allows you to download the PDF PDF provided to Planning Commission and BoCC
Separating Myth from Fact on Wind Turbine Noise	**October 2025**	Prof Ken Mattsson	https://www.youtube.com/watch?v=nDwsd32SDEY	**Setbacks of at least 5 to 10 kilometers (3.1 to 6.2 miles) from residences**	Transcript PDF provided to Planning Commission and BoCC
Efficient finite difference modeling of infrasound propagation in realistic 3D domains: Validation with wind turbine measurements	**Feb 2026**	Ken Mattsson, Gustav Eriksson, Leif Persson, Jose Chilo, Kourosh Tatar	https://www.sciencedirect.com/science/article/pii/S0003682X25006280?ref=pdf_download&fr=RR-2&rr=9a872537bf69df1b	**No specific distance given, see notes for conclusion of study**	Conclusion of study page 14: This study also shows that modern, large-scale wind turbines generate infrasound levels substantially higher than those reported for older, smaller turbines / PDF provided to Planning Comm & BoCC

I-7

Original Article

Wind turbines: Vacated/abandoned homes – Exploring participants' descriptions of their personal views, effects on safety, security, trust, and social justice

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Abstract

Introduction: Some neighbors living in proximity to industrial wind turbines (IWTs) have described adverse health effects and contemplated vacating their homes. While the decision to vacate a home is reported by sources such as judicial proceedings, the scientific literature, media outlets, social media, and Internet websites, research on its extent and outcomes is limited.

Methodology: This ethics-reviewed study used the qualitative Grounded Theory methodology. Sixty-seven consenting participants, 18 years or older, who had previously lived or were currently living within 10 km of IWTs were interviewed. Audio files were transcribed to text and the data were coded and analyzed using NVivo Pro (v. 12.6) software.

Objectives: The objective is to explore participants' descriptions of their personal views on wind turbines and their effects on safety, security, trust, and social justice, and generate a theory of influences contributing to these decisions.

Results: Data analysis revealed primary and subthemes associated with environmental interference and altered living conditions. Descriptions of participants' personal views associated with the use of wind energy and effects on safety, security, trust, and social justice are provided.

Discussion: It is recommended that members of the public, government authorities, policymakers, researchers, health practitioners, and social scientists with an interest in health policy acknowledge these effects and seek resolution for those who are negatively affected when living or working near IWTs.

Conclusion: We conclude that using a systematic methodology, data analysis lends support that the Grounded Theory was applicable to this study as it assisted with the development of a coherent theory which explained participants' housing decisions.

Keywords: Grounded Theory, safety and security, social justice, trust, vacated homes, wind turbines

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Submitted: 05-Feb-2023, **Revised:** 05-Jul-2023, **Accepted:** 06-Aug-2023, **Published:** 30-Dec-2023

Access this article online	
Quick Response Code:	Website: www.environmentmed.org
	DOI: 10.4103/ed.ed_4_23

How to cite this article: Krogh CM, McMurtry RY, Johnson WB, Punch JL, Dumbrille A, Alves-Pereira M, *et al.* Wind turbines: Vacated/abandoned homes – Exploring participants' descriptions of their personal views, effects on safety, security, trust, and social justice. Environ Dis 2023;8:86-100.

INTRODUCTION

The U. S. Department of Energy states that Wind Power Plants (WPPs) produce electricity by having an "array of wind turbines in the same location."[1] Globally, neighbors and workers report adverse health effects (AHEs) when living[2-17] or working[18-24] in proximity to a WPP. These reported AHEs were consistent with the cluster of symptoms described by Physician/Researcher Dr. Nina Pierpont. She labeled this cluster Wind Turbine Syndrome (WTS). Symptoms include headache, tinnitus, ear pressure, dizziness, vertigo, nausea, visual blurring, tachycardia, irritability, problems with concentration and memory, and panic episodes associated with sensations of internal pulsation or quivering when awake or asleep. These were severe enough to drive people from their homes.[9] Sources such as judicial proceedings (written submissions, factums, and legal arguments); government hearings;[3-8,16] and the scientific literature[9-11,14,17-19,21-24] have reported occurrences of AHEs.

Research participants described occurrences of AHEs or the potential for such effects when living within 10 km of a WPP.[25-29] While the topic of wind turbines is debated,[30,31] some neighbors have contemplated vacating/abandoning their homes.[2,5,7,9,12,25-29] In some cases, neighbors have temporarily left during the day and/or night to alleviate their AHEs.[26] In Ontario, Canada, it was reported that some have effectively "abandoned their homes, been billeted" by, or negotiated "financial agreements."[2] At the same time, research on the extent and outcomes of vacating a home is limited.

This ethics-reviewed study used a qualitative methodology, specifically Grounded Theory to conduct a study in Ontario, Canada. It explored the events that motivated neighbors living within 10 km of a WPP/industrial wind turbine (IWT) to contemplate vacating/abandoning their homes. In addition to this publication, five papers have presented preliminary results,[25] an overview of findings,[26] an exploration of the study's use of the GT methodology,[27] the effects of an Ontario government Act regarding WPPs,[28] and research participants' descriptions of their medical diagnoses provided by their physicians and physician specialists.[29]

METHODOLOGY

Our study methodology conformed to the COnsolidated criteria for REporting Qualitative research (COREQ) checklist. Two additional processes that are not identified in COREQ were included in our methodology to further strengthen study rigour, a Process Controller and Scrutinizer. The process controller documented schedules, the interview process, and data records. The scrutinizer maintained the integrity of the data collected. These processes and the capability to recruit participants, schedule and conduct interviews, and manage participant selection and communications were supported by the logistical coordination managed by the study's process controller.

To gain an understanding of why some families living in proximity to an IWT facility contemplated vacating their homes, several research questions were identified:

1. What are the particular circumstances that influenced whether to vacate or not vacate a family home?
2. How did families arrive at their decision?
3. Were there consequences related to their decision?
4. Did these circumstances influence physical, mental, and social well-being?

Once the study design and the ethics review were finalized, an interview guide consisting of a single neutral question was piloted. This tapped the events leading to participants' housing decisions. While the interview question was distinct from the above research questions, these aligned. The pilot's outcome supported the use of a semi-structured interview to generate a thick, rich description for a Grounded Theory approach.

The formal study began with purposeful and snowball sampling strategies inviting potential participants who were 18 years of age or older, proficient in the English language, and having lived or currently living within 10 km of a WPP/IWTs to contact the researcher. Invitations were distributed to key informants such as community leaders and neighbors as these individuals were likely to generate rich data.[32] There were no restrictions on the invitation's distribution.

Residents who responded were provided information on the study's purpose to explore the "extent of these occurrences and the impact or lack of impact" of living within 10 km of a WPP/IWTs. They were informed that there would be an opportunity to describe the circumstances that may have influenced "whether to vacate or remain in their home."

Before consent, all the participants were advised that even if they had signed the consent form, they could decline to answer any question and decline to continue with the interview. If this occurred, all their information would be immediately destroyed. There were no participant withdrawals and the individual interviews were conducted as scheduled.

With informed consent, face-to-face interviews were held with each participant in their homes with few exceptions. In these cases, travel issues such as distance or inclement weather resulted in some interviews being conducted by telephone. Participants were advised the interviews would last one hour; however, the interviewers allowed that limit to be exceeded.

Trained interviewers began by collecting demographic information and then started each interview with a single, nonleading question, i.e., to discuss the events that led them to contemplate vacating their home. If required, probes were used to seek further clarification of participants' descriptions. At the conclusion of the interview, participants were given an opportunity to raise additional insights.

All 67 participants agreed to have their interviews recorded and were offered an audio copy at their conclusion. The audio files were transcribed into text. The use of the NVivo Pro (v. 12.6) (Available from QSR International (Americas) Inc., Burlington, MA, USA. www.qsrinternational.com) software facilitated data coding and indexing. The Grounded Theory's iterative methodology was followed. Data analyses began after the first interview, and as new data were introduced, the themes and subthemes evolved. This sampling approach continuously supported theory development and adjustments in response to the data being collected. Functional requirements such as process/logistical control that was managed by the process controller facilitated maintaining the iterative process. The interviews concluded with the 67th participant when saturation occurred and no new information was forthcoming. Reproduced from:[28]

A rigorous and systematic process to transcribe, code, and analyze evolving trends and themes resulted as shown in Figure 1. Themes and subthemes and their relationship to the 5 Elements. Statistical and demographic information and the home status of participants are available at Krogh *et al.*[26]

Themes, subthemes, and the 5 elements

Rose *et al.* comment that Strauss and Corbin suggested a coding paradigm that was intended to help with data analysis and provided a version of this approach, i.e., the 5 Elements.[33] Krogh *et al.* found that this approach and the use of a systematic method to transcribe, code, and analyze the data acquired during the interviews were applicable to the vacated/abandoned home study.[27] The application of the 5 Elements is illustrated in Figure 1.

The 5 Elements as proposed by Rose *et al.*, and their relationship to the analyzed data are:

- Element 1: the "*central phenomenon*"-the focus of the study is the siting of IWTs within 10 km of participants' homes
- Element 2: the "*causal conditions that contributed to the phenomenon*" include findings of the primary

Figure 1: Themes and subthemes and their relationship to the 5 Elements.*Reproduced from[26]

and subthemes of the effects of environmental interference and altered living conditions as described in Figure 1, Element 2

- Element 3: the "*context in which the phenomenon is embedded*" is associated with a Government policy. Participants became informed and took action through government and other processes as described in Figure 1, Element 3
- Element 4: the "*actions and interactions taken by people in response to the phenomenon*" resulted in participants contemplating housing decisions as described in Figure 1, Element 4
- Element 5: the "*aftermath of actions and interactions*" as described in Figure 1, Element 5.

This manuscript continues to explore the primary themes and subthemes of the causal conditions that include environmental interference and altered living conditions in Element 2. It analyses the findings of the subthemes of effects related to safety, security, trust, and social justice. Findings of participants' personal viewpoints are included in this manuscript. Tables 1 and 2 provide examples of these descriptions.

Effects related to Elements 4 and 5 will be addressed in separate manuscripts.

As proposed by Castillo-Montoya, every effort was made to accurately represent the voices of participants through the use of verbatim quotations throughout this manuscript.[34]

To maintain participant confidentiality, we have intentionally avoided reporting details that could identify specific individuals, geographical locations, siting distances, or WPP/IWT projects.

RESULTS

Personal views relating to wind turbines

Before the WPPs/IWTs became operational, some participants described their support for renewable energy. In some cases, this included an understanding of why their neighbors leased their property to a wind energy developer. Each example is by a different participant.

> *They [lease holder] can get $10,000 (CAD) a year for having a turbine on their land. People who have worked and want to have a better retirement…You wish that for people. But not if it's going to hurt or it's going to damage other people. It's a trade-off.*[29]
>
> *The farmers, the signers I feel sorry for them now. There's a couple I don't because they don't regret it...there's people who do regret it and they were snookered just as we were. [A lease holder] who owns this little piece of land here that has [a number of] turbines, he thought he was saving the planet, he really did.*[29]
>
> *If somebody would've came along and gave me enough to pay my mortgage payment every year for the permission of putting a windmill up that was government approved, I would've went right along with it.*[29]

Table 1 presents additional examples of participants' descriptions of their personal views on the use of renewable energy and IWTs.

While Table 1 as it relates to participants' personal views described positive attitudes toward the use of IWTs, it has been suggested that "perceived socioeconomic benefits enhance" public acceptance.[35] Aidun *et al.* found that in some cases, the opposition was related to potential effects on human health and the environment.[36] Tomkiewicz commented that there were indications of countries suffering "from NIMBY (Not In My Backyard) syndrome."[37]

Ontario's Environmental Review Tribunal (ERT) was a judicial process for appellants to appeal a Renewal Energy Approval (REA). During 2009 and 2010, the first ERT was held under Ontario's Green Energy Act (GEA).[38] Government and industry witnesses and a legal counsel proposed that NIMBYism, Build Absolutely Nothing Anywhere Near Anything; anti-wind; against or opposed to wind energy; or that there was a dislike of the visual or look of the IWTs were the reasons for appealing the REA.[39] However, the use of these terms could potentially distract from the deeper issues that were of concern and/or were affecting some of the appellants and their neighbors.

In correspondence to Ontario Government officials, a neighbor stated that as a "victim of industrial wind," she was being labeled a NIMBY and requested that the officials "change the narrative." She also commented that this was:

> ...in my back yard, and on the side and in the front... I am surrounded by industrial wind. The sleepless nights, the swooshing sound of the blades-the cyclical turns prevent me from even enjoying being outside on my own property. Why is it that so many people around the world are subjected to the same pain, to the point that some have abandoned their homes for relief?[40]

The neighbor concluded "What if this was your backyard?"[40]

Historically, terms such as NIMBY have been used during other debates. For example, during policy decisions associated with homeless shelters and jails, the term NIMBY was first adopted by "lower-and middle-income people fighting for environmental justice."[41]

Table 1: Participant's description of their personal views on the use of renewable energy and industrial wind turbines

- *These turbines coming into my backyard and I'm thinking, "Oh, this is going to be a good thing." It's for the good of the environment... I used to look at them…I'd watch them build them…I thought they were interesting and somewhat beautiful…I thought of them as positive and as structures of beauty.*
- *When they started up the wind turbines around us we had no problems…we were taking pictures as they were going up.*
- *We do believe that turbines or other alternate energy possibly have to be used… I was okay with having them near our house.*
- *I was very supportive of renewable energy options, but there's a big "but" there. In the right places…I thought the concept was terrific and I'm sure that many people, like in the GTA [Greater Toronto Area], they don't take the time to look into it because it's not going to impact them.*
- *When we first moved here and heard about the wind turbines going up, we were kind of all for them. We built an extremely green house. We have solar panels up front.*
- *It's not that we're against green technology. But the scale of these has gone to a point where if they're installed, they should not be in close proximity to where people live. I think they've outgrown the size where they could be in communities like ours.*
- *When I built the house I thought of maybe even having wind or solar because I really believe in renewable energy...I realized that A, it was very expensive to install. But B, I didn't feel the technology was there yet to be able to generate power safely without making these transients and harmonics [i.e. electrical and acoustic emissions].*
- *Certainly, from a high level, we were in favor of wind power generation when we first moved in…I was in favor of wind power until these issues [health effects] occurred.*
- *We really were quite vocal about our concerns about turbines because initially we thought like everybody else. They were clean, green and free. We started living with them when they started operating and it's just been hell.*
- *I see no problem with alternate energy…We were basically off-grid…I do believe that alternate energy does have its place. However, there is enough information out, and there was even before Ontario started getting wind projects close to residents, to state it's a bad idea to get them too close to residences... I do know in our case, the current values for setback - far too close.*
- *Wind turbines, cool. I'm sure it'll be fine...They said it was going to be fine. That we wouldn't see them, we wouldn't hear them.They sent out their modeling stuff and basically said, "It'll be fine". We took their word for it. They were wrong. Yes, so now we're considering leaving the place that was supposed to be our last home...It's just a constant problem that we can't do anything about.*
- *I thought wind turbines were excellent. I really did but when I started looking a little deeper, doing a little bit of homework. I found out that they were disgusting, invasive and terribly bad for our health. It got us thinking and we listened to a lot of people's problems and their health issues.*
- *The impact was the reality that we got to move... the fact is that every day you are waking up nauseous. The noise is so bad that it wakes me up... It's not that I'm seeing them to feel sick. I'm hearing the noise...The effects are the disturbance...The quality of our life is slipping. We have been disturbed.*
- *We thought this was great. We have clean energy, no fossil fuels. It was only after moving here that we realized that some people are being severely impacted and I mean severely impacted, not just annoyed or irritated.*
- *It was just such a disappointment that at the beginning I thought there was a glitch with the turbines and that they would be fixed because I was okay with having them near our house...if it ever comes to the point where anywhere close to us they even think about [building turbines], we will sell this place before that even comes to fruition. We will not stay beside the turbines anymore.*

Each example is by a different participant. [brackets] indicate where data have been omitted to maintain privacy.

In an article entitled "*Why we should retire 'NIMBY,'*" one of those interviewed commented that:

> ...one could choose to either engage in the process put forward by the city or oppose it and be called a NIMBY.[42]

Another interviewee simply wanted to be "fairly heard, and not called names, or conveniently categorized by those who don't share his views." Another commented that NIMBYism was "an incredibly prejudiced thing to say." The individual stated that "what you are saying when you label somebody a NIMBY is, 'I am not going to listen to you; I don't have to listen to you.'" The term is "pejorative, and not useful for broader discussions."[42] [*Author note: pejorative is defined as a word or phrase that has negative connotations or that is intended to disparage or belittle*].[43]

It was reported that the former Premier of Ontario stated that regarding wind turbines, it was ok to "object on the basis of safety issues and environmental standards" and that if there were "real concerns," put them forward. However, "don't say, 'I don't want it around here'... NIMBYism will no longer prevail."[44]

Those expressing uncertainty or concerns about exposure to WPPs/IWTs and other contemporary topics may continue to be dismissed by government authorities. For example, Ontario's Chief Medical Officer of Health (CMOH) was quoted as saying that there will be a "vocal minority" in opposition whether it is WIFI, 5G or wind turbines or vaccines.[45]

Regarding the above comment, the Premier of Ontario and the CMOH received feedback that concluded:

> Dr. Moore's gratuitous affront quoted above is not helpful. Certainly, it will not advance the government's agenda and from the evidence is not worthy of the position he holds. One cannot but wonder if he might not be best served by being more reflective and less arrogant in his public remarks.[45]

Ontario neighbors who were living in proximity to IWTs had filed complaints associated with operating WPPs. Records obtained by a Freedom of Information (FOI) request revealed that by 2018, approximately 6,000 Incident Reports/complaints had been submitted to the Ministry of Environment.[46] Since that time, "noise pollution and environmental harm have never really wound down" with about 7,000 complaints being filed.[47]

Wilson *et al.* reviewed Ontario's IWT-appeal process and found that the concerns leading to the "decisions to appeal" an IWT project are "borne out in real-life experience" and there was a need to acknowledge that community concerns about IWT projects were "genuine."[48]

Rather than characterizing neighbors as NIMBYs or anti-wind, it is recommended that Ontario authorities quickly respond and acknowledge the risk of AHEs associated with living near WPPs and initiate effective and timely remedies/resolutions.

Safety, security, trust, and social justice

Participants described effects related to safety, security, trust, and social justice. Three participants described a sentiment of feeling experimented upon.

1. *I remember him [a researcher] coming out and proposing to experiment on the people in [our] County. He didn't call it an experiment. He just called it that it was the unique opportunity to observe.*
2. *I'm not a guinea pig. We felt like we were guinea pigs with the turbines being there and that we were fools for thinking that something would be done to help us.*
3. *We are being treated as guinea pigs and lab rats. There's no other word for it and at the expense of the population...they're elected officials, will not do anything for us. Yes, that's all we are now. The whole population is.*

A fourth participant compared the experience of living near IWTs with a tragedy that occurred in Canada. This is related to the use of thalidomide medication during the first-trimester stage of fetal development that has resulted in his loss of trust in Canada's health-care system.

4. *My first child was a baby girl, was stillborn. That was in the thalidomide thing. The child was deformed. What bothers me about that one, that's an example of where the government was well aware, and they were made aware of the side effect of thalidomide. In Canada, it was allowed for another three to six months, before they actually acknowledged it…it's an example of how I've started to distrust the decisions…Yes, eventually somebody will admit maybe we've done somebody wrong. I don't trust the health system here. We're told that they will protect our welfare.*

   Author's note: The use of thalidomide during the first trimester of pregnancy led to limb deformities in newborn babies.[49]

A fifth participant described concerns about the ability to meet work requirements.

5. *I'm not steady. When I was doing the hay this summer and working so hard in the heat, I'm not getting the rest I need to be able to give my body the chance to recover to do all the work that is expected of me. I couldn't be able to take care of them [farm animals] to the same degree and quality that I did all this year previous to these things [IWTs].*

Table 2 provides additional examples of described effects on social justice, trust, safety, and security.

DISCUSSION

Structural safety and security

As demonstrated by the reported occurrences of IWT-related accidents, there are potential risks for residents and workers living and working near WPPs.[50-53] In 2018, the Caithness Information Forum found that based on data collected, the most common accident was blade failure followed by fire.[50]

Blade and structural failure

Manufacturer warnings for its 3 MWatt IWTs advised:

> Do not stay within a radius of 400 m (1,300 ft) from the turbine unless it is necessary. If you have to inspect an operating turbine from the ground, do not stay under the rotor plane but observe the rotor from the front.
>
> Make sure that children do not stay by or play nearby the turbine. If necessary, fence the foundation.[54]

Structural failures have been reported under a variety of circumstances.[55-58] For example, an investigation was underway after an IWT leaned, then collapsed.[55] In another case, the wind energy company confirmed the collapse of another turbine at a different WPP.[56] When a wind turbine "suddenly started spinning out of control," a piece of a blade flew off the tower. A witness commented on being very frightened because of being in the path of the falling debris.[57] A report comments that while investment in "green products" continues, the "failure issue" is raising concerns.[58] News media reported that an IWT collapsed and fell across an access road located on public land. An investigation revealed "serious structural issues," i.e., cracks in the IWT's foundation. An additional 49 IWTs were at risk resulting in 50 foundations being replaced.[59]

Ertek *et al.* identified a gap associated with the investigation and analysis of IWT accidents. They described the use of text mining and machine learning techniques to discover

Table 2: Participant's descriptions of effects on safety, security, trust, and social justice

- *I feel somewhat violated. I guess in a physical sense too.*
- *Unfortunately, it was our dream house. It was our retirement home, and it was something that was extremely special to us. We absolutely loved living there, loved the neighbours, loved everything. To feel that you weren't being listened to, and to feel that it didn't matter if you got sick, I wanted to leave in [date].*
- *There are some efforts to describe the situation but many seem to feel they are falling short of encompassing all the chaos that replaces what used to be everyday life. Wrongness. Pretending life is fine when in public. Disbelief that this could be happening in Canada. Helplessness at watching your family suffer without relief from any who could grant it. Horror at being unable to protect your children, elderly parents in your own home. Loss of everything, physical, emotional, faith, financial. No one cares. No one understands, sometimes including your own partner in life.*
- *I don't know if you could trust him [developer's representative]...he was polite yet, ridiculed us a little bit. He said he would look into testing...and then he said, 'I want you to continue to keep records, but I don't want you to put down the wind direction or anything like that.'...I said to him "Well, I'll continue to keep records of just what the noise level is."*
- *It was unbearable in this house. We could not stand it in here…We thought we were going to have testing done. I think we were lucky they didn't show up because I don't think we could have trusted the report…He [engineer] said, 'I don't think you can trust any of their tests.'…That just made us mistrust them more than ever... we were still leery.*
- *The financial impact has been immeasurable…I was working full-time…[partner] had 20 appointments…It just became unmanageable…*
- *It does not really give this justice...disgust over how the politicians have forced these monstrosities on us without any consideration for what others have experienced globally...all we know is that we were fine before this started. We tried the Ministry, we can't get any where there. They won't do anything and yet by law, they have to. So what do you do? Do we have to get a lawyer on it? You shouldn't have to.*
- *The property was bought in [date] as a dream farm to come and live at and work at and expand, raise our family. In [date], the wind turbines went up and near immediately, I didn't want to be here. Because it is not peaceful, it is not enjoyable, it is nothing that I anticipated having to deal or live with...I can't ignore the wind turbines…I've been told to by my mental health therapist to mourn the loss of enjoyment of my property as a death.*
- *It's [the noise level] all modeled. They didn't account for different weather patterns, wind patterns... We didn't trust them [government officials].*
- *I've lost a lot of trust in the newer generation of people that look after our public health...it's injustice...I thought that their [the government] role was our protection...We decided to try to protect what we have here, so we gave a lot of our resources, financial and a huge amount of time over the last 11 years... It's taken over our life. It's longer than a war...This is not right.*
- *I think the lack of trust - you know that the whole project and you know that the landowners, it's all based on money...It really did affect our family in huge ways and yet we're thankful for our children who understand it and who have supported us...it just solidified it more and more for us then, we just need to move away from all of these [IWTs].*
- *It's very upsetting, if you think of it, that somebody could drive you out of your house...That's what's bothering me a lot. I truly did not think that ever would happen in Ontario...Doesn't feel quite safe anymore...The people don't seem quite as friendly anymore because there are two sides to it,..We on one side and we are the majority. But the minority controls it because they have the backing of the government in this venture..*
- *I didn't trust anybody, and I was bitter...My sister came...It was about 45 minutes and she said, "I feel an incredible pressure and vibration in my chest. " She's been an unbeliever [of health effects]...she woke up and said, "I have a headache. I still have that pressure in my chest." We went next day to the lake and went for lunch...I asked her, "How are you feeling?"...[She said]"I'm great"...[Later] she was complaining again about her chest...She doesn't live near them [IWTs] but she said, "I feel like my face and head will cave in," and she's just driving through the area. She will not come over.*
- *We owned the home and I did not want to sell to anybody and have them have the same situation as us, maybe worse. It took a long time to get over those thought processes too at the very same time as I kept hope that they [the IWTs] could be stopped - that the governments would listen...We went through four years of not being listened to, not being helped, being told that it doesn't matter that our lives are just on the wayside, this was new technology and this was going to save everybody. My desire to be out of that house was instant from the first day they started to spin.*
- *I just was not okay with the fact that they were affecting our lives so negatively in all aspects. All aspects of our lives: no sleeping, the health problems, the worry, the not being able to have family over.*
- *I just couldn't get off the couch. I couldn't stay awake enough to be able to keep moving. Even to get up and go across the floor go to the bathroom or anything like that, with the effects of the wind turbine, I felt dizzy and lightheaded. I was on crutches and I didn't feel safe.*
- *We had to leave just to keep our family together, our health, our lives...we moved way [to a location] for a year...We had to sell everything...It was very hard...we had no roots, we had nothing really. We had our families but we want a place. We found [a place] that we purchased and moved in and my [partner] said, if there's ever any hint of a single turbine being put up around here, we're gone...We cannot go through that again...It was really, really hard...We learned a lot along the way about our governments.*
- *I just felt it [the basement] was a safer place. You always tried to think of some place you'd feel a little safer...*
- *I need to find out where these things [IWTs] are going, because I don't know where is safe, where it's safe to be in this province…there is no assurance from the government that they're going to protect you from exposure anywhere you live. They're just putting them [turbines] in… there is no safety and that is part of my right as a Canadian to feel safe where I live. I don't have that anymore and I don't know where to go...It is been one of the roughest decisions ever, my [partner]and I bought that place 25 years ago, knowing that we were going to retire and we would live there for the rest of our lives. He's fighting the symptoms, and fighting everything to stay [cries] I'm so tired [cries]. I'm just afraid to go anywhere...don't know where is safe, where it's safe to be in this province.*
- *We've lost the trust in government big time. That came as a shock to us that this would be allowed and that our voices would not be heard. We keep shaking our heads...Do we live in a third world country or what we call a third world?*

Contd....

Table 2: Contd....

• *I was stunned, absolutely stunned...you can't tell me where to go and where to live but apparently, they can.*
• *I have no faith in the government, but I have spiritual faith and that releases some of my stress…I'm trying to not let this kill us.*
• *This [leaseholder's] house will be affected more than any other house on the [location] and our neighbours are proponents....so we have no allies right around us or anything. When we realized that was the situation we are in, that's when we started thinking about selling out.*
• *Kept feeling that I had to find somewhere safer to be…my [partner] was willing for me to actually look at a property listing…to give me somewhere safer to be. You try to protect your children…I was trying to protect the children…it was very upsetting to know that we were never safe and that's why I wanted to leave and go live somewhere else...*
• *It was mentally exhausting to trying to fight for the safety and health of your family and your home...Just at a human level to care enough to stop the harm... There was one time they [IWT developer] were going to turn them off so that we could go home... they were still on, I had slept over in my car...*
• *I have other family who, to this day, cannot understand what's going on here...they're just not capable of understanding...we continue to pay residential property taxes to [Name] County for a house that we cannot safely reside in.*
• *Living with this, the turmoil over making the decision to leave or to stay is a lot like my experience from my past, with my first [partner] who was abusive. It took me years to leave. And this is the same thing. This is abuse. It's the same kind of feeling, the same torture trying to make that decision. There's so much to lose...*
• *I've got lung issues...[my partner has] heart issues. That's concerning about it. Are the conditions we already have going to be exacerbated by the turbines?*

Each example is by a different participant. [brackets] indicate where data have been omitted to maintain privacy

actionable insights and knowledge. They proposed that IWT manufacturers, engineering and insurance companies, and government institutions utilize this approach to address "problem areas and enhance systems and processes throughout the wind energy value chain."[60]

An Ontario municipal working group expressed deep concerns that while the IWT industry reports that each accident is an "isolated incident" there were "too many accidents." The working group recommended establishing: a formal public process for investigations, comprehensive and complete inspections of existing projects, a review of emergency response processes, predictive maintenance requirements, and an increase of setbacks from property lines. It concluded:

> When these projects were approved and built, provincial regulations limited municipal input into the projects and the supervision of their construction. This self-regulation process led to some serious problems for the municipalities. Now that further gaps in this process are becoming evident, the province needs to take responsibility for addressing the mistakes that were made.[61]

Fires

In 2011, a guidance note about the risk of IWT-related fires was issued by the Ontario Ministry of Labour. It proposed that Fire Departments should develop standard operating procedures for emergency incidents involving "wind turbines." It stated that IWT fires may present a "health and safety hazard to firefighters due to the electronics, flammable oils, and hydraulic fluids that exist in the turbines."[62]

Another announcement by the Ontario Association of Fire Chiefs advised that with the increase of IWT facilities, new challenges were arising for the fire service and that firefighters needed to understand the "top three types of wind-turbine failures." These included blade failure, fire, and structural failure of the tower. Firefighters were advised to know the "life-safety" guidelines that include the height of the IWT if a fire occurs in the motor and a risk of electrocution if the IWT is turning and generating power. During a fire, there is a risk of falling debris occurring over a wide area and firefighters were advised that approaching a burning turbine is usually "not an option unless there is a life risk involved." Firefighters were also advised that during a runaway event, rotating blades can throw debris over long distances – over 4,200 feet (1,280 m).[63]

Since the risk of fire and debris from a runaway event can travel over 1,280 m, Ontario families are at risk; the Ontario guidelines allow IWTs to be placed as close as 550 m to residents' homes.

Uadiale *et al.* highlighted the "unique nature of the fire problem faced by the wind energy industry" and that while there were numerous media reports of accidents, there was a "paucity" of information about IWT-fires in the scientific or public domains. Much of the information is proprietary. Due to the nature of wind turbines, fire-fighting is challenging and a "concern to all stakeholders" and that fire events can "cast a shadow on the green credentials of the technology."[64]

Firetrace International noted that while there is "little rigorous data that insurers or manufacturers share publicly," it encouraged that disclosure be untaken. It advised that "when a turbine fire takes hold then it's impossible for firefighters to extinguish it."[65] In a second advisory, Firetrace International proposed how IWT operators could assess the risk of fire and reduce a risk of injuries, avoid fatalities, and limit damage to assets.[66]

While occurrences of IWT fires may seem uncommon, they have occurred. For example, on June 3, 2023, a fire occurred at an Ontario WPP site. This was the second fire at this site. While fire crews from the township had remained on scene, the current fire was "so high off the ground" (approximately 100 m), the firefighters could not "put it out"[67] – a safety concern in itself.

Participants described feeling unsafe. This is reinforced by a similar finding by Health Canada's Wind Turbine Noise and Health study of "concern for physical safety."[68]

Trust and social justice

Trust supports a sense of security and is described as the belief that someone can be "relied on to do what they say they will do" and that the person in a position of power will "wield it responsibly."[69]

Some Ontario Member of Provincial Parliament (MPP), supported constituents' concerns related to IWTs. For example, in an Open Letter to the former Ontario CMOH, MPP Thompson noted that an FOI document revealed that as far back as 2009, AHEs had been confirmed by the provincial Ministry of Environment's field officers and an abatement plan was being developed. Thompson also requested a review of Ontario's CMOHs 2010 report and clarification of the direct/indirect link between wind turbines and AHEs.[70]

In 2017, IWT noise testing of one of the projects found that 11 out of the 20 measurements were noted as out of compliance and above Ministry guidelines. It was reported that MPP Thompson had urged that the Minister of Environment shut the IWTs off.[71]

MPP Fedeli stated that wind power is "simply unreliable," that "Ontario can do better" and proposed what the "caucus will do differently," i.e., by implementing an immediate moratorium on Ontario IWT development.[72] His colleague MPP Walker supported this moratorium.[73] MPP McNaughton pledged to end the "failed" IWT energy experiment. He stated that if he became the Premier of Ontario, he would propose "specific legislation to repeal and decommission" IWTs and that his party "will stop the further development of industrial wind turbines."[74] Another news report said that MPP Nicholls intended to introduce legislation to "prohibit non-disclosure clauses" in leases associated with locating IWTs on a landowner's property.[75]

A neighbor advised the Attorney General of Ontario that she did not consent to any exposure to "any of the following contaminants" associated with the construction or operation of the IWTs near her home. For example, she would not "be made a medical experiment by a turbine size, make and model" that was never tested in Ontario. Nor would she consent to:

- Environmental respiratory contaminant(s) in any form:
  - Emissions and Immissions of: Audible and inaudible noise such as:
    - dBA, infrasound, low frequency, and tonal noise
    - Electromagnetic and radio frequencies
    - Low-frequency vibrations.
  - Night time noise.
  - Noise at any time during my rest periods if I am required to work shift work, be on call for emergency support, extended hours or for any reason requiring my service outside of normal working hours.
  - Shadow Flicker.[76]

Other Ontario neighbors advised government officials that they also did not consent to the above exposures. One of the neighbors tracked the number of non-consenting advisories that were sent to government officials by other neighbors. The total numbers were: Medical Officer of Health (128), Premier of Ontario (42), Minister of MECP (43), Minister of Energy (42), Minister of Health (41), Attorney General (35), the system operators (30), the local MPP (41), the local federal Member of Parliament (28) and the Ontario Energy Board (27).[76] The number sent by postal service and e-mail is unknown[76] and the neighbor is unaware of anyone receiving a response.[77]

Regarding IWT deployment, it has been proposed that:

> Individuals have a right to make informed decisions about their health. IWT knowledge gaps and potential risks to health should be fully disclosed. Individuals should not be exposed to IWTs without their informed consent.[78]

Effects related to social justice can have significant outcomes. The WHO states that:

> Social justice is a matter of life and death. It affects the way people live, their consequent chance of illness, and their risk of premature death.[79]

The WHO also "recognizes the enjoyment of the highest attainable standard of health as one of the fundamental rights of every human being."[80] The WHO presents a number of recommendations that include: measuring and understanding the problem by ensuring that routine monitoring is in place locally, nationally, and internationally.[79] It also proposes several actions for tackling the "Inequitable Distribution of Power, Money, and Resources" by empowering all groups in society through:

> ...fair representation in decision-making about how society operates, particularly in relation to its effect on health equity, and create and maintain a socially inclusive framework for policy-making.[79]

However, while the WHO proposes "fair representation in decision-making" a former Ontario official who held duel positions as Minister of Energy and Infrastructure and the Deputy Premier of Ontario, was quoted that regarding a newly established law associated with WPP/IWT projects:

> We passed a law, and the law does not create an opportunity for municipalities to resist these projects just because they may have a concern.[81]

At the same time, the WHO[79] and Health Canada[82] acknowledge that a government policy has limitations:

> Different government policies, depending on their nature, can either improve or worsen health and health equity.[79]
>
> It is clear, however, that existing policies and practices are not sufficiently effective to ensure that Canadian men and women of all ages and backgrounds can have an equitable chance of achieving health.[82]

The WHO's recommendation to ensure that routine monitoring is in place[79] has been adopted by Ontario. In 2009, IWT monitoring by an Ontario Environmental Officer revealed in a memorandum that was addressed to senior management:

> It appears compliance with the minimum setbacks and the noise study approach currently being used to approve the siting of WTG will result or likely result in adverse effects.[83] *(WTG refers to Wind Turbine Generating).*

Fortier *et al.* acknowledged that there were challenges associated with quantifying (and qualifying) "procedural justice." They proposed a framework to address potential energy "justice issues" related to new energy systems life cycle.[84]

Ontario's monitoring/complaint process includes IWTs, However, WCO (Wind Concerns Ontario) noted that Ontario's Environment Ministry "says everything is OK." This is despite the thousands of IWT noise complaints and operator compliance issues. WCO comments that the Ontario government is out of touch and has not changed the regulations for noise levels or setbacks established by the previous government.[85]

In 2011, Krogh investigated the "reported loss of social justice" through a literature review, personal interviews, and communications with some of those reporting AHEs. Findings included that there was a feeling of being abandoned by the procedural systems they thought would protect them. It was observed:

> ... a progression of impacts starting with the identification of physiological and psychological symptoms and culminating with frustration, grief and anger, disempowerment, loss of trust, and an overall sense of social injustice.[14]

And that:

> The negative psychological effect of disempowerment interacting with the AHEs attributed to IWTs has intensified the negative synergy of justice lost. Impact statements indicate that the violation of procedural justice will not be easily forgotten.[14]

An Ontario study commented that placing WPPs in rural areas is similar to aggregate mineral mining in Ontario. The multiple case study approach found "environmental injustice in rural Ontario." The mining areas are treated as "sacrifice zones, i.e., places where urban resource demands can be met." A "most notable" finding was the notion that regional policy directions were driven largely by "urban centres of power disconnected from the realities of rural life." It was also noted that this was more a "lack of representation in regional political processes."[86]

In 2021, Ontario lawyer Whiteley recommended reforms to Ontario's Justice System. He used the GEA as an example and commented on "its impact on the rights of citizens." The document was sent to Ontario government officials. No reply was received from "any of the government officials." The lack of response increased his concern regarding "the value of the voice of the public." He concluded that at present:

> Ontario's Acts have resulted in "justice delayed is justice denied," and in some cases, no justice at all. Justice is the right of all citizens. Can the Justice system be modernized to allow this right?[87]

Cranmer *et al.* found "distributional inequities across all types of power plants." These findings were along different "sociodemographic lines and to various degrees." The findings opened several research questions – assessing the impact of "intersectional sociodemographics, public policy, and the desirability of power plants to better understand the injustices of power plant siting and their impacts on the hosting communities."[88]

Wilson *et al.* wrote:

> If the usual avenues of social input to decision-making processes have been removed by legislation, an imposed government policy may result in a loss of confidence and, despite the government's good intentions, may not achieve the intended outcome. While citizens may protest that a policy has inflicted significant social change without consent, some governments may maintain that the overarching goal of environmental benefit outweighs social concerns.[89]

CONCLUSIONS

In a previously published manuscript, Krogh *et al.* found that the Grounded Theory was an effective analytical approach for this study.[27] Participants had the opportunity to describe the effects of living near a WPP/IWT and the events that resulted in contemplating a housing decision. Through the use of uninterrupted narratives, participants' observations and comments, the Grounded Theory methodology generated insightful and rich data. The theory has been applied to a range of disciplines-health research, law, economics, and business studies.[90] It has been used to research "social justice" and to conduct "critical inquiry in the public sphere."[91]

Study participants resided throughout Ontario and were located in proximity to different WPP sites. The WPPs had either been operating for some time, had recently initiated operations, or the onset of operations was pending. Despite these operational differences, data analysis revealed that participants' descriptions of their effects were consistent. This contributed toward answering the research questions and the findings of the themes and subthemes as presented in the schema - Themes, Subthemes and the 5 Elements.

It was anticipated that some of the participants' housing decisions would be based on other factors such as: upgrading to a better home, downsizing and moving to town or to a condo or an apartment, deciding to move to a less expensive residence, school opportunities for their children, relocating to a better neighborhood, establishing a change of household or marital status, a better employment opportunity; retirement, being closer to health-care facilities and wanting a change of climate. However, all 67 participants associated occurrences of AHEs, or the potential for such effects, when living within 10 km of a WPP. Lack of resolution by authorities, regulators, and wind energy developers influenced and altered some participants' and expectations of social justice, safety, and security.

The Grounded Theory methodology served as a practical approach to support the theory that all 67 participants' contemplated a housing decision. This was motivated by the proximity of a WPP within 10 km of their homes and the occurrence or potential risk of AHEs.

It is recommended that members of the public, government authorities, policymakers, researchers, health practitioners, and social scientists with an interest in health policy and disease prevention acknowledge these occurrences and seek resolution for those who are negatively affected while living or working near a wind energy facility.

Ethics review

Chesapeake Research Review, LLC ("Chesapeake IRB"), Pro00022827, dated on September 25, 2017. *Note: Chesapeake Research Review, LLC ("Chesapeake IRB") and Schulman Associates Institutional Review Board, Inc. ("Schulman IRB") have merged to create Advarra, Inc. ("Advarra IRB").*

Data availability statement

The data generated and/or analyzed during this study are included in this published article.

Author contributions

All authors have contributed to this manuscript by providing their input, comments, support and agreement to this manuscript's publication.

Acknowledgments

This article is dedicated to those who participated in this important research and revealed their experiences when living in proximity to IWTs. We would like to thank them for their commitment, sincerity, courage, trust, and their candid, in-depth, and knowledgeable insights. They spoke openly about the profound impact on the lives of their families that followed permanently vacating their family homes and while contemplating to do so. Our interviewers were welcomed into the participants' homes. We acknowledge the interviewers who volunteered their time and traveled considerable distances to conduct the interviews. We also dedicate this manuscript to two of our co-authors who have recently died. We wish to acknowledge their contribution to this research. Mr. James was a respected acoustician whose numerous contributions are valued nationally and internationally. On behalf of Appellants, he testified under oath during numerous judicial proceedings. He was a consummate professional and a beloved friend to many of his colleagues, authors, and others who were fortunate enough to know him personally. Mr. Ambrose had a long and successful career as a principal investigator in acoustics and held paramount the safety, health and welfare of the public. He co-authored two ground-breaking peer-reviewed acoustic papers and for the next decade provided professional consulting to numerous communities on the effects of wind turbine noise. Both gentlemen are deeply missed. Finally, we thank those who encouraged us to conduct the study and who provided the funding for the Ethics Review, the coding software, and costs associated with open access publishing that enabled the conduct of this study and its publication.

Financial support and sponsorship

MAGENTICA RESEARCH GROUP, not for profit (Corporations Canada), partially funded by private donation.

Conflicts of interest

There are no conflicts of interest.

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Setback Recommendations Per Various Studies

Name of Study	Date of Study	Author(s)	Link to Study	Author's Advised Setbacks	Notes
Wind Turbine Syndrome: A report on a natural experiment	**2009**	Dr. Nina Pierpont	N/A, PDF provided	**Setbacks from residences should be a minimum of 2 kilometers or 1.24 miles, but 2-3 miles in hilly terrain**	PDF provided to Planning Commission and BoCC
Your Guide to Wind Turboine Syndrome...a road map to a complicated subject	**July 2010**	Calvin Luther Martin, Phd	N/A, PDF provided	**Setbacks from residences should be a minimum of 2 kilometers or 1.24 miles, but 2-3 miles in hilly terrain**	This is a summary of Dr. Pierpont's book PDF provided to Planning Commission and BoCC
Health Effects of Wind Turbines: Testimony of Ben Johnson versus MidAmerican Energy (Madison County, Iowa) / Hearing before the Madison County Board of Health	**August 2019**	Dr. Ben Johnson, M.D.	https://www.masterresource.org/wind-turbine-noise-issues/health-effects-of-wind-turbines-testimony-of-ben-johnson-versus-mid-american-energy-project-in-madison-country-iowa/	**No recommendation given for a specific distance in this hearing. Afterwards the Madison County Board of Health passed a resolution recommending that any future turbines be built at least 1.5 miles from non-participating homes**	PDF provided to Planning Commission and BoCC
Wind Turbine Noise and Human Health: A Four-Decade History of Evidence that Wind Turbines Pose Risks	**Ocober 2016**	Professor Jerry L Punch and Professor Richard R James	https://hearinghealthmatters.org/wp-content/uploads/2023/03/16-10-21-Wind-Turbine-Noise-Post-Publication-Manuscript-HHTM-Punch-James.pdf	**Setbacks from residences are recommended at 1/2 mile to 2.5 miles, 1.25 miles is most favored by scientists.**	PDF provided to Planning Commission and BoCC
Infrasound from technical installations: Scientific basis for an assessment of health risks	**July 2021**	Dr. Werner Roos and Dr. Christian Vahl	https://www-asu--arbeitsmedizin-com.translate.goog/wissenschaft/wissenschaftliche-grundlagen-fuer-eine-bewertung-gesundheitlicher-risiken-infraschall?_x_tr_sl=de&_x_tr_tl=en&_x_tr_hl=en&_x_tr_pto=wapp	**Minimum setback from residences should be 10 X turbine height as in Bavaria Germany**	PDF provided to Planning Commission and BoCC
Assessing Adverse Health Effects-(Confirmed and Potential) from Industrial Wind Turbine Noise Emissions / Power point slides of presentation before the Kansas State Legislature	**2022**	Dr. Ben Johnson, M.D.	https://www.kslegislature.gov/li_2022/b2021_22/committees/ctte_s_utils_1/documents/testimony/20220207_01.pdf	**Setbacks of 1.25 miles from residences**	PDF provided to Planning Commission and BoCC
Presentation before the Kansas Senate and Utilities Committee: Effects of Wind Turbine Noise on Human Health	**2022**	Prof Jerry L Punch	https://www.kslegislature.gov/li_2022/b2021_22/committees/ctte_s_utils_1/documents/testimony/20220208_02.pdf	**Setbacks of 1.25 miles from property lines (specifically) should be considered**	PDF provided to Planning Commission and BoCC
Wind Turbines: Vacated/abandoned homes - Exploring participants' descriptions of their personal views, effects on safety, security, trust and social justice	**Dec 2023**	Carmen Marie Krogh, Robert Y McMurty, W Ben Johson, Jerry L Punch, Anne Dumbrille, Mariana Alves-Pereira, Debra Hughes, Linda Rogers, Robert W Rand, Lorrie Gillis	https://journals.lww.com/endi/fulltext/2023/08040/wind_turbines__vacated_abandoned_homes___exploring.2.aspx	**Residents living within 10 kilometers/6.21 miles of industrial wind turbines were documented having Adverse Health Effects**	See page 96 for the conclusion of the study regarding setbacks. PDF provided to Planning Commission and BoCC.
A fundamental basis for all living creatures, mechanotransduction, is significantly endangered by periodic exposure to impulsive infrasound and vibration from technical emitters - in particular cardiovascular and embryological functions	**June 2025**	Dr. Ursula Bellut-Staeck	https://www.scirea.org/journal/PaperInformation?PaperID=12440	**Setbacks of 10 kilometers / 6.21 miles from people and animals**	NOTE: The link shows the abstact and allows you to download the PDF PDF provided to Planning Commission and BoCC
Separating Myth from Fact on Wind Turbine Noise	**October 2025**	Prof Ken Mattsson	https://www.youtube.com/watch?v=nDwsd32SDEY	**Setbacks of at least 5 to 10 kilometers (3.1 to 6.2 miles) from residences**	Transcript PDF provided to Planning Commission and BoCC
Efficient finite difference modeling of infrasound propagation in realistic 3D domains: Validation with wind turbine measurements	**Feb 2026**	Ken Mattsson, Gustav Eriksson, Leif Persson, Jose Chilo, Kourosh Tatar	https://www.sciencedirect.com/science/article/pii/S0003682X25006280?ref=pdf_download&fr=RR-2&rr=9a872537bf69df1b	**No specific distance given, see notes for conclusion of study**	Conclusion of study page 14: This study also shows that modern, large-scale wind turbines generate infrasound levels substantially higher than those reported for older, smaller turbines / PDF provided to Planning Comm & BoCC

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SCIREA Journal of Clinical Medicine
ISSN: 2706-8870
http://www.scirea.org/journal/CM
June 16, 2025
Volume 10, Issue 2, April 2025
https://doi.org/10.54647/cm321372

A fundamental basis for all living creatures, *mechanotransduction,* is significantly endangered by periodic exposure to impulsive infrasound and vibration from technical emitters - in particular cardiovascular and embryological functions

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Abstract

Mechanotransduction is *the* common basis for all organisms for converting physical forces into biochemical and biological information. Ongoing PIEZO channel research confirms PIEZ0-I and II channels in numerous other tissues including outside the endothelium. The prerequisite for a inflammatory transformation of the endothelium *is chronic oxidative and oscillatory* stress, as vital regulatory processes depend on an *uninterrupted laminar flow in the* capillary system *and the* integrity of the endothelium. Vascular health, in turn, is closely linked to demand-driven NO bioavailability and its homeostasis.

The latest findings on a growing environmental factor show clear signs of an incompatibility between chronic and impulsive low frequencies and a fundamental information pathway of all organisms. The potentially serious consequences of an interaction, e.g., loss of endothelial integrity, increased blood pressure and tissue remodelling of the heart, reduced fertility, stranding`s and death of whales, decline in animal species and insects and reduction in plant

biomass, have a common basis, which is discussed in this article: *mechanotransduction*. A force that is not demand-oriented can lead to irregular information.

There is an urgent need to reassess the far-reaching effects and consequences of infrasound and vibrations *from technical installations such as biogas plants, heat pumps and* in particular, *large (250 m+) industrial wind turbines* (IWT). *'If you want to discover the secrets of the universe, think in terms of energy, frequencies and vibrations'* (quote from Tesla). Mechanotransduction is a common basis for all life and must be preserved.

Keywords: *mechanotransduction, cardiovascular diseases, embryogenesis, oxidative and oscillatory stress, infrasound and vibration, endothelial integrity, NO homeostasis, PIEZO-channels, biodiversity.*

1. Introduction

For years, researchers have been searching rather unsuccessfully for the pathophysiological mechanism that explains why people living near infrasound-emitting installations exhibit similar symptoms everywhere, domestic animals display conspicuous behaviour and why animals avoid the immediate vicinity of increasingly taller wind turbines or other technical installations that emit infrasound and vibration. The research was for longer times mainly planned, carried out and evaluated by acousticians. Since around 2017, international studies have increasingly pointed to cellular stress effects and serious health impacts from chronic exposure to periodically occurring, low-frequency infrasound and vibrations. The knowledge of the specific properties of this far-reaching environmental factor and the current state of research on endothelial mechanotransduction and PIEZO channels has enabled *a paradigm shift*. The cellular effects could be reclassified.

Ongoing investigations of the PIEZO channel show high concentrations in varying distributions of PIEZO- I and -II channels, even outside the endothelium. The possible effects on the affected organisms are becoming increasingly clear. Sound, whether audible to organisms or not, is subject to the laws of physics.

2. Relevant Foundations

2.1. Structure, Components and Regulation of the Microcirculation System in Mammals

The vascular endothelium serves as *interface* and "*switching point*" between bloodstream and tissue. Endothelial regulation of vasodilation and contraction, vascular permeability and fluid homeostasis, inflammation and immune signalling, are vital for vascular health, which in turn is pivotal to our survival [1]. The endothelium perceives physical and chemical signals from the environment as information and converts them into a response. It consists of the sum of all flat endothelial cells (ED`s), lining all the mammal's vessels - including lymph vessels - as *the body`s largest organ* [2,3]. The ED corresponds in its structure to a somatic cell and is specified for its diverse tasks [3,4]. The surface area of the *endothelium* corresponds approximately to two football pitches – according to new estimates approximately 7,000 square meters for an adult male – and its total weight is estimated at around one and a half kilograms [2]. On the one hand, this enables a nutrient supply that is well adapted to current needs [2,3,4,5], on the other hand, this large surface area also provides a target for *internal and external disruptive factors*. For an overview, which cannot be complete, the complex tasks of endothelial cells are shown in Fig.1. [4].

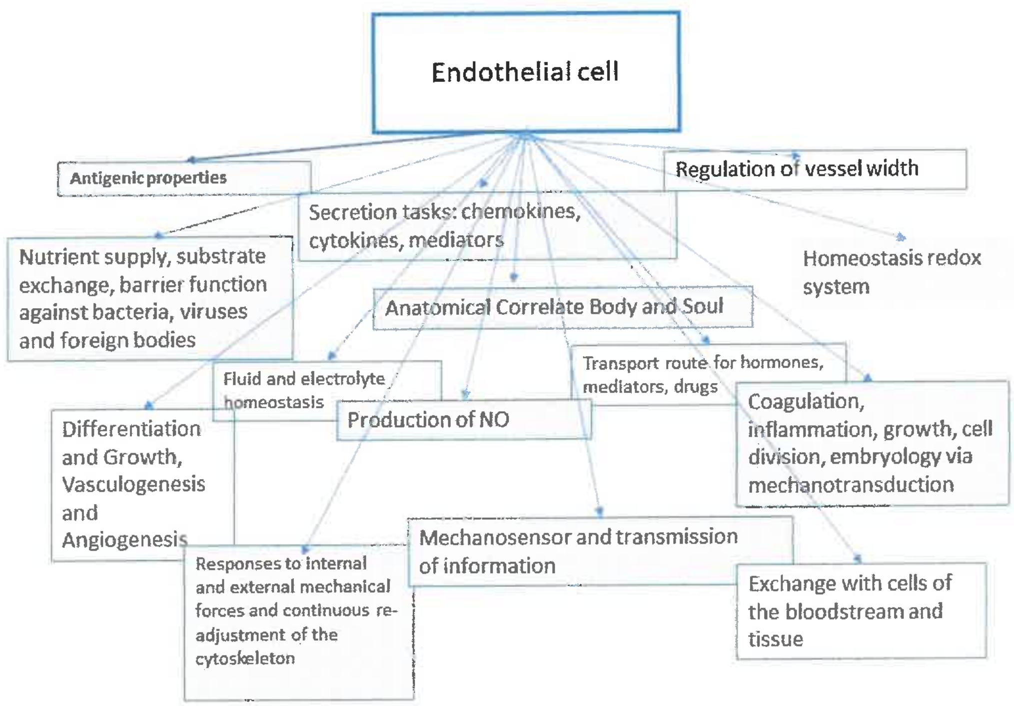

FIG 1: A selection of the most important endothelial functions. Bellut-Staeck UM.2022 [4], translated in English

By regulating the resistance via the upstream arterioles, we physiologically find laminar flow with uniform velocity, strictly bound to vessel size. This is a *crucial precondition* for the diverse and vital tasks of microcirculation and endothelial cells, which take place *in the circuit's low-pressure system* [3,4,6]. Under physical strain, a so-called *capillary recruitment,* according to Moore and Fraser [8], begins by lowering the vascular resistance of upstream arterioles, resulting in a significant increase in the nutrient exchange surface and decrease in the distance between two capillaries [5]. Vascular regulation is controlled by *intrinsic and extrinsic* factors. The autonomic nerve system and vasoactive hormones, e.g., *adrenalin, vasopressin, angiotensin, serotonin,* modulate the intrinsic activity [2,3,7,8]. Vascular segments *are acting in a coordinated manner*, which is attributed to the *Endothelium-derived-hyperpolarising-factor* (*EDHF*) [1]. *EDHF* has a far-reaching effect as vascular response, both upstream and downstream. *Calcium-dependent* activation of potassium efflux by *EDHF* is followed by *hyperpolarisation* with almost simultaneous transmission of electron transfer within the vessel wall via *gap junctions* [11]. This reaction is comparable to *a "school of fish"*, very fast and synchronized [12]. The mechanosensitivity of the capillaries was demonstrated when a positive micro-tactile physical stimulation was confirmed [12]. For further insight in vascular regulation and vasodilating substances [4,10].

2.2. The integrity of the endothelium

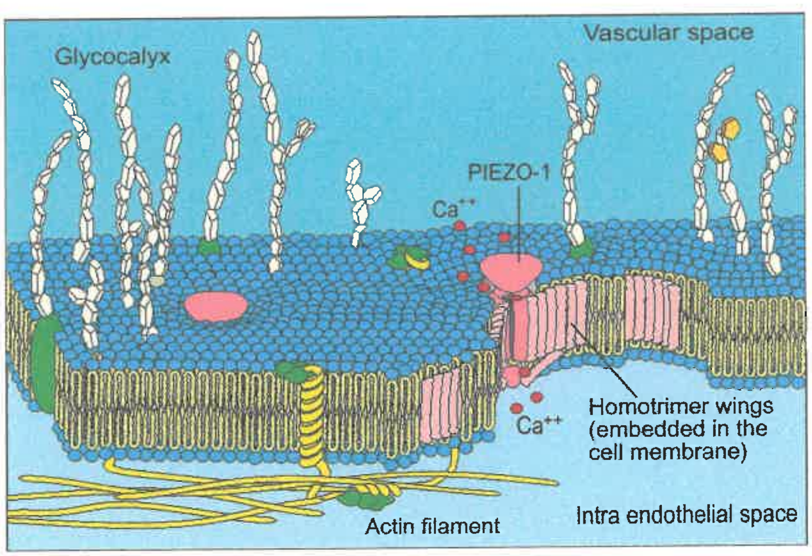

Fig 2 Schematic presentation of the endothelial semipermeable bio membrane with Glycocalyx and PIEZO-I channel, embedded in the endothelial cell membrane. One channel with a triggered Ca^{2+}-inflow. The actin ring (intra-endothelial) is indicated. The wings are moved by mechanical forces on the membrane and release the channel in an opening movement. Blue/Yellow: endothelial bio membrane with lipid bilayer structure [5]

The integrity of the endothelium is crucial for maintaining endothelial functions properly.

a) *Vasomotion*: A fine, non-pulsating vascular movement is extremely typical for a microcirculation with an *intact endothelium.* Even the smallest disturbances can cause *vasomotion* [13] to disappear. Due to its very low movement with sinusoidal changes of 0.1 Hz in the vessel, vasomotion *cannot* be easily observed in *SDF microscopy* [14]. Allowing precise measurements of vasodynamics, authors Zhang et al., 2024, introduced the method of *two-photon microscopy* [15]. As the authors note, vasomotion is crucial for e.g., brain homeostasis. In studies of cerebral blood flow in a mouse model, both native and after occlusion, they showed that vasomotion is of great importance in both the central and peripheral nervous systems. After stress caused by occlusion and reperfusion, vasomotion disappeared for a prolonged period. It was clarified that vasomotion also modulates fluid filtration pressure in the pulmonary vessels and that proper testicular function depends on intact vasomotion. It is expected that the benefits of intact vasomotion can also be demonstrated for the cardiovascular system and other vital systems.

b) *Glycocalyx:* The *glycocalyx* plays a special role in endothelial *integrity*. Only its base is firmly anchored in the endothelium. The part that extends into the bloodstream is subject to constant change, as it is in a continuous state of formation and degradation and at the same time acts as a sensitive mechano-sensor. Damage, known as *shedding*, has been shown to be caused by the effects of increased mechanical and oscillating stress as well as increased free oxygen radicals *(ROS)*. In critically ill patients, the extent of *glycocalyx* damage correlates with their morbidity and mortality [2,16,17].

Loss of endothelial integrity:

Other factors that can lead to an oxidative stress syndrome (OSS) include elevated blood sugar levels, increased lipid peroxidation and stress factors, caused by vasoactive substances, e.g., the sympathetic nervous system or angiotensin axis. Elevated cortisol levels also lead to the formation of oxygen radicals (ROS), [5], cap. 8.2. page 54.

Why we must expect more than additive harmful effects with especially big wind turbines of current design is explained below:

The microplastic abrasion from today's wind turbines includes not only epoxy which is 40% Bisphenol-A (BPA), a frequently banned endocrine disruptor, but also per- and polyfluoroalkyl substances (also known as PFAS, PFASs, and sometimes referred to as 'forever chemicals`) [19]. One of the deleterious effects of *overproduced NO* is Increased susceptibility for radiation, alkylating substances and toxic metals, compare 2.4. TAB 1.

Loss of endothelial integrity: Early atherosclerotic lesions usually develop at vascular bifurcations and curvatures of large and medium-sized arteries, where laminar flow is disturbed and oscillating stresses are present [22]. In [7,18,20,21], the development from an intact endothelium into a state of inflammation, is presented. Endothelial dysfunction is both, a consequence *of* and a causal contributor *to* an altered metabolism in the endothelial cell. As a result, the endothelial communication with other cell populations such as macrophages, monocytes and also smooth muscle cells is disrupted, leading to vascular dysfunction and triggering a cascade of intra- and extracellular signals such as endothelial secreted mediators (*cytokines*) [23]. All these factors together lead to easier transport of lipoproteins in the subendothelial space and to the maintenance of chronic inflammation and an increased risk of thrombosis. In case of chronic circulatory disorders and proatherogenic stimuli, endothelial cells partially or completely undergo a transition to *mesenchymal* cells with corresponding properties. In addition, the pathological activation of PIEZO channels leads to expression of *various pro-inflammatory genes* and also serves as a critical mediator for an inflammatory response [18,24,25], At the same time, an intracellular increase in Ca^{2+} can be registered.

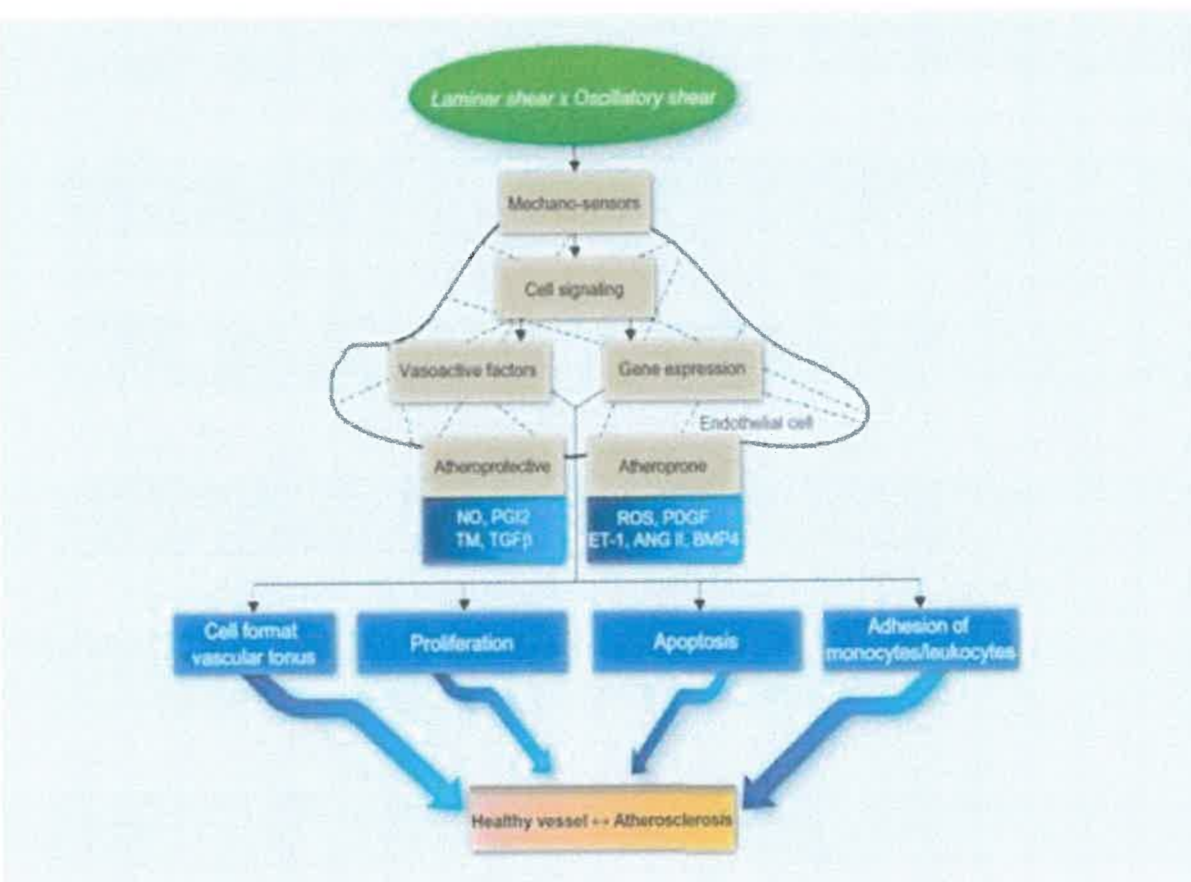

Figure 3 Original description [7]: Different effects of laminar and oscillatory shear on cell function and atherosclerosis. The *dotted lines* represent the endothelial cell cytoskeleton.

Laminar and oscillatory shear forces are recognized in endothelial cells by mechanosensors and the mechanosignals initiate signalling cascades that regulate the production of vasoactive factors and the balance between these factors. While laminar shear stimulates the production of atheroprotective factors, oscillatory shear stimulates the production of atherogenic factors and the balance of these factors determines the vessel tendency to stay healthy or to develop atherogenic plaques. PGI2, prostacyclin; TM, thrombomodulin; TGFb, Transforming Growth Factor beta; PDGF, Platelet-Derived Growth Factor; ET-1, Endothelin-1; BMP4, Bone Morphogenetic Protein 4. Adapted from Jo H, Song H, Mowbray A. Role of NADPH oxidases in disturbed flow- and BMP4-induced inflammation and atherosclerosis. Antioxid Redox Signal 2006; 8: 1609-19. Overview over the different effects of laminar and oscillatory shear stress on cell function and atherosclerosis. Original source [7]: *Fernandes CD, Araujo Thaı's S, Laurindo FRM, Tanaka LY. Hemodynamic Forces in the Endothelium. Mechanotransduction to Implications on Development of Atherosclerosis. In: ENDOTHELIUM AND CARDIOVASCULAR DISEASES. Vascular Biology and Clinical Syndromes. Edited by PROTASIO L. DA LUZ.PETER LIBBY ANTONIO C. P. CHAGAS. FRANCISCO R. M. LAURINDO. Publisher: Mica Haley. Sao Paolo. (2018) ISBN 978-0-12-812348-5 Cap. 7 FIG 7.3, p 90*.8 With permission.

2.3. Redox System Homeostasis

NO is one of the most potent antioxidants and plays *a critical role in the homeostasis of overall redox metabolism by interrupting lipid peroxidation and thus reducing ROS* [1,23] (Tab 1]. In all organisms, NO freely diffuses through the membranes [3,5]. The vascular effects of *NO* are either presented *as vascular protective*, *regulatory or damaging* [1,23]. Various factors determine how the effect is realised. Protective effects have an appropriate *NO production* [1], but remarkably, *excessive NO production* is associated with *detrimental effects [1,23].* NO overproduction leads *to lipid peroxidation*, *depletes antioxidant stores* and *increases susceptibility to radiation, alkylating agents and toxic metals like already mentioned.* It also *inhibits enzyme function and causes DNA damage* (Table 1).

Table 1. The different possible effects of Nitric Oxide as protective, regulatory and deleterious

Protective effects:
• Antioxidant
• Inhibits leucocytes and platelets adhesion

• Protects against toxicity and peroxidation
Regulatory effects:
• Vascular tone • Cell adhesion • Vascular permeability • Neurotransmission • Bronchodilation • Inflammation regulation • Regulation renal function
Deleterious effects
• Inhibits enzymatic function • Induces DNA damage • Induces lipid peroxidation • Increases susceptibility for radiation, alkylating substances, toxic metals • Depletes reservations of antioxidants

After Original source [23] FIG 1 in WINK AA. MITCHELL J (1998) CHEMICAL BIOLOGY OF NITRIC OXIDE: INSIGHTS INTO REGULATORY, CYTOTOXIC, AND CYTOPROTECTIVE MECHANISMS OF NITRIC OXIDE, Radiation Biology Branch, National Cancer Institute, Bethesda, MD, USA from Book Free Radical Biology & Medicine, Vol. 25, Nos. 4/5, pp. 434-456, 1998. Published by Elsevier Science Inc. 0891-5849/98 $0.00 1.00 reference FIG 1 Page 435.

Crucial for both, a synchronised blood flow regulation and the maintenance of high *NO bioavailability,* is an *adequate release of NO in the right amount, the right place and at the right time.* This is only possible if the triggering forces result in demand-driven information. More details to the whole theme inclusive the involvement of endothelial NO- synthase isoenzymes in redox signalling pathways in orig. articles [1,22,23,26].

2.4. A `Tensegrity Structure` of the Endothelial Cytoskeleton offers the precondition for endothelial mechanotransduction

Named after Fuller [27], the structure combines structural stability, lightness and elasticity *for power transmission.* Actin filaments, microtubules and intermediate filaments as *intercommunicating networks*, take on the *elastic*, the *non-compressible* and *the connecting part*, respectively. Actin filaments serve to maintain the cell shape by forming a ring under the cell membrane [27,28] FIG. 2 which is connected to flow sensors (mechano-sensors) and membrane focal adhesion points (FAS*) – the 'anchor points in the tensegrity model' – as well as the intercellular gap junctions (CCAP)*. The original article [28] provide a more in-depth insight into this topic. In response to contractile stimuli, *actin and myosin filaments* form membrane-bound, parallel-organised units called '*stress fibres*', which stimulate myosin to slide along actin filaments. This leads to an increase in intracellular tension and thus cell contraction according to Wang [29] and Lee [30]. The closing and opening of paracellular gaps in response to inflammation, ischemia and invading substances (*gate-keeper-function*) is essential according to [31].

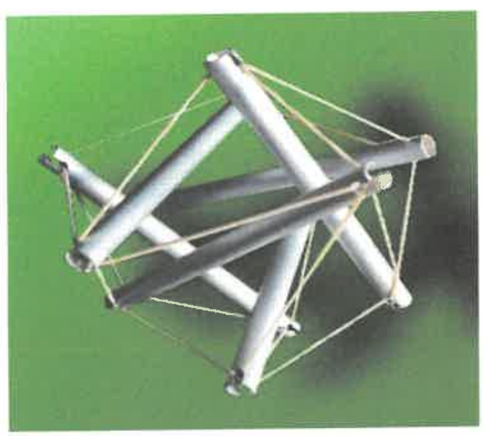

FIG 4: "Tensegrity" Model "in a schematic presentation [5].

Graphic Bellut-Staeck

2.5. Selected endothelial functions

2.5.1. Inflammation and Fibrosis Homeostasis

To maintain structure and function, an inflammatory response is essential as *a physiological defence mechanism* against, e.g., bacteria, viruses and injuries. All consecutive reactions depend on the *integrity of the endothelium* and involve the *endothelial cytoskeleton.* Since it is a *vital endothelial function*, the complex process of inflammation can be disrupted at any level, Suthahar [32]. Point of no return is the *diapedesis of leucocytes*. The further course leads in the favourable case to a *restitutio ad integrum*, in the unfavourable to a *chronic inflammation* with fibrosis, defect healing and possible organ damage with loss of function. Important works on the state of the science come from Ley [33]and Serhan [34], related work in particular from Nussbaum and Sperando [35,36]. According to these authors, the orderly process in all phases is crucial for its outcome. At the centre of the process is the adequate *gate-keeper-function* of an *endothelium in an integrity state.* In order to *lead to a restitutio ad integrum*, the whole process is dependent on the *absence of increased oxidative and oscillatory stress*, in detail in [4,] in cap.2.4. In clinical medicine, shifts towards chronic inflammation play a major role.[12].

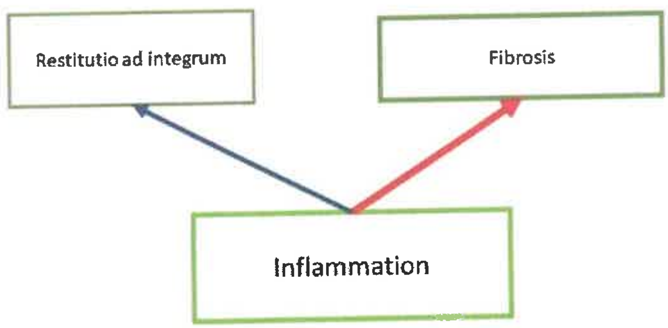

FIG 5: Schematic representation of the homeostasis of inflammation. Disturbance under chronic oscillatory and/or oxidative stress drives shift towards defect healing [5] Graphic 1.4 Bellut-Staeck

The standard works by Buckley [37]and Serhan [34] describe the sequences after the leukocyte diapedesis [5,38]. Failure of such regulatory mechanisms can likewise lead to a state of *chronic inflammation*, causing continuous tissue damage and progressive fibrosis. A classic example is the chronic heart failure by "remodelling" of heart, which can trigger a vicious circle [32, 5]. At heart, immunocompetent myofibroblasts and factors of the ECR actively modulate the development of initially perivascular and later progressive fibrosis. Starting points can be the development of myocarditis into a chronic form, state after myocardial infarction and/or *chronic mechanic pressure load on the heart* (systemic high pressure or pulmonary hypertension). The consequence is the increase in diffusion distance, the decrease in capillary density, an impaired electroconductive system with cardiac arrhythmia, disruption of angiogenesis, leading again to a deteriorated substrate and oxygen supply with a self-reinforcing process: *a vicious circle* [34]. According to the state of PIEZO research, the overstimulation of PIEZO channels can also contribute to this deterioration [24], cap 2.4.

2.5.2. Embryogenesis

According to the current state of knowledge, the importance of external forces, in particular repeated exposure to low frequencies and vibration during the pregnancy, must be classified as significantly more harmful than previously assumed. The high sensitivity is related to various stages particularly of embryonic development which are physiologically based on an undisturbed capillary flow. Examples of particular phases of increased sensitivity are e.g., the *vasculogenesis*. After differentiation of endothelial progenitor cells [4] and their fusion into a primary capillary plexus [31], the growth direction of the vascular tree is essentially regulated by shear *stress* of the blood stream and thus by mechanotransduction, Hahn and Schwartz [40]. PIEZO-I channels play a vital role here, without no embryogenesis would take place. Changes in shear stress pattern drive *immediate vasomotor* changes, which are regulated, as we know, on a '*beat-to-beat*' basis [19,38]. In this way, unexpected force driven disturbances can have *deleterious effects* [19]. Basing on some mutational *human PIEZO- gene* diseases such as the congenital *xerocystosis* or *congenital lymphatic dysplasia,* the erythrocytes and the lymphatic system is highly dependent on adequate forces. The last is characterised clinically by a lymphoedema. The network of lymphatic vessels with its own endothelium regulates the turgor and homeostasis of the interstitium and the lymphatic valve formation by shear forces. In consequence also there is a high sensitivity for an impact with external forces [41].

The neural development process is comparably sensitive to mechanical properties of its environment. One aspect is the alignment of neural stem cells into different *phenotypes* [24] and cap. *3.4. The important role* of Piezo-I in endothelial morphogenesis with dependent endothelial functions, suggests that damaging external forces must be strictly avoided during pregnancy.

In the dissertation "*Acquired flexural deformation of the distal interphalangeal joint in foals*" the influence of deep frequencies and vibration on embryogenesis becomes apparent. With the commissioning of three IWT`s at distances of 350 to 800 meters from the farm in 2008, an increased incidence of flexural deformities – especially 11 individuals affected- was observed, also abnormalities in other tissues were found. Histologically, the most significant alterations were the dissociation of myofibrils of the smooth muscle cells. This was predominantly seen in the small intestine but also in the walls of small capillary vessels, including those of the tendon vasculature [32}.

The chapter PIEZO channels in cap. 3.4. presents current results of PIEZO research on the occurrence and function of PIEZO channels in various organs. This may only be a small part of what influences embryonic development and how is its sensitivity to external and internal forces.

2.5.3. Homeostasis coagulation

Healthy endothelium plays an important anticoagulatory and antithrombotic role. Further insight is provided by ANNICHINO-BIZZACCHI und VINICIUS DE PAULA (2018) [43] in cap. 11, S. 148 and [4] in cap. 4.3.

3 Mechanotransduction

The conversion of mechanical forces into biological information, which is increasingly emerging *as a comprehensive mechanism for all living* things, is represented by the conductivity of biological structures, the presence of mechano-sensors, the conversion process from a physical into a chemical or electrical signal as information and the induced biological and/or biochemical response.

3.1. Hemodynamic Forces

Physiologically, physical forces constantly act on the organism, e.g., *gravidity, pressure, proprioception, shear stress* and *vibration.* The major ones come from the blood flow itself and are tangential forces e.g., *laminar shear stress* or stretching forces e.g., *pulsatile distention* according to Fernandes et al. [19] and Mazzag et al. [44] As described above, *internal oscillatory stressors are physiologically limited in the capillary bed by the vessel size* [1]. As a result, we find *physiologically laminar flow* in the capillary bed. [1,2,19].

3.2. Mechanical Force Transmission via "Biophysical" Pathway"

The observation that many processes take place very much faster than the *mechano-chemical* pathway via *gene expression* and *protein synthesis* would allow – protein synthesis needs a minimum of some seconds – led to intensive research in the "tensegrity" structure of the cytoskeleton and to the definition of the "*biophysical pathway*" [1,44]. *In the example of endothelial mechanotransduction,* this pathway relies on direct physical links between *specific mechano-sensors of* the endothelial surface and the endothelial cytoskeleton. It allows cells to transfer mechanical stimuli over long distances and very importantly, in a "*spatially heterogenic excitation ", quote Mazzag* [44]. Crucial work with important relevance to our work is the research on the dynamics and distribution of transmission in response to "*noisy flow*" from Mazzag and Gouget in [44] and Mazzag and Barakat. in [45]. By "noisy" flow, the authors mean an "*oscillating or turbulent flow* under *conditions with random fluctuations in* *the flow properties of pressure and velocity*", quote Mazzag, Barakat 2010 on page 912 [45]. To the predecessors in the exploration compare [38]. To better understand the dynamics of force transmission via cytoskeletal filaments, several *mathematical models* have been developed. The authors Mazzag and Barakat present an overview with possibilities and limitations in [45].

The "Temporal Network Model 2, as presented in [44] and [45] is based on a *viscoelastic structure* of a *tensegrity model (*FIG 4). The results show that the amplitude of the *oscillations* in the 'noisy' flow is *more strongly answered than its duration, which could be an explanation for why an 'impulse force' is answered more strongly than a constant.*" [45]. A summarising evaluation is provided in Mazzag [44] with further developments of models, e.g., such as the "*spatio-temporal network model*". Important quote on this topic on page 101[44]: *"At sufficiently low oscillatory frequencies, the peak deformations match those for constant forcing; however, above a threshold frequency, the peak deformations drop significantly. The analysis demonstrated that this threshold frequency is in the range of* 10^{-5} - 10^{-4} *Hz for microtubules and* 10^{-3}- 10^{-2} *Hz for actin stress fibres, suggesting that stress fibres can effectively transmit force over a wider frequency range.*"

Na *et al.* [46] confirmed in an experimental study the transfer speeds and effects, predicted by the computer model. The experiment *used infrasound* as physical force. It could be demonstrated, that the *biophysical way* is about 40 times faster–*namely 300 milliseconds*– than the route by pathway of gene expression.

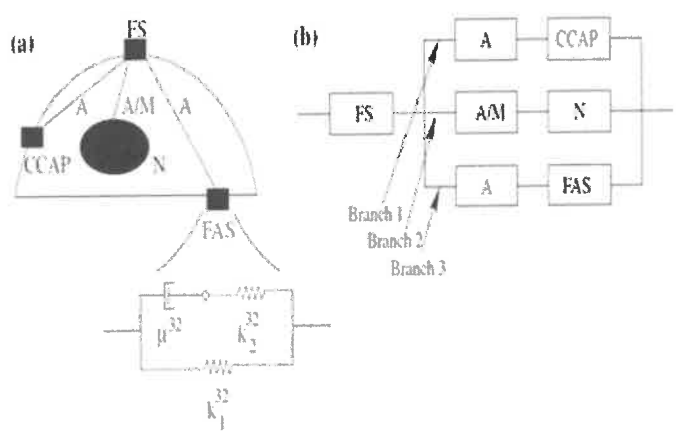

FIG 6. Original description [44,45*]*: Schematic representation of an EC consisting of a mechano-sensor (MS), cytoskeletal elements (either actin stress fibres (a) or microtubules (M)), a nucleus (N), cell-cell adhesion proteins (CCAP), and focal adhesion site (FAS). The inset shows a TPMM (or Kelvin body) representation and the viscoelastic parameters for

FAS. The superscripts '32' on the parameters indicate that this element is the second element on the third branch (see text). (b) Branching network representation of the EC components in panel A. Each cell component corresponds to a TPMM, coupled to other components according to the diagram shown. Actin stress fibre and CCAP connected in series are referred to as Branch 1, actin stress fibre/microtubule in series with the nucleus is Branch 2, and actin stress fibre in series with the FAS is Branch 3. (a) Schematic representation of an endothelial cell consisting of a flow-sensor (FS), cytoskeletal elements actin filament (a) or microtubules (b) and the connections (N), (CCAP), (FAS). (b) Mathematical representation. Original source [44,45]: Temporal Network Model FIG 1 *Bori Mazzag, Cecile L. M. Gouget, Yongyun Hwang* and *Abdul I. Barakat* (2014) [44] Cap. 5. Page 98 [45] Mechanical Force Transmission via the Cytoskeleton in Vascular Endothelial Cells. In Endothelial Cytoskeleton. *Editors* Juan A. Rosado and Pedro C. Redondo Department of Physiology, University of Extremadura Cáceres, Spain. With permission

3.3. The Mechano-Sensors of the Endothelial Cell

The endothelial *mechanotransduction* occurs *directly*, without delay, as shown in chapter 3.2.

On the side facing the vessel (luminal), mechano-sensors are especially *the cytoskeleton itself* [19], the *glycocalyx, integrins, cell-cell junctions (CCAP), caveolae, lipid rafts, G-protein coupled receptors and PIEZO-I-channels (*designated as ion channels as of 2019, FIG 4 in [1]. They are activated according to their location via shear stress [1,48]. Endothelial mechano-sensors are altered in their microenvironment by shear stress and can activate intracellular signalling pathways in this new formation. The fluidity of microdomains in the plasma membrane is altered after [1]. This leads to a spatial rearrangement of various proteins and thus to the activation of signalling pathways. The *transmission of forces* takes place via the three intercommunicating networks to the basal region of the cytoskeleton (e.g., Integrins) [1,44,45]. One of the most important mechano-sensors is the *glycocalyx* ([1,2]. In critically ill patients, the extent of the *glycocalyx* damage –so called *shedding*– correlates with the severity of disease and mortality [2,21,47].

3.4. A closer look to a special mechano-sensor: the PIEZO-channels

Ardem Patapoutian was awarded 2021 the Nobel prize in Medicine for establishing PIEZO channels *as a sensory system of internal organs via receptors for pressure and vibration in all vessels and the skin,* David Julius was awarded for TRPV1- channels as receptors for heat and cold. "*TRPV1 and PIEZO channels provide a completely new basis for sensing mechanical forces and vibration, heat and cold.*" *Quote page 1 [48]. [...] "The work by the two laureates* *has unlocked one of the secrets of nature by explaining the molecular basis for sensing heat, cold and mechanical force, which is fundamental for our ability to feel, interpret and interact with our internal and external environment."*

PIEZO ion channels in general mediate the *conversion of mechanical forces into electrical signals* and are conserved structures in *all* multicellular organisms, also plants, therefore important for all living entities from plants, bacteria up to mammals. In line with their significance, they are *in the focus of actual PIEZO research.*

PIEZO proteins form *homotrimer structures* with a central ion-conducting pore and three peripheral large mechano-sensitive propeller-shaped wings. See schematic graphic in FIG 7. *When Ca^{2+} permeable PIEZO-I* channels are activated by physical force on the cell membrane, they flatten the wings in an opening movement and reveal the entrance to a central pore, using a *unique lever mechanism* [24]. The Na^{2+}/Ca^{2+} channel is activated and triggers a signal transduction via a Ca^{2+} influx, Rode et al. 2017 [49], therefore *PIEZO-I is responsible for flow-sensitive, non-inactivating, non-selective cationic channels which depolarize the membrane potential.* In a remarkable research progress, authors like Fang [24] characterized PIEZO- I and- II channels in their protein structure, biological functionality and their possibly biophysical significance and used new techniques such as the *cryo-electron-microscopy*, comparative studies with a mouse model (*mPIEZO*) and e.g., the comparison with known PIEZO channel gene mutations. These are for example the autosomal dominant xerocystosis, the autosomal recessive congenital lymphatic dysplasia, the autosomal recessive syndrome of muscular atrophy with perinatal respiratory distress. In FIG 7 there is a schematic presentation of a PIEZO-I channel in an A closed and B open position.

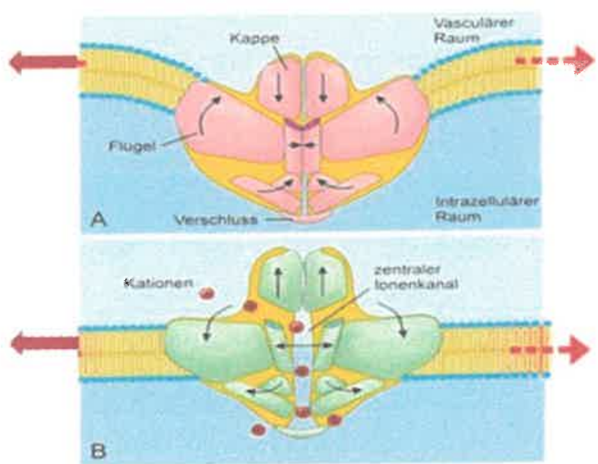

FIG 7 Schematic representation of a PIEZO 1 channel in a closed A and B open position. Graphic Bellut-Staeck

In eukaryotic cells, a plurality of ion channels is involved in *mechanotransduction* pathways. An overview is given in [24] in Tab. 9. Some do not occur as conserved structures in mammals, but in invertebrates. Some of them, *transient receptor potential channels in particular (TRP)* are not only sensible to forces, but also to chemicals, temperature, osmolarity and heat [24]. Quote page 1 [24]: "*Furthermore, most MS candidates, the TRP channel in particular, are activated not only by mechanical stimuli by but also by chemicals, temperature, osmolarity, and heat (> 27–34 °C).*" An additional voltage dependence is described from Sachs, Gottlieb and Moroni [50,51].

3.4.1. Expression of PIEZO- I and -II in multiple tissues

As a result of actual PIEZO-channel research, the following body regions and organs are apparently particularly characterized by *mechanotransduction processes* via PIEZO-I channels such as the *cardiovascular system*, the neuronal *development*, the gastrointestinal *tract*, the lung *endothelium* and the *urinary tract,* (FIG 8). PIEZO-II channels dominate in the somatosensory via Dorsal Root Ganglion, articular cartilage, balance, proprioception and pain. [24]. FIG 8 demonstrates an overview of the occurrence of PIEZO-I channels and II channels in different organs.

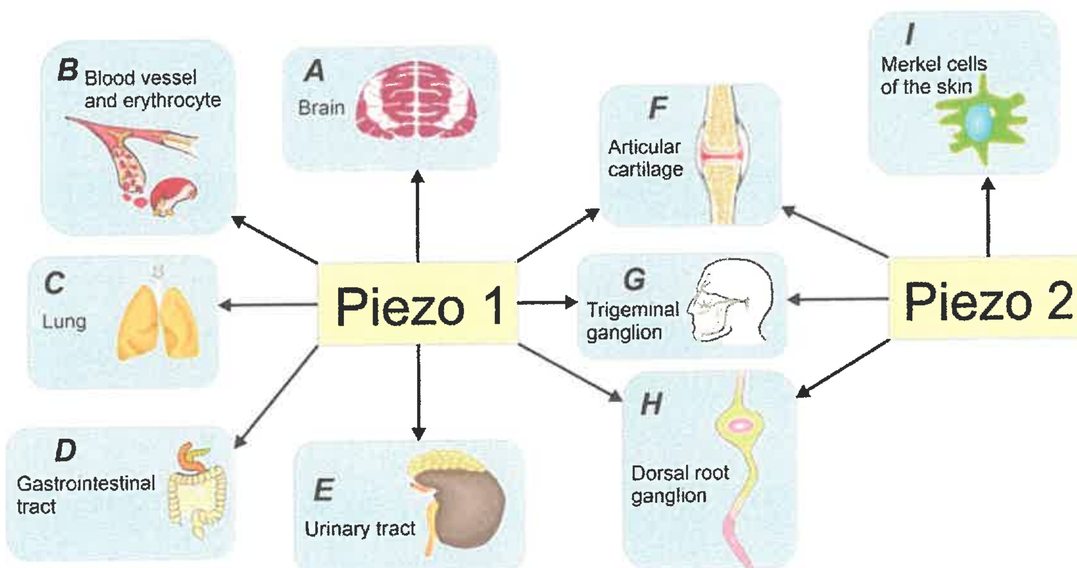

FIG. 8 After Fang⁺ et al. [24] Schematic overview: Expression and function of Piezo channels Multiple tissues and cells express Piezo channels. a–e demonstrates the vital role of the Piezo1 channel in the CNS, blood vessels, erythrocytes, lungs, gastrointestinal tract and urinary tract. f–h illustrates the expression of both the Piezo1 channel and Piezo2 channel in articular cartilage, trigeminal ganglia, and dorsal root ganglia. i shows that the Piezo2 channel is expressed in Merkel cells, which are involved in sensing light touch

The *cardiovascular system*: The regulation *of vascular tone, blood pressure and adequate provision of NO,* takes place in the classical *laminar shear stress reaction***.** The PIEZO-I channel is activated and releases adenosine triphosphate *(ATP)*. The phosphorylation of endothelial *NO-synthetase* leads to NO-production and adequate vasodilation [24,38]. PIEZO-I channels also play an important role in erythrocyte homeostasis in regulating its volume and plasticity [24]. Erythrocytes themselves release *ATP* via own PIEZO-I channels. Different manifestations of the dominant hereditary disease *xerocystosis* are incompatible with life. PIEZO-I senses whole body's physical activity to reset *cardiovascular homeostasis* and enhance performance by a *dichotomic* reaction of the endothelial cell in the mesenteric tract as answer to physical stress [49,5].

A new aspect in Fang's work is the involvement of PIEZO channels in the *baroreceptor reflex. B*oth PIEZO -I and -II channels are highly expressed in the *nodose-petrosal-jugular-ganglion complex*. Physiologically a *beat-to-beat* regulation of the blood pressure takes place. According to Fang, the knockout of both PIEZO-I and -II channels led to a fully impairment of the baroreceptor reflex [24], FIG 8. Hailin Liu et al. (2022) [52] confirm the correlation between uncontrolled overstimulation of PIEZO-I channels, usually in connection with increased tissue pressure and the development from an acute to a chronic inflammation situation. This applies, for example, to *cardiac fibrosis. In a feedback loop*, myocardial fibrosis leads to *increased atrial pressure* and *overstretching of the heart muscle* via stimulation of PIEZO-I, which in turn leads to increased Ca^{2+} -influx, *promotion of inflammation* and *proliferation of fibroblasts* with increasing fibrosis.

PIEZO- I and its role *in the endothelium of lung*: Due to an increased hydrostatic and alveolar pressure, the lung endothelium as well as alveolar cells are physiologically and artificially – in mechanical ventilation— exposed to an increased mechanical stress. There is a high expression with PIEZO-I channels in the lung´s endothelium. Proven is that mechanical stress like a mechanical ventilation is activating PIEZO-*I* and leading to an increased Ca^{2+} influx that subsequently is followed by an *apoptosis* of the alveolar cell. Conversely, mechanical stimulation of Piezo-I channels in alveolar type I cells triggers *ATP* release and paracrine stimulation of surfactant secretion that maintain lung function. According to [52], in chronic lung diseases, the increase in tissue pressure causes positive feedback on PIEZO-I channels, which exacerbates the process via pro-inflammatory pathways and via fibrosis. According to these authors, overstimulation of PIEZO-I channels which is leading to excessive surfactant formation, also tends to have negative effects on the outcome.

Organ systems with a high number of PIEZO channels outside the cardiovascular system and lung:

The PIEZO- I channel and its role *in* ***nervous system***: The discovery of PIEZO-I channels in structures of the *central nervous system (CNS)* led to research in their biophysical functions. According to Fang, the result is the transmission of mechanical forces from the environment of *the extracellular matrix (ECM)* into information that results in many processes such as cell *division, migration, morphogenesis, vesicular transport, gene expression and fluid homeostasis*. In *CNS* PIEZO-I was detected in myelinated axonal pathways (more than in demyelinated) of the mouse brain, including *corpus callosum and cerebellar* arbor vitae [24]. PIEZO channels apparently play an important role in the *neuronal development* such as the differentiation of neural stem cells into *neurons, astrocytes* ***or*** *oligodendrocytes*. Here a particular sensitivity to external forces is described. Ca^{2+}-influx, following triggered PIEZO-channels, directed the choice of neuronal stem cell towards a *neuronal phenotype*, while inhibition or knockdown of Piezo1 suppressed *neurogenesis* and enhanced *astrogenesis,* Quote Fang [24] page 12: "[…]" "*Is the Piezo1 channel also involved in astrocyte-neuron interactions that are key for the maintenance and regulation of neuronal function? An elegant study by Blumenthal et al. showed that pharmacological inhibition of Piezo1 abolished neuronal sensitivity to nanoroughness, a mechanical signal resulting from neighbouring cells and ECM molecules, and sequentially promoted the decoupling of neurons from astrocytes, thus providing evidence for the role of Piezo1 in neuron–astrocyte interactions. This information provides a clue for answering this question.*" According Liu et al., local increase of stiffness in the brain with a high mechanical sensivity of neurons and astrocytes, can lead in a positive loop to *further stiffness*. Connections with Alzheimer's disease are under discussion. Deeper insight in the original article.

PIEZO-I and –II channels in the ***gastrointestinal (GI) tract***: According to Fang, chromaffin epithelial cells are enriched in humans and e.g., mouse GI tract and produce serotonin in response to mechanical forces within milliseconds. In the submucosa, multifunctional mechano-sensors in enteric neurons have been identified. The function of the PIEZO channels, found in enteric neurons of humans and mice still needs to be investigated in more detail in [24].

PIEZO-channels in *the* ***urinary tract***: According to Fang, piezo-I channels are expressed in the overall urinary tract, including epithelial cells, interstitial cells, and smooth and striated muscle cells. The ability to sense intraluminal pressure and changes in the flow, is a crucial precondition for a proper function. A deeper insight in the original article [24].

In the cartilage, PIEZO -I and-II are apparently partly responsible for the inflammatory processes caused by increased pressure, for example as a result of osteoarthritis.

3.4.2. Mechanotransduction in plants

To demonstrate the extraordinary important role of mechanotransduction, here a chapter to plants. Like animals, plants are *living organisms* with life cycles and vital reactions to environmental stressors. In plants we find corresponding structures such as a *cytoskeleton, mechano-sensors* and *mechanotransduction pathways*. Plants, along with animals and fungi, have a cell nucleus as eukaryotes, unlike prokaryotes. A rigid cell wall surrounds the living cell substance (protoplast) with the cytoplasm and the cell nucleus. We can find structures comparable to those of animals, such as *organelles, mitochondria, endoplasmic reticulum* and *Golgi apparatus, ribosomes, actin filaments and microtubules.* [53}. The difference in plants are especially the *plasmids*, sites of *photosynthesis* and the *vacuoles*. Comparable to animals are the structure and function elements from the six basic components elements H, C, O, N, Ph, S. Correspondingly to animals, four different molecules (glucose, proteins, lipids and phospholipids) and their compositions are the main components. In plants, energy is released by hydrolysis, energy (same amount) is introduced by condensation mechanisms. Similar to animals, *actin filaments* form a complex network with *intermediary filaments* and *microtubules* in the *cytoplasm* [54}. According to [54], plants are „prestressed structures" from shape-derived stress. Due to this fact, it is more difficult to recognize the functional processes in mechanosensory perception in plants. The intrinsic and external mechanical stress cannot be differentiated so easily. The epidermis of plant aerial organs is under *tension*, while inner tissues are under *compression*. As in animals, the *cytoskeleton* is also a central principle of the plant cell's response to mechanical stress. A*ctin* seems to orient along maximal tensile stress; internal turgor pressure is the engine for the growth. The most famous genes are called the TOUCH (TCH) genes, being induced within minutes after touch [54].

About 20 different mechanosensitive channels are described in plants.

An overview to different mechano-sensors in living things is given in FIG 9.

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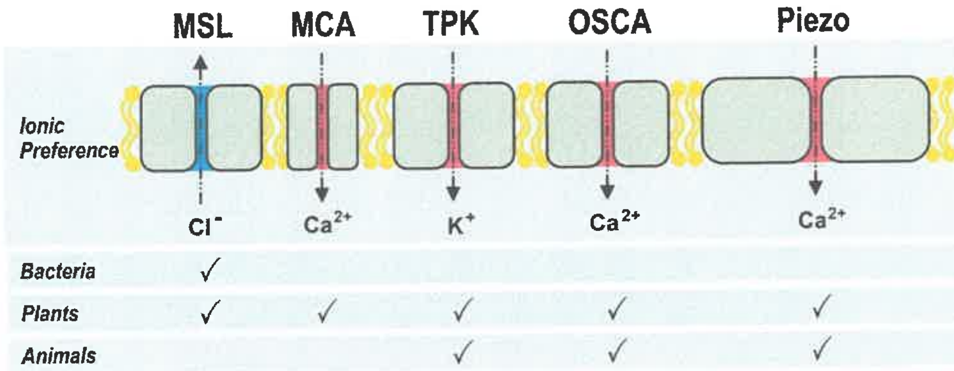

FIG. 9 Overview of different mechano-sensors after [54]. The presence of homologs in bacterial, plant, and/or animal genomes is indicated with a checkmark. The predominant ion flux is shown for each channel, but for simplicity no directionality nor specificity is shown. Shortened original description

Similar to the animal kingdom, mechanosensitive ion channels in plants are opened by lateral membrane tension and Ca $^{2+}$ -Influx in context with mechanical stimuli. The perception of pollen tube growth, hypo- or hyperosmotic stress, gravity, vibration and touch or pathogenic invasion, is assigned to the function of mechanosensitive ion channels. Drought stress increases osmolarity. A trichome is an example for the trigger hair of a *Venus flytrap*. Its deformation leads to an increase in *apoplastic* (outside cytoplasma) pH and cytosolic Ca2+ oscillations in the cells [54]. When plants are under environmental *abiotic or biotic* stress, they reduce growth not only passively, but also actively as defence. This is achieved through stress-triggered cell signalling [55]. When there is an excess of light energy, the electron transfer in photosynthesis is significantly reduced, as a stress response. Similar to the reaction in the animal world, stress *leads to increased oxidative stress* (*ROS*), H_2 0_2 and other oxygen radicals and impairs the functions of the plant [55].

Plants respond to stress. They can release fleeting chemicals to protect themselves and also others from herbivores, e.g., so called VOC`s [56], but plants can also *"cry"*. The authors [56], 2023 examined the communication of plants with their outside world via *airborne ultrasound* that could be measured and recorded in a distance of 3-5 meters. This in turn requires a kind of "hearing ability". Plants can demonstrably respond to sound, inter alia, with a change in expressing specific genes. By training machine learning models, it was even possible to differ the emitted sound in its significance and thus to assign to *drought stress or injury*. Other organisms such as moths, are able to hear ultrasound, in this way could possibly communicate, also other plants. More insight in the theme bioacoustics and limitations of the study [23].

A study conducted between 2000 and 2022 on the reduction of *plant biomass production* (PBP) within a 10 km radius of each individual wind turbine shows that infrasound could be a significant stress factor for the entire environment. The study bases on an evaluation of 2404 wind farms with 108,361 turbines and shows significant consequences for the impact on plant growth [57]. The study analysed 10 PBP indicators such as the normalized differential vegetation index (NDVI), enhanced vegetation index (EVI), percentage of tree cover (PTC), percentage of non-tree vegetation cover (PNTV) and percentage of non-vegetation cover. A buffer zone of 10 kilometers was examined. The results show a significant negative impact on PBP, even if the extent of this impact varies depending on the indicator, respectively. The greatest negative impact can be observed in the summer and fall months and in relation to landscapes that are more flat than hilly. Furthermore, the negative impact increased for three years and persisted. The greatest negative effect e.g., *EVI* could be found between one and seven km with a maximum in 2 kilometers. An Example: "*The negative impact of wind farms on EVI is significant within 1 km to 8 km, with a peak at 2 km and a maximum decrease of − 0.0088 (P < 0.001; 95% CI − 0.0128 to − 0.0047)*". Quote in results [57] The authors consider the negative impacts on biodiversity to be *considerable*.

4. Noise and Sound

Pressure is force acting on a surface (N/ m^2) and measured in Pascal (Pa). Power per m^2(watts) is the *power density*. Sound, infrasound and ultrasound propagate as longitudinal waves in *all viscoelastic materials*, i.e., the pressure changes oscillate in the direction of propagation. It is an *energy transfer*. *Audible sound* is in the range from about *20 hertz (Hz) to 20 kilohertz (kHz)*, *infrasound* is below 20 Hz and *ultrasound* above *20 kHz. Sound* differs physically in frequency and thus in wavelength. The wavelength (L) is in relation to the frequency (f) and to the speed of sound (V) in the respective medium. In general: The lower the frequency, the greater the wavelength, the lower the damping, the greater the flexural capacity of the sound. For example, sound propagation in air with a wave length of 0,1 Hz is about 3,4 km, that of 1000 Hz is about 34 mm. *Infrasound* is much less attenuated by propagation through the atmosphere as well as through roofs and walls than the *audio spectrum*. It propagates in all viscoelastic mediums, therefore also organisms. *Infrasound* is generated by heavily moving masses as well as by *resonance phenomena and vibrations*. Its exposure can be *occupational such as from the aviation industry or residential* such as from heat pumps, combined heat and power plants and as increasing factor from industrial wind turbines (IWT`*s*). *It* can be emitted from *natural* (e.g., earthquakes) or *technical sources* (cars, airplanes) or residential emitters. The sound differs in frequency, sound pressure, time/effect profile (impulsiveness) and duration, which is crucial for *the information* it has and the organism's ability to *compensate and to recover*.

4.1. Properties of infrasound emissions from IWT`s

IWT`s are a particularly far-reaching environmental factor [58]. Every time a rotor blade passes the tower, air masses of high-pressure differences are emitted, which propagate as *infrasound.* These pulses lead to several integer multiples of the determined fundamental frequency, the so-called ´harmonics´. Harmonics occur with any waveform that *deviates* from a sinusoidal wave. Since infrasound does not propagate linearly from the source, higher values can often be measured at greater distances than near the source due to reflections [59]. Due to the increasing number and size of IWTs, complaints from local residents are therefore on the rise, especially after the so-called repowering (the replacement of an IWT with a greater one) [60]. The reason is suspected of being in the increasingly lower frequency due to the increasing length of the rotor. The larger the rotor, the lower the emitted frequency. Infrasound of IWT's is meanwhile with big parts in the range of 0.2 to 8 Hz according to the authors in [61,62,63]. The infrasound emissions are impulsive in the effect/time profile according to Roos, Vahl [62] and Vanderkooy [63], as shown in FIG 10. This is an important factor for the relevance of information when comparing reactions to impulsive signals or consistent signals [44.45].

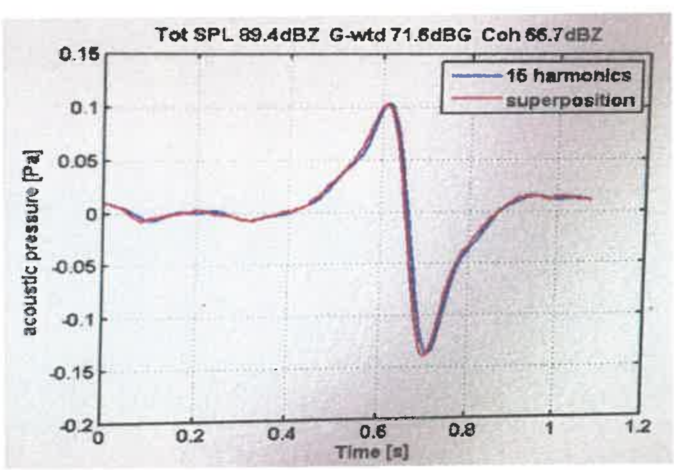

Figure 10 [63]: An infrasonic pulse extracted from the emission of a wind turbine. The fluctuations of sound pressure measurable near a wind installation usually contain noise, *i.e.*, irregular sound events of different origin. Noise removal is possible by averaging the sound pressure over a large number of mast-blade passages (here 4100), which reveals their common element (red line). The red peak thus visualized from the time sequence coincides

with the blue peak, which shows the fundamental pulse as reconstituted in the frequency domain from 15 (very sharp) harmonic lines by Fourier analysis. The result is the coherent fundamental peak of this turbine of 0.9 Hz frequency, accordant to 1.08 seconds required per blade passage. The extracted infrasonic pulse of a wind turbine shows the relation between sound pressure (P) and time (s). Original source [63]. corresponding to Figure 7 in Vanderkooy[1] J, Mann[2], R Measuring Wind Turbine Coherent Infrasound Department of Physics and Astronomy 1, Department of Computer Science 2 University of Waterloo, Waterloo, ON, Canada, N2L3G1 jv@uwaterloo.ca, mannr@uwaterloo.ca Date posted: 2 October, 2014. With permission.

Particularly in indoor spaces of buildings, interferences of airborne sound pressure and *structure-borne sound are possible*, which can lead also to relevant amplifications or attenuations of the total impacting sound [64]. The recording of the measured values must be done with suitable sound pressure levels [SPL], unweighted as shown in FIG 11.

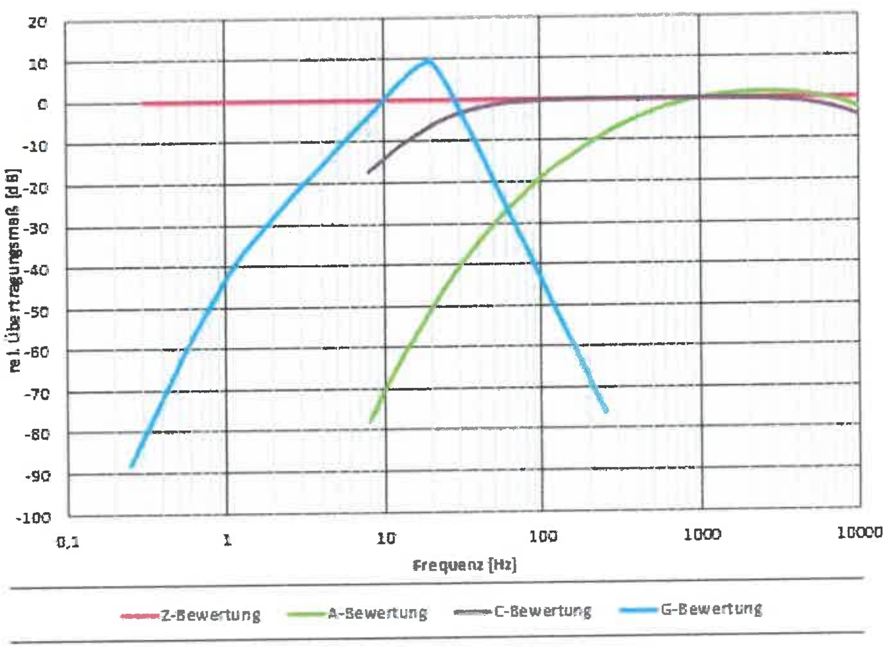

FIG 11: Typical frequency weighting curves in dBA, dBC, dBG and dBZ. Original source: Eulitz C., Zobel P., Ost L., Möhler U., Schröder M. (2020) Ermittlung und Bewertung tieffrequenter Geräusche in der Umgebung von Wohnbebauung, TEXTE 134/2020 [65]

As result in FIG 11 only the unweighted curve dBZ (red), can actually images infrasound. The G rating extends far into the infrasonic range, but with a significant loss of real sound pressure values.

The A- rating, which is suitable for evaluating audible sound, and the C- rating only extend to just below 10 Hz. The difference between the A- and C- ratings when more than 20 dB, can only indicate the presence of infrasound, not assess it.

The spectrum in FIG 12 shows that the main frequencies emissions from a IWT are below 8 Hz.

Remarks: According to the UBA (Environmental Protection Agency), the frequencies in the 30 Hz range cannot originate from the rotor blades, as the frequency difference is significantly different. It is assumed that these frequencies originate from the gearbox present in this wind turbine.

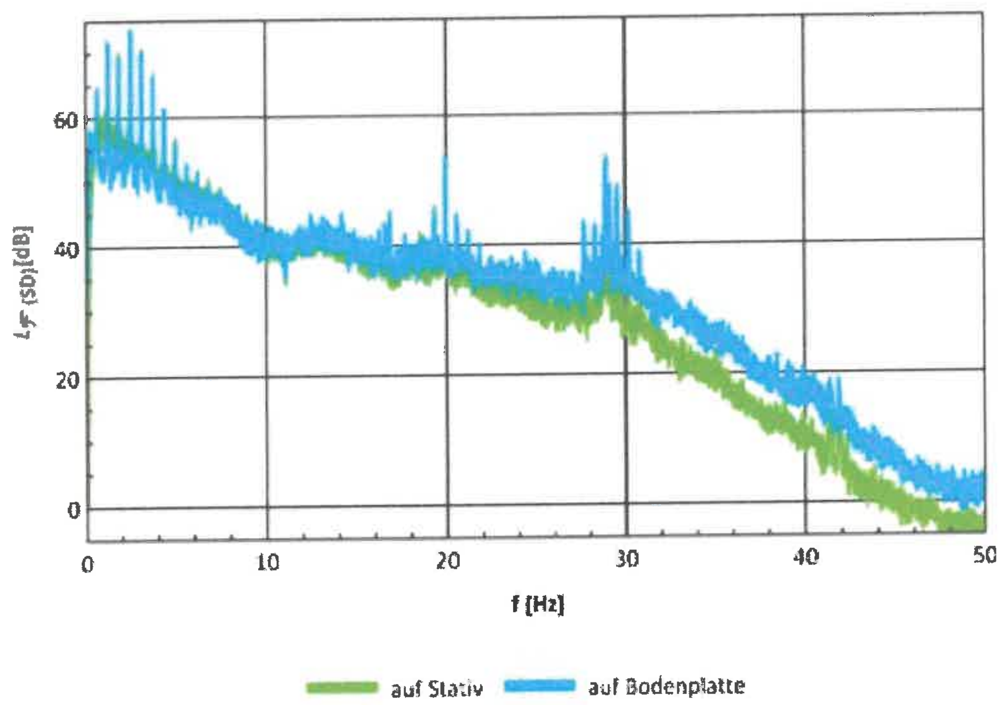

FIG 12: The following spectra are taken from: Texte 70/2022 (in English) Final Report, Federal Environment Agency, UBA Image 39: [66] Page 73

4.2. Information of an infrasound signal arises from all its qualities

Every cell interacts with its environment by exchanging *tiny quanta of energy* [59]. According to Persinger [59], it has been known for some time that living organisms vibrate in a range of mainly 6-12 Hz with amplitudes of 1-5 µm, and about 50 µm when muscles are tensed, and thus emit *sound* as a result of the fusion of all activated muscular subunits. During sleep, the amplitudes are reduced. In addition to natural sources, the environment is increasingly confronted with human-made sound waves in different frequencies, also increasing *infrasound.* At the current heights of the IWT`s above 250 meters and high rotation speed, the emitted frequencies are in a similar range to one's own body vibrations. It is known that resonances, which arise in spatial and temporal similar patterns, can lead to a significant instability of the *overall system* even with minimal stimuli.

Quote Persinger [59] page 503: "*Pure sine waves or simple time-varying patterns are found less frequently in the environment than complex acoustic and electromagnetic patterns that have the potential to mediate information between the environment and cells at very low levels of intensities. Relying on only the average intensity overtime for these sources (such as infrasound) as indicators of their importance is about as useful as only measuring the loudness of a conversation to discern its syntactic content and meaningfulness* ". Thereby the effects of impact do not require awareness [83].

Black box IWT: IWT`s with heights of 250m+ reach meanwhile verifiable a ground frequency of about 0,25 Hz. The frequency between 0,2 and 4 Hz corresponds to the slow delta waves of the brain during sleep; this could disrupt the synchronized *release of hormones and proteins* involved in repair mechanisms and disturb the homeostasis [59] inclusive the production of *serotonin* and *noradrenaline* of the brain stem. This could mean greater sensitivity during night-time sleep. According to Persinger frequencies below 10 Hz have *a high biological significance*.

Music also consists of a fundamental tone, which is overlaid with other tones in integer multiples of the fundamental frequency. As with music, the totality of information is not determined by a single characteristic, but by the interaction of all characteristics. These tones are called overtones or harmonics. Music can activate neural circuits that reach specific areas for emotions and reward. This leads to an instant improvement of the microcirculation [71,4]. An example according to Persinger of the variability of an information content: under slightly different circumstances, mundane stimuli can lead to a "disaster". According to Persinger, Murugan et al. (2013) [67] demonstrated that planarians - a type of aquatic flatworm- exposed to a specific field pattern of sound for a few hours per day, dissolved within two hours. The decisive factor was the effect over time. They dissolved when a different temporally structured field was applied on day five, but not after the first day.

4.3. Hydroacoustic

In the sea, sound propagates at 1480 m/s, which is about 4.3 times faster than in air. The pressure increases with depth; therefore, the speed of sound increases with the depth. However, it also increases with salinity and temperature. In the low-frequency range, water sound waves can be perceived over any uninterrupted stretch of water on earth. In an infinite space at a constant speed of sound, sound intensity decreases with the square of the distance ($1/r^2$) and sound pressure decreases with the linear distance ($1/r$). According to Lurton,[68] in the northern hemisphere, the background noise below the surface of the sea is now permanently characterized by a diffuse noise from ships in frequencies between 100 and 300 Hz. More insight in the complex thematic, measured quantities and reference levels in the original article.

The authors [68] examined acoustic differences between deep and *shallow waters*, which is important in regard to the location of offshore turbines (verifiable *offshore installations are anchored in the ground, from about 21 meters water depth up to about 120 meters water depth)*. It is important to note that only sound sources between *50 Hz and 50 KHz* - not the infrasound range- *were included in this study*. Quote in Chapter 6 in Katsnelson B, Petnikov [69]: *„An extremely important part of shallow water acoustics is the study of long-range, low-frequency reverberation. In particular, one is studying acoustic wave backscattering by medium inhomogeneities, which are generally separated by a distance of a few to several tens of kilometres from a sound source and receiver. [...] This reverberation, along with its main role as an undesired noise signal, can also play the role of an additional source of environmental information "*. When infrasonic sound waves are continuously emitted from *offshore wind turbines*, they will be likewise carried continuously to the next land mass in a constant repetition. So far, no studies have been conducted that look at the effects of inaudible noise in deep frequencies *on marine ecosystems*. The special hydroacoustic properties not only threaten the orientation of whales and their communication, but also their *vital functions.*

5. The Hypothesis

5.1 The paradigm shift

Effect and conscious perception must be considered completely independently of each other. [24,59,83]. The biological significance of information depends on *numerous factors*. All cells exchange information and oscillate. All organisms have a crucial level of perception via mechano-sensors. Mechanotransduction is one of the essential foundations for *maintaining structure, function and communication*. For this reason, external forces are able to cause a disruption of vital functions due to certain properties.

5.2. The Hypothesis in Detail

- Noise, when it affects organisms, is under *certain conditions in frequency, sound pressure, effect/time profile and duration* able, to lead to irregular information's on the mechano-sensor level.
- The consequences of irregular information's at the endothelial mechano-sensor level of the PIEZO channels are e.g., an inadequate NO release with an increase in oxidative and oscillatory stress as well as a lack of energy due to a disruption of the autochthonous vascular regulation.

In chronic impact this will lead to a loss of endothelial integrity with all consequences.

- With decreasing frequency, there is an increasing transmission of irregular information. This means increasing harm with decreasing frequency.
- Functional and later on structural disorders are particularly conceivable in all organ systems.
- Plants have comparable mechanisms and can therefore also be affected in essential functions by irregular information.
- Once the homeostasis of tissue pressure is disturbed in various organs, there is an additional risk of aggravation and self-reinforcement due to overstimulation of PIEZO channels everywhere they are located.
- The possible consequences might be severe, In particular for embryological, cardiovascular and neurological functions.

5.3. The Hypothesis Is based on the Evidence for

- ➢ Noise is a mechanical force, therefore subject to physical laws
- ➢ Mechano-transduction has a key role in the transmission of maintenance of structure, function and information in all living beings
- ➢ The information of a sound event arises from its complex qualities
- ➢ Low frequencies demonstrate increased conductivity in conductive structures such as actin fibres and microtubules
- ➢ An impulsive signal is more likely to be answered than a uniform signal
- ➢ The cardiovascular system is controlled and adjusted beat-to-beat
- ➢ Vital developments in the morphogenesis of the embryo are particularly susceptible to interferences not only for chemical substances or radiation, but also for external forces
- ➢ Overstimulation of PIEZO channels leads to gene expression with inflammatory mediators and thus intervene in processes of mutual reinforcement

- ➢ The low frequencies emitted by IWT`s lie within a frequency spectrum comparable to that of an animal organism, which means that there is a risk of resonance effects
- ➢ The effect of a stressor is independent of its conscious perception.

5.4. Evaluation of the Hypothesis

5.4.1. Positive Support for Evidence

Mechanotransduction which is responsible for many vital regulatory processes, has been scientifically proven [1,2,24,44,45]. Several international studies have shown that the transmission of *infrasound* is associated with verifiable stress reactions: infrasound interacts with cell metabolism and leads to perivascular fibrosis in *Infrasound induces coronary perivascular fibrosis in rats* according to Lousinha [70]. Similar findings are presented in [25,72,73]. Empiric data in experimental studies show clear indications that exposure to infrasound leads to a *ROS increase* [18,19,74]. Also, the study of Chaban et al. *indicates positive evidence by decreasing myocardial contractility of heart under Infrasound [75*] and the direct cell effect is shown in *the Effect of infrasound on the growth of colorectal carcinoma in mice* [76]. There is evidence for a direct cell and membrane effect in the review of Roos and Vahl [62]. A positive evaluation is also the *metanalysis* from Dumbrille et al. [60]: This evaluation results in the causality of *adverse health effects (ADH´s)* and the stressor in *all* "*Bradford Hill criteria*". Reported adverse effects on animals revealed not only stress reactions but also negative effects on *fertility, development, and reproduction* [76]. Positive evidence for the frequent occurrence of atrial fibrillation is presented in the "*nurse cohort study*" [78]. increased diastolic intracellular Ca^{2+} plus levels under infrasound [18,24,62]. A case study reports on a family in Ljungbyholm, southern Sweden, with a chicken farm. From 2009 to 2020, the normal hatch rate *after 21* days of incubation was at least 95%. After 12 turbines of 4.5 MW were commissioned at a distance of 950 metres, egg mortality was 100%. A direct link was established between the distance of the eggs to be hatched and the wind farm; noted by the Swedish authorities and published in a veterinary medicine journal 2024 {79]. Further positive support for evidence results from the re-evaluation of the pathohistological images from Alvez-Pereira and Branco [80,81] who examined the long-term effects of occupational exposure to infrasound and vibration in the context of the aircraft industry, known as *vibroacoustic syndrome. The pathohistological findings in FIG 13, FIG 14 and 15 confirm the effects of infrasound on cells and membranes.*

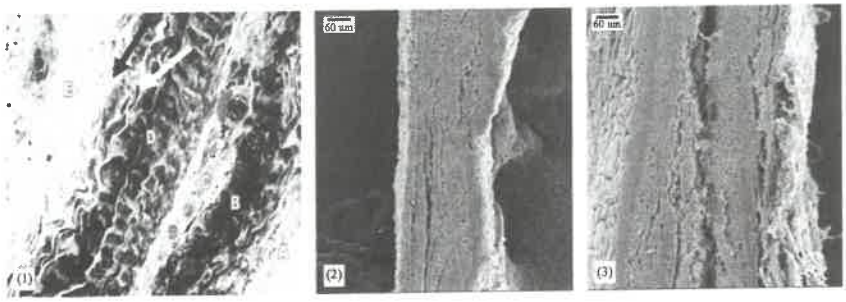

Figure 13. *Original description*: Light microscopy (100×)—VAD patient pericardium, with pericardial sac on right. Five (instead of the normal three) layers are identifiable: (A) mesothelial, (B) internal fibrosa, (C) loose tissue, (D) external fibrosa, and (E) epipericardium. The loose tissue is rich in vessels. No inflammatory cellularity was identified in any of the five layers. In both fibrous layers, wavy collagen bundles are visible, however the wave length of fibres in layer B (internal fibrosa) is smaller than that in layer D (external fibrosa). Taking together the increased amount of collagen bundles, in wavy, accordion-like arrangements, with different orientations in relation to each other, and with more than one elastic fibre accompanying the bundles at seemingly perpendicular angles (seen through electron microscopy, not shown), seems to suggest a pneumatic-like structure, designed to absorb abnormally large external forces. Similarly, this functional arrangement also explains why there is no diastolic dysfunction, despite the thickened pericardial walls. (2) SEM of non-VAD patient pericardium. Normal three layers are visible: mesothelium (white arrow), fibrosa (black arrow) and epipericardium. (3) SEM of VAD patient pericardium. Fibrosa has split into two halves (arrows) that sandwich a newly formed layer of loose tissue (L). [..]Remarks: ultrastructure micrographs, obtained with scanning (SEM) and transmission (TEM) electron microscopy. Pericardial wall in exposed and non-exposed persons 1) exposed (Light microscopy) 2) non-exposed (SEM) and 3) exposed (SEM)Alves-Pereira M., Branco C. (2007) Vibroacoustic disease: biological effects of infrasound and low-frequency noise explained by mechanotransduction cellular signalling http://www.sciencedirect.com/science/article/pii/S0079610706000927. [80] Page 11 FIG 2. With permission.

FIG 14 *Original description* (SEM) Non-exposed bronchial epithelium. The BC in the centre of the image exhibits a tuft of microvilli that are individually identifiable, uniformly distributed, and sprouting upward into the airway. Surrounding the BC are SC with microvilli of different sizes. Tufts of cilia featuring vesicles are also visible. No sheared, shaggy or wilted cilia are visible SEM). No oedema is present. *BC* (*brush cells*), *SC* (*Secretory cells*). Rat bronchial epithelium, exposed to 2160 h of continuous IFLN. With permission

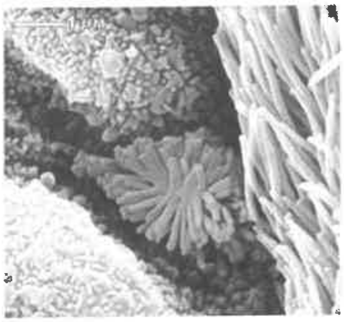

FIG 15 *Original description* (SEM) Rat bronchial epithelium exposed to 2160 h of continuous ILFN. A *BC* is in the centre of the image. Its *microvilli* are not sprouting upward and, instead, have fused, forming a central indentation that seems to be spreading outward. The prominent *SC* that surrounds the *BC* are swollen forming deep valleys at the intercellular junctions. SC microvilli are very irregular. Ciliary vesicles are visible. *Ultrastructure micrographs, obtained with scanning (SEM) and transmission (TEM electron microscopy. BC (brush cells), SC (Secretory cells).* Rat bronchial epithelium, exposed to 2160 h of continuous IFLN. With permission.

A positive support for evidence is the state of scientific knowledge in PIEZO research, which has made significant progress in elucidating *mechanotransduction`s processes* in various organ systems (24, 52). Mechanotransduction regulates essential functions such as cell *division, migration, morphogenesis, vesicular transport, gene expression and fluid homeostasis*. Both the symptoms such as increased cardiovascular symptoms, blood pressure, cardiac arrhythmias, pericardial thickening can be conclusively explained for the first time. Systematically higher MI incidences, *not case fatalities,* in rural environment, are the result of myocardial-infarction-related mortality in Germany 2024 [82]. Data collection took place between 2012-2018 nationwide for all MI incidences and case fatalities.

The study from Weichenberger et al. 2017 shows the unconscious regarding and processing of infrasound beyond the acoustic perception threshold in certain brain structures [83].

Several current studies show comparable areas of influence that speak in favour of the infrasound factor as stressor. What the studies have in common is the affected radius of minimum 10 kilometers, also in the study [57].

1) The considerable decline in plant biomass production in all indicators of the current study [57] on over 100,000 IWT shows clear positive evidence for a negative influence of installed IWT`s on plant growth. Other factors such as changes in local surface temperature or moisture content add up to the effect of infrasound, but can be differentiated by the sphere of influence of infrasound, which always remains in the same radius [57].

2) A recent study (2023) shows a significant decline (63%) in the population of seabirds a) with loons within a 10-kilometre radius after the installation of new offshore wind turbines [84] and b) with kittiwakes: 46 offshore wind turbines also had a significant impact on the kittiwake (Rissa tridactyla), used in the current study showing a 45% decline in the observed area during the breeding season [85].

3) The Impact of Wind Farms on Suicide, Eric Zou, October (2017) [86].

5.4.2. Possibly Negative Support for Evidence

In [42] there is a small sample size, but the results are based on a careful study design and consistent results. Several studies about the possible *adverse health effects* (ADH`s) of infrasound on its environment show contradictory results or do not show any effects when using infrasound. On closer inspection, the study designs and/or the used criteria, prove therefore to be unsuitable for their purpose. Investigations either used invalid frequency weightings such as dBA, were conducted *after* the impact *or* cannot reflect the influence on mechanotransduction processes because impact and measurement did not take place at the same. One example therefore is [87].

Regarding the question of the validity of computer-aided statements, we refer to Mazzag [44,45] for a detailed statement and our comment [5] regarding to this.

The current PIEZO research and vasomotion research is an ongoing process. The authors themselves point out corresponding limitations and partially contradictory results that require further research.

6. Established Methods to Assess and Visualize Microcirculatory Processes

The microcirculation can be visualized *in vivo* on new born babies via the skin, and on adults via the oral mucosa [2,14]. Appropriate techniques are video microscopy techniques such as *side stream dark field (SDF)* imaging [14]. A further visualization of vasomotion *in vivo* has become possible [15]. The *microcirculation* in the context of diseases can be visualized and quantified immediately after exposure to the stressor, as well as in its absence. Parameters that are be specifically observed, include:

- *The intact vasomotion in the first order*
- *An instantaneously changing in vasomotion under a defined stressor effect*
- *The functional blood vessel density (FVD) (mm/mm2)*
- *The red blood cell flow velocity (RBCV)*
- *The number of perfused capillaries (N/A) (n/mm^2)*
- *The capillary vessel diameter (DM)*
- *The glycocalyx thickness in nm (conceivable for further research projects)*

7. Proposed Research Avenues and Questions Regarding Target

- Direct experimental verification of endothelial mechanotransduction in on/off setting under impact with different low frequencies and different sound pressure
- Clarification of the issue, which sound pressure is required at a certain frequency to obtain a transfer response? Based on this: Below which frequency does a *particular danger for all living organisms exist (we call it a threshold frequency)*?
- What role do resonance effects play?
- Evaluation of pathohistological effects after longer exposition and increased markers for inflammation in the blood of mammals

8. Discussion

The information of a sound depends on its complex pattern, as well as its temporal occurrence. Low frequencies encounter particularly high conductivity in organic structures, which may be a reason why low frequencies below 10 Hz *have a particularly high information content.* Research results show an increasing transmission of infrasound through *actin filaments and microtubules* depending on the *depth of its frequency*, even to cell nuclei. It remains to be demonstrated that the transduction, as already calculated, leads to an increase in irregular information as the frequency decreases. This would mean an increasing incompatibility with foundations of life.

Many studies have already confirmed the stress effects of low frequencies and interactions with cellular structures and membranes.

The conversion into *partial irregular information* and a possible *overstimulation of PIEZO channel is a further logical and compelling step.* Since the frequencies of conventional IWTs are in a comparable range to the body's own frequencies, harmful resonance effects cannot be ruled out, in particular, interferences with the body's own hormone and protein production during sleep.

Much research is still needed to clarify the significance of *mechanotransduction`s processes* in individual organ regions, however the ongoing PIEZO channel research demonstrates already a high sensitivity to uncontrolled external forces esp. during embryogenesis, in the growing organism as a whole, in the cardiovascular system and in the neurological system according to its equipment with PIEZO channels.

It is state of the art that inadequate NO supply leads to an increase in *oxidative and oscillatory* stress which is an important prerequisite for the *loss of endothelial integrity* and consequently for all endothelial functions with consequences such as blood pressure increase, inflammation, arteriosclerosis, myocardium fibrosis, cardiac arrhythmia, myocardial infarction, stroke, infertility, immune deficiency and possibly cancer.

Over-additive effects must be taken into account, e.g., the possibility of an impact with alkylating substances and the already reduced resilience of the redox system under increased oxidative stress.

The shift in the inflammatory balance towards fibrosis in the event of increased tissue pressure and overstimulation by PIEZO channels in the direction of myocardial or pulmonary fibrosis, therefore takes on new significance in connection with mechanotransduction`s processes.

9. Conclusion

An organism can be viewed *both mechanically and energetically. Every atom vibrates.* Communication takes place through the *exchange of energy and forces*, which forms the basis for the *maintenance of structure and function* both within an organism and within a biosphere. The principle of undisturbed *mechanotransduction* is a fundamental prerequisite for all life functions.

The possibility of infrasonic frequencies being transmitted to mechano-sensor levels, is highly evident.

Depending on the individual's ability to compensate, exposure to a chronic stressor such as impulsive and periodic infrasound must lead to an exhaustion which manifests first in functional disorders of the substrate and oxygen supply, later on in an increasing loss of endothelial functions. New knowledge in a clinical context can contribute to behavioural changes e.g., awareness of high sensitivity to external forces, especially in the first trimester of pregnancy during *vasculogenesis* where a random event can have significant effects according to the stochastic principle. Another example is the risk of a workplace with vibrations and low frequencies that could aggravate cardiovascular diseases. Recent studies indicate that *humans, animals and plants* within a radius of *at least* 10 kilometers can be harmed by far reaching emissions through IWT techniques.

Since all organisms are equipped with mechanosensory systems, a further increase in far-reaching low frequencies in open-air and open-water situations is likely to pose a major *threat to biodiversity* as *a whole*. Marine ecosystems and also whales and dolphins are particularly vulnerable to low-frequency emissions from offshore installations due to the specific properties of hydroacoustic. It must be assumed that insects, bees and other pollinators are also affected which would mean a potential threat to a further fundamental basis of life. Urgent questions arise, such as the connection between the increase of cardiovascular diseases and neurological disorders, the decline of fertility, the decline in insect and bee populations and the plant biomass reduction in the affected surroundings. The common denominator is with high evidence *malfunctioning mechanotransduction`s process.* Appropriate preventive measures should be taken now, as stressors are currently present in the home environment well as open-air and open-water situation before all scientific questions are clarified. Sensitive groups must be the benchmark.

10. Acknowledgements

I would like to thank Christian Lehmann, PhD, MD, FRCPC, Department of Anesthesia, Pain Management & Perioperative Medicine , Faculty of Medicine, Department of Microbiology & Immunology , Department of Physiology and Biophysics , Department of Pharmacology, Dalhousie University, Halifax, Nova Scotia, Canada for his critical review and constructive contributions. I would also like to thank Manfred Krueger, graphic designer, Berlin for graphic FIG 2,4,7,8,9.

11. Disclaimer

For the author there are no conflicts of interests. The author would like to clarify that: Alternative forms of renewable energy are considered as worthful additions at suitable locations. The data reported herein have been scrutinized under one, and only one agenda, that of pure scientific inquiry. There are no commercial, financial or professional agreements.

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Setback Recommendations Per Various Studies

Name of Study	Date of Study	Author(s)	Link to Study	Author's Advised Setbacks	Notes
Wind Turbine Syndrome: A report on a natural experiment	**2009**	Dr. Nina Pierpont	N/A, PDF provided	**Setbacks from residences should be a minimum of 2 kilometers or 1.24 miles, but 2-3 miles in hilly terrain**	PDF provided to Planning Commission and BoCC
Your Guide to Wind Turboine Syndrome...a road map to a complicated subject	**July 2010**	Calvin Luther Martin, Phd	N/A, PDF provided	**Setbacks from residences should be a minimum of 2 kilometers or 1.24 miles, but 2-3 miles in hilly terrain**	This is a summary of Dr. Pierpont's book PDF provided to Planning Commission and BoCC
Health Effects of Wind Turbines: Testimony of Ben Johnson versus MidAmerican Energy (Madison County, Iowa) / Hearing before the Madison County Board of Health	**August 2019**	Dr. Ben Johnson, M.D.	https://www.masterresource.org/wind-turbine-noise-issues/health-effects-of-wind-turbines-testimony-of-ben-johnson-versus-mid-american-energy-project-in-madison-country-iowa/	**No recommendation given for a specific distance in this hearing. Afterwards the Madison County Board of Health passed a resolution recommending that any future turbines be built at least 1.5 miles from non-participating homes**	PDF provided to Planning Commission and BoCC
Wind Turbine Noise and Human Health: A Four-Decade History of Evidence that Wind Turbines Pose Risks	**Ocober 2016**	Professor Jerry L Punch and Professor Richard R James	https://hearinghealthmatters.org/wp-content/uploads/2023/03/16-10-21-Wind-Turbine-Noise-Post-Publication-Manuscript-HHTM-Punch-James.pdf	**Setbacks from residences are recommended at 1/2 mile to 2.5 miles, 1.25 miles is most favored by scientists.**	PDF provided to Planning Commission and BoCC
Infrasound from technical installations: Scientific basis for an assessment of health risks	**July 2021**	Dr. Werner Roos and Dr. Christian Vahl	https://www-asu--arbeitsmedizin-com.translate.goog/wissenschaft/wissenschaftliche-grundlagen-fuer-eine-bewertung-gesundheitlicher-risiken-infraschall?_x_tr_sl=de&_x_tr_tl=en&_x_tr_hl=en&_x_tr_pto=wapp	**Minimum setback from residences should be 10 X turbine height as in Bavaria Germany**	PDF provided to Planning Commission and BoCC
Assessing Adverse Health Effects-(Confirmed and Potential) from Industrial Wind Turbine Noise Emissions / Power point slides of presentation before the Kansas State Legislature	**2022**	Dr. Ben Johnson, M.D.	https://www.kslegislature.gov/li_2022/b2021_22/committees/ctte_s_utils_1/documents/testimony/20220207_01.pdf	**Setbacks of 1.25 miles from residences**	PDF provided to Planning Commission and BoCC
Presentation before the Kansas Senate and Utilities Committee: Effects of Wind Turbine Noise on Human Health	**2022**	Prof Jerry L Punch	https://www.kslegislature.gov/li_2022/b2021_22/committees/ctte_s_utils_1/documents/testimony/20220208_02.pdf	**Setbacks of 1.25 miles from property lines (specifically) should be considered**	PDF provided to Planning Commission and BoCC
Wind Turbines: Vacated/abandoned homes - Exploring participants' descriptions of their personal views, effects on safety, security, trust and social justice	**Dec 2023**	Carmen Marie Krogh, Robert Y McMurty, W Ben Johson, Jerry L Punch, Anne Dumbrille, Mariana Alves-Pereira, Debra Hughes, Linda Rogers, Robert W Rand, Lorrie Gillis	https://journals.lww.com/endi/fulltext/2023/08040/wind_turbines__vacated_abandoned_homes___exploring.2.aspx	**Residents living within 10 kilometers/6.21 miles of industrial wind turbines were documented having Adverse Health Effects**	See page 96 for the conclusion of the study regarding setbacks. PDF provided to Planning Commission and BoCC.
A fundamental basis for all living creatures, mechanotransduction, is significantly endangered by periodic exposure to impulsive infrasound and vibration from technical emitters - in particular cardiovascular and embryological functions	**June 2025**	Dr. Ursula Bellut-Staeck	https://www.scirea.org/journal/PaperInformation?PaperID=12440	**Setbacks of 10 kilometers / 6.21 miles from people and animals**	NOTE: The link shows the abstact and allows you to download the PDF PDF provided to Planning Commission and BoCC
Separating Myth from Fact on Wind Turbine Noise	**October 2025**	Prof Ken Mattsson	https://www.youtube.com/watch?v=nDwsd32SDEY	**Setbacks of at least 5 to 10 kilometers (3.1 to 6.2 miles) from residences**	Transcript PDF provided to Planning Commission and BoCC
Efficient finite difference modeling of infrasound propagation in realistic 3D domains: Validation with wind turbine measurements	**Feb 2026**	Ken Mattsson, Gustav Eriksson, Leif Persson, Jose Chilo, Kourosh Tatar	https://www.sciencedirect.com/science/article/pii/S0003682X25006280?ref=pdf_download&fr=RR-2&rr=9a872537bf69df1b	**No specific distance given, see notes for conclusion of study**	Conclusion of study page 14: This study also shows that modern, large-scale wind turbines generate infrasound levels substantially higher than those reported for older, smaller turbines / PDF provided to Planning Comm & BoCC

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https://www.youtube.com/watch?v=nDwsd32SDEY 8-Oct-2025

Transcript: Professor Ken Mattsson on Infrasound

My name is Ken Mattsson. I'm a professor in scientific computing at Uppsala University. I have some important things to say that I feel deserve more spreading in the world, and that is this issue about infrasound. Wind turbines emit a lot of infrasound, and the authorities and the industry claim it's harmless. I've seen the opposite. We really need to stop and investigate how dangerous this infrasound is.

Infrasound can potentially spread at least ten kilometers at levels that have been proven to affect people. So I would say a safe distance is most likely five to ten kilometers at least. In animal studies, they've seen that animals move more than five kilometers from wind turbines, which is a strong indication that they don't like infrasound.

We have measurements where people live only six hundred meters from new, modern wind turbines. I should also say that the larger you build them, the more infrasound you will get — and that's something the industry doesn't want to talk about. What I'm saying is: make a real study where you actually test the levels that we record. They are quite high.

I will demonstrate what we have done, what levels we have measured, and also provide some references to new research showing that infrasound affects people well below what you can hear. This is an important message, so please share this data I show you with others — local politicians, authorities, anyone you know. I think this deserves much more attention.

[2:27]
This is a short CV, mainly for the industry, because they believe that I'm a prophet against wind turbines only — and that is not true. I've been working since 2018 as a professor in scientific computing at Uppsala University. I did my PhD in Uppsala, and then worked a few years at Stanford and NASA on air acoustics, jet engines, rockets, and helicopters. I also worked at the Swedish Defense Research Agency with underwater acoustics, developing methods to detect submarines, for example. After that, I spent a year working at a nuclear power plant.

I'm definitely not against green energy, but my personal experience has made me increasingly critical toward wind turbines. My views are based on facts, not ideology or belief.

In physics, there are many types of waves, and that's what I've been working on for 25 years — partial differential equations. The first two are the Schrödinger equation and the Dirac equation. The new Nobel Prize in Physics was actually awarded for work related to these equations, and I've done research on similar topics, including tunneling effects. I could spend a whole lecture talking about that, or show you some of the fascinating effects from quantum mechanics.

I've also done simulations involving what are called Boussinesq equations, or solitary waves — a tsunami is an example of a solitary wave. And I've worked on Einstein's equations as well. Out in space, you have something called gravity waves, which are also very interesting. But most of my work has focused on acoustic waves. I'd say the majority of my research has been in acoustics, which is a type of partial differential equation — that's what I specialize in: how to model reality using PDEs and how to solve them.

The acoustic wave equation, which forms the foundation of acoustics, is central to that work. If you're interested in acoustics, you have to solve the wave equation — and that's exactly what we've been doing. We use a method called SPT-SUT, which is a finite difference method. You don't have to worry about the technicalities, but it started in 1974 in Uppsala with Professor Engquist, continued with a PhD student there, and then another PhD student in 2004 — that was me. Since then, we've published about forty papers on this topic.

[6:01]
I just want to briefly mention that there is a distinction between the *generation* of sound and the *propagation* of sound. The generation of sound is very, very complicated — to model it, you have to solve something called the Navier-Stokes equations, which is extremely difficult. Then you have the propagation of sound — once it's generated, it travels outward. That part is much simpler, and for that you can use the acoustic wave equation.

What we do is assume that we know the source — in this case, the wind turbine — and how much sound it generates. That's our model. Then we can simulate how that sound spreads through the atmosphere. The key point here is that both the generation and propagation of sound are *highly affected by atmospheric conditions*. I'll show you some examples of that.

One of the biggest lies from the industry is the claim that turbines aren't very loud — they say each has a sound power level of 105 dBA, and that it's constant. That's a big lie. It's not constant. It can vary by more than 20 decibels within a single day, and I'll show you results to prove this. The biggest uncertainty in all of these models is the sound power level itself.

When you look at the simulations provided by industry, they often use data from manufacturers — for example, from Vestas — describing how much sound a new turbine emits. When that data is put into simplified models, it produces contour maps: here's 40 dBA, and since no one lives inside that contour, they conclude it's fine to build. But there are many uncertainties — first, how much sound is actually generated, and second, how it propagates. In both cases, the results aren't very reliable.

Here's an illustration I often show my students. This is a volcano. I've actually done research on volcanoes and infrasound, so this is connected to my work. It demonstrates both the generation of sound — for example, from the eruption — and the propagation of sound through the atmosphere.

One of my main motivations for studying this came about fifteen years ago: traffic noise. At that time, I was working at the Swedish Defense Research Agency on methods to simulate underwater acoustics. We came across some very simplified models, like NOC 2000, which I'll talk about more later. We tested them — and they didn't work at all. In Sweden alone, traffic noise costs roughly seventeen billion kronor annually due to cardiovascular disease and reduced productivity, not to mention the decrease in property values and other impacts.

When it comes to wind turbine noise, it's treated differently; there are separate rules. This is something I presented to the Swedish Environmental Protection Agency in 2012. We did a careful evaluation of these simplified models. The blue line here represents our model, which we can prove is correct. This example was a benchmark problem where we compared our model to two different parabolic-equation methods published in 2010, and the results were quite similar.

Then we compared those results to ray-tracing methods — highly simplified approaches that assume sound behaves like rays, which is only valid for high-frequency sounds, around 1,000 hertz. In this benchmark case, the source was a helicopter at 50 hertz — a low-frequency sound. The terrain in the model includes small hills, and what's shown is the *transmission loss*, meaning how much the sound is reduced as a function of distance.

[11:43]
You see, these ray-tracing methods don't work at all. I spent four hours with three of my PhD students trying to convince the agency not to use Nord 2000 for low-frequency sound. They didn't want to listen. We met with them again three years ago, and they still didn't want to listen — they never will. This is clear proof that the Nord 2000 method, which is one of those simplified models, doesn't work.

A colleague of mine at the university did long-term measurements on wind turbines back in 2014 and proved that the Nord 2000 model fails when compared with real-world data. It consistently underestimates by roughly five to seven decibels at one kilometre distance.

Now, let's talk about infrasound. Volcanoes emit large amounts of it, and by detecting that infrasound, you can model a volcano and even anticipate when it might erupt — just by listening for those deep, inaudible vibrations. Nuclear explosions also generate significant infrasound, as do high-speed trains and wind turbines.

There is a global infrasound network called **CTBTO**, which monitors nuclear explosions and other atmospheric phenomena. One of the network's stations is located in Norway, in Älvbyrum. We've been there twice. The people who operate those stations truly understand infrasound and how to measure it properly. Unless you've been there and calibrated your own instruments against theirs, you can't measure it accurately — and as I said, we've been there twice.

[13:55]
And the careful calibration. So, you're all familiar with electromagnetic waves — and how we give them different names depending on their frequency: radio waves, microwaves, up through X-rays and gamma rays. These are all electromagnetic waves, just at different frequencies. The visible spectrum — what we can actually see — is just a very narrow part of that range.

When it comes to acoustic waves, we have a similar situation. There's audible sound, which is roughly between 20 and 20,000 hertz. Then there's *infrasound*, which is everything below 20 hertz. You can't hear it in the normal sense — you can only sense it. And then there's what's called *low-frequency sound*. In Denmark, that's defined as 10 to 160 hertz; in Sweden, about 31 to 200 hertz. It's something you can partly hear, but infrasound, you primarily *feel*. Some people can hear it faintly, but for most, it's a physical sensation rather than an audible one.

There are many human activities that generate infrasound, and many natural ones as well. Volcanoes, as I already mentioned, produce strong infrasound, but so do tornadoes, storms, and earthquakes. Even meteor explosions and the northern lights can create infrasound. Some animals also communicate using these very low frequencies.

However, infrasound from wind turbines is very different from natural infrasound. This is what it looks like when you measure it — pressure as a function of time. It appears as a series of implosions, because every time a turbine blade passes the tower, there's a pressure drop — an implosion. In the frequency spectrum, it looks like a pattern of small explosions or implosions. This is *not* what natural infrasound looks like — not at all.

You can't hear infrasound from wind turbines, but that doesn't mean you can't perceive it. If you could hear it, it would be like a dripping faucet — that irritating, repetitive sound that keeps you awake at night. Natural sounds like ocean waves, by contrast, make you *want* to sleep with the window open. I think that's a very fitting comparison — though I'm not sure of the right English word for it.
(Transcriber's note: He appears to be searching for the word "analogy.")

[16:39]
This was a really good YouTube video that came out a few years ago — *Infrasound Affected by Industrial Wind Turbines.* It's about people who have done extensive work in this field, and in this particular video. These are some of the common questions I get, such as: how is infrasound generated, how far can it travel, how much of it is lost into the ground and the atmosphere? I'll show you that. Also, how it interacts — how it penetrates buildings and affects people — and then, how important the atmosphere is, not only for propagation but also for the generation of these sounds.

If you want to answer these kinds of questions, you have to simulate everything with *extreme precision*. And that's exactly what we've done. The solution is something we call **SoundSim 360**. It's a software system that is very, very accurate and can solve many types of problems in acoustics. It represents about twenty-five years of research, so it's not something trivial you could develop using AI. There's real physics built into it.

Now, these are some of the challenges in infrasound research and regulation, including low-frequency sound, not just infrasound. The biggest challenge, I think, is the resistance from both industry and authorities to absorb the research that already exists. They simply don't listen. What's particularly odd is that they still use **dBA measurement** for low-frequency sound — I'll explain what that means in a few slides.

Much of this depends on the **Nord 2000** model. In Denmark, they use something even simpler, called the Danish model — just a basic low-frequency model. We have something similar in Sweden, called the **Naturvårdsverket calculation model**, an ISO-based approach for low-frequency noise with many parameters. Nord 2000 is also based on low frequency with numerous parameters — and depending on who uses it, you can "tune" it. You can get almost any result you want, which makes it very user-dependent.

Authorities also claim that you can't measure infrasound — that it's not possible to measure this kind of sound. They say, "We don't believe in that; we only believe in Nord 2000 simulations." That's a real misuse of science — a distortion of research.

This next example is from a conference paper. It involved two 2-megawatt turbines located near a house, about 650 meters away. The person living there complained about it — which, of course, made him unpopular and dismissed by others: "No, no, no, it's all in your head." But the researchers, **Tomas and Bertil**, carried out long-term measurements. First, they wanted to establish the background noise — the levels when the turbines were turned off. That background was between **30 and 35 dBA**.

[20:49]
Roughly. So this is a two-week measurement. I don't know if you can see it, but if you follow this green line here, that's the dBA variation over the two-week period. This line here is the legal limit — forty. Almost all the time, the levels are much higher. Up here, it reaches sixty. You can see the variation clearly — how the sound levels change with time. And this is a legitimate measurement.

Since they were allowed to build this, Nordproducer must have said that it was well below forty. But it's *never* below forty. Well — here. This is from January, six o'clock in the evening at **Lagerstorp**. You can see the meter up there — it's close to sixty. And this measurement was done correctly: shielded from wind and everything.

This next one is half an hour later at **Snyggebo**, also where people live, one kilometre away. Notice the light as well — imagine living here. The first thing I reacted to was actually the light. But it's sixty decibels — sixty dB. You hear this pulsating sound. This isn't the infrasound; this is something called *amplitude-modulated sound* that happens in the evening. It's sixty. The difference between thirty-seven and sixty, if you understand decibels, is enormous.

All right — so this is a simulation that we did based on those measurements. According to Nord 2000 here, it gave thirty-seven point six at these two locations. But if we put this into our own software and use the real atmospheric data from that exact time, to match the data the sound power level has to be one hundred twenty-eight decibels — not one hundred six — to fit the data.

The atmosphere does affect propagation, but not that much. It might add about five decibels, but not twenty-five. The rest comes from the source. So these turbines aren't generating one-oh-six at that time — it's one-twenty-eight. And he did some measurements earlier that same day — then it was around forty-two or forty-three. So it can vary *a lot* during the day.

[24:17]
Okay, that was all. This is the building where we are sitting. I'm sitting here. This is Ångström, Uppsala University. We had a rock concert here in August, so we wanted to simulate that. This is 50 hertz. I just want to mention the physics here. If you want to simulate this, you really have to simulate it correctly, including the buildings, the ground, and the atmosphere. We have something called diffraction. Low-frequency sound bends around the corners. It also bends in the atmosphere. If you don't get that into the model, you can't simulate it.

Okay. We made a comparison with Nord 2000. In Sweden they have decided to use Nord 2000 for everything. This is 31 hertz. Here you see the sound levels. The dark areas are the buildings. The sound is two meters above the ground. Look at the difference here — here and not here. Nord 2000 has no diffraction. This is 63 hertz, low-frequency sound. Low-frequency sound is completely off. This is the difference. The sound is lower than Nord 2000. Red means more than 30 decibels error — too little. Blue is 20. Here you see the effect of using a good method. Near wind turbines, there aren't so many houses. Here it's more objective why it doesn't work.

This is indoors — 200 hertz, 50 hertz. You can see 50 hertz through doors and openings in doors. This is the building where we are sitting. Here we put the source outside — 1 hertz, 100 hertz. One hertz is very relevant when it comes to wind turbines. This is transmission loss — how much of the sound is reduced. You can't see the doors here. Infrasound just goes through. There are no protections against it.

This is a submarine outside Gotland. I want to show that you can also do sound in the sea. It's very important to include the sediments at the bottom, because the sound also goes down into the seabed. This could be ships, boats, wind turbines in the sea. They generate a lot of infrasound and low-frequency sound. The reason we wanted to develop a meter was to validate the model — to make sure that it's correct. You have to do that against measurements. So we went out to make measurements.

[28:23]
With this equipment, it's called LeadStrom. This is a highly accurate piece of work. It can measure infrasound only down to one hertz. So we took this to DTU to have it calibrated against their Hyperions. So it's very accurate at one hertz. Unfortunately, it cannot go below one hertz, and the highest levels are below one hertz. But then you need even more accurate equipment, like Hyperions, and we have bought two of them. And yesterday we

did the first measurement with them, so I actually had time to put it on the last slide. So it's really new.

All right. So this is what the Swedish Environmental Protection Agency says in 2025: no special models are needed to calculate the infrasound from wind power, and this has been found in several studies to have no impact on humans. And then they list their references. Two of the references are to their own reports, and these reports are not scientific reports — they're like, you can't even see the data.

Here are two real articles, eleven here. If you read this, it's like — yeah, it doesn't say anything. "Available scientific research does not provide a definite answer about the question whether wind turbine sound can cause health effects which are different from those of other sound sources. Wind turbines do stand out because of their rhythmic character, both visually and aurally."

This study has not done measurements. There are no medical studies — it just goes through old studies. Then there's this Finnish study that they like to show, saying it's the proof that infrasound is harmless. Okay, what did they do? For ten minutes, they exposed roughly thirty people to seventy-three-decibel infrasound at one hertz — seventy-three decibel. In total, if you sum everything up, it's ninety decibel — for ten minutes. Håkan was not invited to that study.

Here are some more references that I dug up, but I'll leave that for Håkan. An interesting study is from 1985, where they actually did some testing on humans. They found that ninety-five-decibel infrasound hit pressure. Then there are some new studies that show between eighty and ninety decibel, the brain picks this up, even though you can't hear it.

[32:13]
So those are really interesting studies. And I should mention that in this report, the people who did these measurements got sick while doing them — they got really sick. The same thing happens to me and Kourosh when we go out. That's the reason why I'm standing here. Every time I go out and measure infrasound, I get sick. The day after, I get a terrible migraine, and then I can't sleep for a few days. That's when I started to think, well, okay, some people say that infrasound can be dangerous or affect people. And then I found this out through Håkan. And after that, I started to dig into the literature.

Every time I go out and measure, the same thing happens. So for me, this isn't a belief or a religion — I *know* it affects people. Not everyone, but it definitely affects me and Kourosh and some others I've spoken to. They report the same thing. So for me, it's a little bit personal. Otherwise, I wouldn't be standing here talking about it.

Okay, so here are five serious deficiencies. What needs to be done is a study that actually exposes people to the *true* levels. And it has to involve many test subjects — not just thirty, but probably a thousand. You also have to include someone like Håkan in the study, someone who knows about the brain. You have to include people who are migraine-sensitive. And it has to be *long-term exposure* — not ten minutes. That's ridiculous.

Also, the infrasound from wind turbines is *pulsating*. It's not natural infrasound. Personally, I believe it's that pulsating nature that makes it affect us more than the actual level — that's my personal belief. And in many of these studies, you see higher levels indoors than outdoors because there are vibrations involved too. So this is probably very complicated. Okay.

[34:58]
So this is from one of the measurements in December. It was very cold and very windy. This is a wind farm in Målaberget — twenty-seven turbines. You can see a few of them here. Here's the equipment — we have four of these LeadStrom units, and this is a windshield. This is what a windshield looks like for infrasound. It's made of metal.

All right, this is from a measurement we did in October last year. We captured the moment when they turned the turbines off, because the industry says you can't measure it — that you're only measuring the background. Okay? So this is when it's *on*. What you see here is the amplitude of the sound, roughly speaking. Then they turn them *off*. And this is when they're *off*. On, off — in the same recording.

These are the decibel levels for off and on. So yes, it *is* the wind turbines that generate the infrasound. You have seventy-eight decibels at one hertz from just the wind. And in their Finnish tests, they exposed for seventy-three. But when the turbines are on, it's ninety-nine decibels at one hertz. That's a big difference — twenty decibels. So yes, infrasound is caused by wind turbines, but you also have some infrasound from the wind itself — just much lower, much lower.

Okay, so this is something called "Peshband," which is how you represent sound sometimes in frequency bands — one hertz up to twenty hertz — showing how much energy you have in each frequency band. So you have on and off, and then you can decide how to represent those levels.

You have something called dBA, dBC, dBG, and then you have something called dBZ, which is with *no weighting* — it's just like dB. So if we sum all the infrasound from one to twenty hertz, we get one hundred six decibels when they're on and seventy-nine when they're off.

In dBA, that becomes twenty-two when on, and minus two point eight when off. So you can trick the numbers by using different weightings. But this dBA — if you look at, for example, one hertz, how much do you remove when you do the summation? You remove one hundred fifty. So if the wind turbine emits one hundred fifty, it becomes zero. That's how it works.

So dBA — you can't use it for low-frequency sound or infrasound. dBC isn't very good either. dBG is often used, but it's also not good for really low infrasound. It's useless.

[39:09]
That doesn't say very much. So, yeah, don't use that. So this is from the measurement — the first measurement we did at Målaberget 1. These are the measured values. Here are two locations where we did the measurements — measurement and calculation. So there's a deviation between what we measure and what we simulate, around two decibels.

Here we have a resident — I spoke with him. He's not feeling well, and he's very worried. Here he has around ninety-five decibels at one hertz. So everything here is at one hertz. One year later, we have two different locations — again, measurement and calculation — and here the deviation is around one decibel. So I would say that's quite good, considering there are some uncertainties.

Okay. So what we do is measure, then take the real atmospheric data from that exact time and feed it into the model. Then we look at how much sound is emitted from each wind turbine to fit the data. If we really solve the physics accurately, we see that the sound level here is around one hundred fifty-four decibels; here it was one hundred fifty-five. This was in October last year. This one was in December, two months later. We measured one hundred fifteen instead of ninety-nine.

Here it was much higher — it was windier, it was cold, so yes, much higher. Here you can see the wind level; it was also blowing hard. And here you can see the atmospheric effects — the sound propagates in the direction of the wind. The box to the right shows much higher levels because of the wind effects.

Here you can look at night and day — typical day, night, and day. This is the day; this is the night. What happens is that the atmospheric layers are compressed — that's physics. This is also the reason why you get this amplitude-modulated sound in the evening. When the blades pass through these layers close to the ground, you get this disturbing sound. When you see something like this, it means that the sound is bending down. And here, it bends down even more.

[42:32]
Here we see an effect at 1 Hz, 5 Hz, 50 Hz, 500 Hz. This is a wind turbine, 120 meters long.

Here we use the assumption that the water level is the same for all frequencies — not in reality, just to show the effect of the ground and the atmosphere. Here we use a real atmosphere, day and night atmosphere, 8 meters per second. This is how the sound at 2 meters above the ground looks — how much is lost. This is infrasound — it's not lost very much. The yellow is 500 Hz, so after 2 kilometers it's more or less lost. For example, when you have this night atmosphere, you get this kind of spreading. So day atmosphere, night atmosphere with more wind — it becomes quite different how the sound spreads and how much is lost. You have losses in the ground and in the atmosphere.

This is how the sound looks if you visualize it. This is 5 Hz, this is 50 Hz. At night the sound is trapped, it stays here. But it's also lost to the ground and the atmosphere. Higher frequencies are lost a lot. Infrasound not at all. This is a place called Åseda. That's where Kenneth lives. He has a damn migraine all the time. He can't live there. He asked us to visit and make measurements. The industry refused to cooperate — that was an interesting episode. We did simulations for him.

This is a typical day, a typical night — 8 meters per second. They have the same wind turbines as in Målaberget. We can use it at certain power levels. This is what you get. Here in the village we have Åseda — it's actually quite a large town. At all these locations we have small towns. These are the infrasound levels at those locations. Kenneth has 99 here. This is if it were only 1 meter per second — then it doesn't travel as far compared with 8 meters per second. It's the same sound power level. The sound power level itself also depends on the atmosphere. The industry will never explain that. When it's windier, the sound propagates farther, but the level is also higher.

The last image is from Lervik, where Kjell-Åke lives. This is from his house. These turbine levels are quite large. The sound power level is 85 meters.

[46:36]
6.6 megawatts. He has seven of them. This is last year in May. We recorded 105 decibel where he lives. This is what it looks like if we simulate it. This is a few months later. It was different weather. It was only 97 at that time.

This is an animation of this. We did this just to show the politicians because they like to have something that looks nice. It's the same simulation — it just looks nicer. This is a big simulation of how infrasound is propagating.

The last slide I added just before I went up there. I got it actually two hours ago. We did a measurement yesterday with the new equipment that we bought. We bought Hyperions, what CTBTO are using. We went in July to have them calibrated. Yesterday, we did the first recording with them because the problem with this LeadStrom is that it can't go below one hertz. The highest level is below one hertz.

This is what we got. Sorry, this is from Leif — he doesn't know how to produce nice plots. The yellow one is LeadStrom. Here it's at one hertz, then it drops. The other lines are the Hyperions. The highest level is at 0.63 hertz, the blade passing frequency. It's roughly 128 decibels at that frequency. This is roughly one and a half kilometers away. I should say there are like 60 wind turbines close to this area.

This is preliminary results. Still, the highest level is below one hertz. Of course, we need to do more validation of this. How much higher it is, we don't really know. This is an indication that it might be quite high, actually. You will hear more about that later.

Thank you very much for listening.

Setback Recommendations Per Various Studies

Name of Study	Date of Study	Author(s)	Link to Study	Author's Advised Setbacks	Notes
Wind Turbine Syndrome: A report on a natural experiment	**2009**	Dr. Nina Pierpont	N/A, PDF provided	**Setbacks from residences should be a minimum of 2 kilometers or 1.24 miles, but 2-3 miles in hilly terrain**	PDF provided to Planning Commission and BoCC
Your Guide to Wind Turboine Syndrome...a road map to a complicated subject	**July 2010**	Calvin Luther Martin, Phd	N/A, PDF provided	**Setbacks from residences should be a minimum of 2 kilometers or 1.24 miles, but 2-3 miles in hilly terrain**	This is a summary of Dr. Pierpont's book PDF provided to Planning Commission and BoCC
Health Effects of Wind Turbines: Testimony of Ben Johnson versus MidAmerican Energy (Madison County, Iowa) / Hearing before the Madison County Board of Health	**August 2019**	Dr. Ben Johnson, M.D.	https://www.masterresource.org/wind-turbine-noise-issues/health-effects-of-wind-turbines-testimony-of-ben-johnson-versus-mid-american-energy-project-in-madison-country-iowa/	**No recommendation given for a specific distance in this hearing. Afterwards the Madison County Board of Health passed a resolution recommending that any future turbines be built at least 1.5 miles from non-participating homes**	PDF provided to Planning Commission and BoCC
Wind Turbine Noise and Human Health: A Four-Decade History of Evidence that Wind Turbines Pose Risks	**Ocober 2016**	Professor Jerry L Punch and Professor Richard R James	https://hearinghealthmatters.org/wp-content/uploads/2023/03/16-10-21-Wind-Turbine-Noise-Post-Publication-Manuscript-HHTM-Punch-James.pdf	**Setbacks from residences are recommended at 1/2 mile to 2.5 miles, 1.25 miles is most favored by scientists.**	PDF provided to Planning Commission and BoCC
Infrasound from technical installations: Scientific basis for an assessment of health risks	**July 2021**	Dr. Werner Roos and Dr. Christian Vahl	https://www-asu--arbeitsmedizin-com.translate.goog/wissenschaft/wissenschaftliche-grundlagen-fuer-eine-bewertung-gesundheitlicher-risiken-infraschall?_x_tr_sl=de&_x_tr_tl=en&_x_tr_hl=en&_x_tr_pto=wapp	**Minimum setback from residences should be 10 X turbine height as in Bavaria Germany**	PDF provided to Planning Commission and BoCC
Assessing Adverse Health Effects-(Confirmed and Potential) from Industrial Wind Turbine Noise Emissions / Power point slides of presentation before the Kansas State Legislature	**2022**	Dr. Ben Johnson, M.D.	https://www.kslegislature.gov/li_2022/b2021_22/committees/ctte_s_utils_1/documents/testimony/20220207_01.pdf	**Setbacks of 1.25 miles from residences**	PDF provided to Planning Commission and BoCC
Presentation before the Kansas Senate and Utilities Committee: Effects of Wind Turbine Noise on Human Health	**2022**	Prof Jerry L Punch	https://www.kslegislature.gov/li_2022/b2021_22/committees/ctte_s_utils_1/documents/testimony/20220208_02.pdf	**Setbacks of 1.25 miles from property lines (specifically) should be considered**	PDF provided to Planning Commission and BoCC
Wind Turbines: Vacated/abandoned homes - Exploring participants' descriptions of their personal views, effects on safety, security, trust and social justice	**Dec 2023**	Carmen Marie Krogh, Robert Y McMurty, W Ben Johson, Jerry L Punch, Anne Dumbrille, Mariana Alves-Pereira, Debra Hughes, Linda Rogers, Robert W Rand, Lorrie Gillis	https://journals.lww.com/endi/fulltext/2023/08040/wind_turbines__vacated_abandoned_homes___exploring.2.aspx	**Residents living within 10 kilometers/6.21 miles of industrial wind turbines were documented having Adverse Health Effects**	See page 96 for the conclusion of the study regarding setbacks. PDF provided to Planning Commission and BoCC.
A fundamental basis for all living creatures, mechanotransduction, is significantly endangered by periodic exposure to impulsive infrasound and vibration from technical emitters - in particular cardiovascular and embryological functions	**June 2025**	Dr. Ursula Bellut-Staeck	https://www.scirea.org/journal/PaperInformation?PaperID=12440	**Setbacks of 10 kilometers / 6.21 miles from people and animals**	NOTE: The link shows the abstact and allows you to download the PDF PDF provided to Planning Commission and BoCC
Separating Myth from Fact on Wind Turbine Noise	**October 2025**	Prof Ken Mattsson	https://www.youtube.com/watch?v=nDwsd32SDEY	**Setbacks of at least 5 to 10 kilometers (3.1 to 6.2 miles) from residences**	Transcript PDF provided to Planning Commission and BoCC
Efficient finite difference modeling of infrasound propagation in realistic 3D domains: Validation with wind turbine measurements	**Feb 2026**	Ken Mattsson, Gustav Eriksson, Leif Persson, Jose Chilo, Kourosh Tatar	https://www.sciencedirect.com/science/article/pii/S0003682X25006280?ref=pdf_download&fr=RR-2&rr=9a872537bf69df1b	**No specific distance given, see notes for conclusion of study**	Conclusion of study page 14: This study also shows that modern, large-scale wind turbines generate infrasound levels substantially higher than those reported for older, smaller turbines / PDF provided to Planning Comm & BoCC

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Applied Acoustics 243 (2026) 111156

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Efficient finite difference modeling of infrasound propagation in realistic 3D domains: Validation with wind turbine measurements

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HIGHLIGHTS

- 3D low-frequency simulation tool for complex domains.
- Validation against infrasound wind farm measurements.
- Verification against realistic 2D and 3D benchmark problems.
- Verification of long-propagation effects in different atmospheres.
- Determination of the infrasound sound power levels of modern wind-turbines.

ARTICLE INFO

Keywords:
Finite difference methods
Infrasound measurement
Infrasound simulations
Validation
Verification

ABSTRACT

We present a high-fidelity simulation tool for accurate acoustic modeling across a wide range of applications. The numerical method is based on diagonal-norm Summation-By-Parts (SBP) finite-difference operators, which guarantee linear stability on piecewise curvilinear multi-block grids. Realistic three-dimensional atmospheric and topographic data are directly incorporated into the simulations, and the solver is implemented in CUDA to achieve high computational efficiency. Verification is performed through convergence studies against highly resolved benchmark problems in both two and three spatial dimensions, while validation is carried out using high-quality infrasound measurements from two modern wind farms in Sweden. The results show that modern, large-scale wind turbines generate infrasound levels significantly higher than those reported for older, smaller turbines. These findings advance the understanding of the acoustic characteristics of contemporary wind turbines and provide important guidance for assessing their potential environmental and societal impacts.

1. Introduction

Silence has become a scarce commodity in modern society. Among environmental stressors, traffic noise is recognized as one of the most significant threats to public health [1,2]. Long-term exposure has been associated with an increased risk of cardiovascular disease [3], as well as annoyance, sleep disturbance, and impaired cognitive performance in children [4]. To mitigate such impacts, reliable and precise computational tools capable of predicting noise propagation and generating noise maps are essential. Such tools are indispensable for the planning of urban communities, transportation infrastructure, airports, and wind farms, as well as for safeguarding quiet areas in national parks and recreational environments.

Low-frequency noise (below 200 Hz) is of particular concern. It penetrates efficiently into and through buildings, and while the human auditory system spans 16 Hz - 18 kHz (often rounded to 20 Hz - 20 kHz) [5], frequencies below approximately 100 Hz are typically perceived as vibrations or pressure rather than tonal sound. Prominent outdoor sources include road, air, and rail traffic, construction activity, and modern wind turbines, while indoor contributions arise from heating, ventilation, air-conditioning systems, and industrial machinery. The combined influence of multiple sources can elevate exposure to levels sufficient to induce adverse health outcomes. Ensuring quiet residential conditions, particularly in sleeping environments, is therefore of critical importance.

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https://doi.org/10.1016/j.apacoust.2025.111156
Received 14 February 2025; Received in revised form 31 October 2025; Accepted 1 November 2025
Available online 12 November 2025

Existing numerical methods for outdoor sound propagation have been shown to be inadequate for large-scale domains with complex and irregular terrain [6]. More accurate and advanced computational approaches have recently been developed to address these shortcomings [7]. Empirical measurements further confirm [8,9] that accurate prediction of sound pressure levels (SPL) over extended ranges requires explicit consideration of both the three-dimensional atmospheric state and the underlying terrain. The dynamic atmosphere influences acoustic propagation across all ranges, but its spatiotemporal variability becomes increasingly significant with distance. Consequently, high-fidelity simulations of long-range sound propagation (typically exceeding 500 m) must incorporate: 1) atmospheric attenuation, 2) wind effects, 3) altitude-dependent sound speed, 4) stratification and buoyancy, 5) irregular terrain, and 6) realistic boundary conditions.

Sound propagation in a heterogeneous atmosphere is modeled in this study using the three-dimensional acoustic wave equation [10]. To guarantee stability and convergence, diagonal-norm SBP finite-difference operators are combined with the Simultaneous Approximation Term (SAT) technique for the weak enforcement of boundary conditions. Over the past two decades, the SBP-SAT framework has been extensively developed and rigorously analyzed, and it has consistently been shown to provide highly accurate and reliable numerical simulations of acoustic wave propagation (see, e.g., [6,7,11–16]).

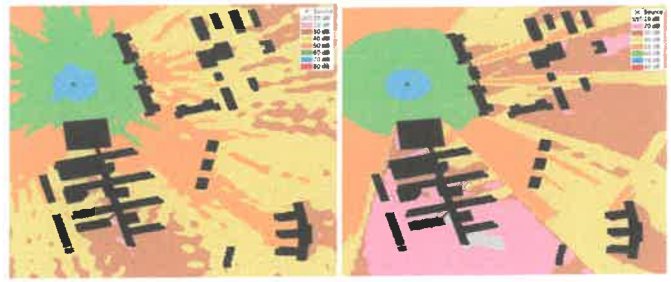
For a computational tool to be broadly useful to the scientific and engineering community, it must satisfy three essential criteria: 1) the methodology must be rigorously validated and transparently documented; 2) the results must be clear, interpretable, and visually accessible; and 3) the tool must be user-friendly, avoiding the need for tuning of ad hoc parameters. To achieve all of this is the overarching goal of the sound simulation tool named *SoundSim360*. In contrast, widely used commercial noise simulation software, including models such as Nord2000, are based on ray-tracing techniques that require numerous adjustable parameters. While such models are computationally efficient, they exhibit several well-known limitations that we avoid by directly solving the full three-dimensional acoustic wave equation. Four key weaknesses of ray-tracing approaches are: 1) inadequate treatment of low-frequency sound (below 200 Hz), 2) difficulty in handling complex geometries, 3) limited capability to model sound transmission through walls, and 4) inability to accurately capture transient sources.

As an illustrative example, Fig. 1 presents a comparison between SoundSim360 and Nord2000 (as implemented in the commercial software SoundPlan 9.1) for a 25 Hz monopole source located at Polacksbacken, Uppsala University. The source is positioned 10 m above ground with a sound power level of 105 dB. Terrain and building data are obtained from Lantmäteriet [17], and the ground is modeled as a hard surface (impedance class H in Nord2000). All other Nord2000 parameters are kept at their default values. The sound pressure level (SPL) distribution at 2 m height is shown for both models. The computational domain for SoundSim360 covers 500 m × 600 m × 250 m.

Significant discrepancies occur in the acoustic shadow zones behind buildings, where Nord2000 systematically underestimates SPL due to fundamental limitations of ray-based propagation at low frequencies. The model cannot accurately simulate edge diffraction at these frequencies, as it relies on geometrical acoustics and is calibrated for higher-frequency sound. At longer wavelengths, these assumptions break down, and wave-based diffraction effects dominate the propagation field.

Infrasound refers to sound waves with frequencies below 20 Hz and is produced by various natural and man-made sources. Examples of man-made infrasound sources include explosions, engines, ventilation, high-speed trains, high-speed aircraft, rockets, and wind turbines. Natural sources of infrasound are diverse: volcanic eruptions, auroras, lightning and sprites, surf, wave-wave ocean interactions (microbaroms), avalanches, meteors, mountain-associated waves, earthquakes, and tsunamis.

Infrasound simulations are increasingly employed in geophysical research and monitoring for a variety of applications. These simulations help scientists study the behavior of infrasound waves in different environments and understand their implications in various geophysical contexts. Here are a few key geophysical applications where infrasound simulations are used: 1) to detect large explosions (including nuclear tests) [18,19], 2) to detect natural disasters like, earthquakes [20,21], tsunamis or volcanic eruptions [22], 3) to provide data on atmospheric conditions [23–25] and to improve forecasting models. These applications typically require the combination of accurate infrasound (and sometimes seismic) measurements and advanced numerical methods to simulate infrasound propagation in the atmosphere up to 140 km. A popular numerical method for infrasound simulations in a relatively flat terrain, with a single source, is the wide angle parabolic equation method [18,20,24,25]. To capture interference from multiple sources in irregular terrain, a three-dimensional wave equation model is necessary.



(a) SoundSim360 (b) Nord2000

Fig. 1. Low-frequency (25 Hz) sound simulation at polacksbacken (105 dB point source at ×, 10 m above ground), comparing (a) SoundSim360 and (b) Nord2000. Shown are sound pressure levels 2 m above ground. Nord2000 cannot accurately model edge diffraction at low frequencies, where long wavelengths cause pronounced wave bending around obstacles.

The main focus of the present study is twofold. The first main focus is to validate the simulation tool against accurate infrasound measurements. Infrasound is an ideal candidate to validate an outdoor sound simulation tool due to the minimal atmospheric (and ground) damping allowing for long-distance propagation. Modern wind turbines are strong infrasound emitters and are often located remotely, far away from cities and highways that would otherwise contribute to relatively high background noise. The second main focus is to map the sound power levels in the infrasound regime for a few modern types of wind turbines and examine the influence of the atmosphere. We have carried out measurements at Målarberget wind farm three times: 2023-10-26, 2024-10-23, and 2024-12-16, and at Lervik wind farm twice: 2024-05-21 and 2024-09-10.

After these initial infrasound measurements, two of us experienced sleep disorders and migraine headaches. These symptoms appeared after being exposed to infrasound levels of just over 95 dB around the 1 Hz frequency band for at least 4 hours (see Fig. 7). Similar symptoms during infrasound measurements have been reported in [26]. It is well-known among specialists in otoneurology and otolaryngology that inaudible infrasound has the potential to trigger migraines in people with a more sensitive nervous system, for example, see [27–29]. One in three people is predisposed to migraines, with a more sensitive nervous system [30,31]. The level of sensitivity is highly individual. There are new studies that link the impact of inaudible infrasound to brain activity [32,33]. As early as 1985, Danielsson and Landström [34] showed that infrasound at levels of 95 dB during 1 h of exposure causes an increase in diastolic blood pressure and decreases in systolic blood pressure and pulse rate. More recent studies also show that many animals move more than 5 km from wind turbines, especially deer and birds [35].

Other (recent) studies [36,37] suggest that infrasound from wind turbines does not produce measurable health effects. In [37], 27 participants were exposed to 89 dB of infrasound for 10 min in a laboratory, while in [36], 37 participants were exposed to 87 dB for three days. These studies have certain limitations: they did not involve experts in otoneurology or otolaryngology in their design, and participants with known sensitivities, such as individuals prone to migraines, were not included. Furthermore, the short-term laboratory exposures may not fully reflect long-term, cumulative exposure in residential environments near wind farms. Consequently, while informative, the results should be interpreted with caution, particularly when considering potential effects on sensitive subpopulations.

It is well-known [38,39] that repetitive, pulsating sounds are perceived as more disturbing than continuous sounds with the same frequency content and average sound level. Each time a wind turbine blade passes the tower, a pressure pulse with steep edges is generated, which propagates as infrasound. The blade passage frequency (BPF) can be determined by counting the number of blade passes per minute and dividing by 60. The BPF decreases with increasing turbine blade size, and larger blades also produce stronger pressure pulses, resulting in more intense infrasound. For modern wind turbines, the BPF typically ranges between 0.2 and 0.5 Hz, whereas older turbines exhibit a higher BPF of around 0.7 to 0.9 Hz. In sound pressure spectra, the BPF and its harmonics (multiples of the BPF) appear as distinct spikes [26,40]. This pattern contrasts sharply with natural infrasound, which is typically broadband generated by meteorological events, and lacks such discrete spikes. Based on this, it is reasonable to hypothesize that humans are generally unaffected by natural infrasound. However, the unnatural characteristics of wind turbine infrasound, arising from its repetitive pulses, may contribute to the symptoms reported in the vicinity of wind turbines.

The health impacts of wind turbine infrasound remain unresolved, largely due to limitations in existing laboratory studies. To date, no controlled experiment has accurately reproduced the characteristic pulsating infrasound emitted by modern turbines. Instead, previous studies have relied on continuous broadband infrasound at comparatively modest levels [36,37]. These conditions do not reflect real-world exposure. A scientifically robust study must therefore include a realistic reproduction of pulsating infrasound, exposure periods lasting several weeks, a sufficiently large and diverse group of participants–including individuals with known sensitivities such as migraines–and the involvement of medical experts in otoneurology and otolaryngology. Until such studies are conducted, it is premature to draw definitive conclusions regarding the health effects of wind turbine infrasound.

The remainder of this paper is organized as follows. In Section 2, we introduce the acoustic wave equation model and establish its well-posedness, including a discussion of various boundary conditions and the model data. Section 3 presents the spatial discretization and the explicit second-order time integration scheme. A brief account of the implementation is given in Section 4. The accuracy of the method is verified against 2D and 3D benchmark problems in Section 5. In Section 6, we describe infrasound measurements from two different wind farms, and in Section 7 we validate the simulations against these measurements and present results on infrasound propagation around the wind farms. Finally, Section 8 summarizes the main findings of this work.

2. The physical model

The model we use for sound propagation is the 3D acoustic wave equation in second-order form [10], given by

$$\frac{1}{c(\boldsymbol{x})^2\rho(\boldsymbol{x})}u_{tt} = \nabla\cdot\left(\frac{1}{\rho(\boldsymbol{x})}\nabla u\right) + \beta(\boldsymbol{x})u_t + \frac{1}{c(\boldsymbol{x})^2\rho(\boldsymbol{x})}S(\boldsymbol{x},t), \quad \boldsymbol{x}\in\Omega, \quad t>0\,, \tag{1}$$

where $u = u(\boldsymbol{x}, t)$ is the pressure deviation, $c(\boldsymbol{x})$ is the speed of sound, $\rho(\boldsymbol{x})$ is the density of the medium, $\beta(\boldsymbol{x})$ is a damping coefficient, $S(\boldsymbol{x}, t)$ is a forcing function, and $\Omega \subset \mathbb{R}^3$ is the computational domain. Here $\boldsymbol{x} \in \Omega$ is the 3D spatial coordinate and t is the time coordinate. Throughout the paper we use bold font to denote vectors. In (1) subscripts are used to denote partial differentiation. In this work the computational domain Ω is a box with a variable bottom boundary to take into account the ground elevation. We denote the boundary of Ω as $\partial\Omega$.

To obtain unique solutions to (1) we have to impose initial and boundary conditions on the solution $u(\boldsymbol{x}, t)$. In this work, we exclusively use homogeneous initial conditions, i.e., $u(\boldsymbol{x}, 0) = u_t(\boldsymbol{x}, 0) = 0$. We split the boundary into two parts, $\partial\Omega_g$ on the ground and $\partial\Omega_o$ elsewhere, and impose the following boundary conditions:

$$\begin{array}{lll} \text{First-order outflow:} & c(\boldsymbol{x})\boldsymbol{n}\cdot\nabla u + u_t = 0, & \boldsymbol{x}\in\partial\Omega_o, \\ \text{Impedance:} & p(\boldsymbol{x})\omega u + c(\boldsymbol{x})\boldsymbol{n}\cdot\nabla u + q(\boldsymbol{x})u_t = 0, & \boldsymbol{x}\in\partial\Omega_g, \end{array} \tag{2}$$

where $\boldsymbol{n}$ denotes the outgoing normal. The first-order outflow boundary condition on $\partial\Omega_o$ is used to truncate the domain and minimize reflections at artificial boundaries. The impedance boundary condition on $\partial\Omega_g$ is taken from [41], and is used for partially reflecting surfaces (such as the ground). The parameters $p(\boldsymbol{x})$ and $q(\boldsymbol{x})$ are defined by $p(\boldsymbol{x})+q(\boldsymbol{x})i = \frac{i}{\hat{Z}(\boldsymbol{x})}$, where $\hat{Z}(\boldsymbol{x})$ is the normalized surface impedance. Here we use a formula from [42] that is valid for low frequencies, given by

$$\hat{Z}(\boldsymbol{x}) = \sqrt{\frac{\sigma_e(\boldsymbol{x})}{2\omega\gamma\rho(\boldsymbol{x})}}(1+i), \quad \boldsymbol{x}\in\partial\Omega_g\,, \tag{3}$$

where $\sigma_e(\boldsymbol{x})$ is the effective flow resistivity of the ground surface, $\gamma = 1.4$ is the specific heat ratio, and $\omega = 2\pi f$ with f being the frequency.

In the present study, the forcing function consists of a single point source, i.e.,

$$S(\boldsymbol{x}, t) = \delta(\boldsymbol{x} - \boldsymbol{x}^*)g(t), \tag{4}$$

where δ is the Dirac delta function, $\boldsymbol{x}^*$ is the location of point source, and $g(t)$ is the time signal. Here we use ramped harmonic signals of the form

$$g(t) = Ar(t)\sin(\omega t), \tag{5}$$

where A is the amplitude and $r(t)$ is a ramping function given by

$$r(t) = \begin{cases} \sin^2\left(\dfrac{\pi t}{2T_{\text{ramp}}}\right), & 0 \le t < T_{\text{ramp}}, \\ 1 & t \ge T_{\text{ramp}}, \end{cases} \tag{6}$$

with $T_{\text{ramp}} = \frac{6}{f}$ (six periods ramping). To model problems with multiple sources, for example a wind farm, we solve (1) with one source at a time and combine the results. As we shall see later, this is necessary to properly incorporate wind effects into the model. Note that we do not include any phase information in the time-signal (5). This is because the phases of the sources we consider here (wind turbines) are generally unknown, and by solving (1) with one source at a time we can reconstruct all possible phase combinations a posteriori regardless.

2.1. Sound pressure level computation

Consider a simulation with all sources active at the same time (with independent, random phases). Let $P(\boldsymbol{x})$ denote the random variable corresponding to the total mean-square pressure at receiver position $\boldsymbol{x}$, and let

$$L(\boldsymbol{x}) = 10\log_{10}\left(\frac{P(\boldsymbol{x})}{p_0^2}\right),$$

be the corresponding sound pressure level (SPL) relative to the reference pressure $p_0 = 20\ \mu$Pa. Depending on the specific realization of phases, the SPL will vary significantly. In this paper we disregard this variation, i.e., we ignore the effects of phases altogether, by considering only the expected SPL over all possible phase combinations, which we compute from the individual simulations with one source at a time. Let $(p_{i,\text{rms}}(\boldsymbol{x}))^2$,

$i = 1, 2, \ldots, N_s$, be the mean-square RMS pressure (with one point source located in x_i^*) sampled over ten periods as follows:

$$(p_{i,\mathrm{rms}}(x))^2 = \frac{f}{10}\int_{t^*}^{t^*+\frac{10}{f}} \left(u(x,t;x_i^*)\right)^2 dt, \quad i = 1,2,\ldots,N_s. \tag{7}$$

Here $u(x,t;x_i^*)$ is the solution with the point source located in x_i^*, and N_s is the total number of sources. We start sampling at

$$t^* = T_{\mathrm{ramp}} + \frac{\sup_{x\in\Omega}|x - x^*|}{\inf_{x\in\Omega} c(x)}, \tag{8}$$

which is sufficiently large to ensure that $u(x,t;x_i^*)$ is harmonic at all points in space when $t > t^*$. It can be shown (derivation omitted) that

$$\mathbb{E}[P(x)] = \sum_{i=1}^{N_s} (p_{i,\mathrm{rms}}(x))^2, \tag{9}$$

i.e., the expected total mean-square pressure is just the sum of the mean-square pressure when simulating with one source at a time. This is intuitive, since the probabilities of constructive and destructive interference balance on average, so the expected level is simply the sum of the individual mean-square contributions without interaction terms. We define the expected SPL as

$$L_{\mathrm{tot}}(x) = 10\log_{10}\left(\frac{\mathbb{E}[P(x)]}{p_0^2}\right) = 10\log_{10}\left(\frac{\sum_{i=1}^{N_s}(p_{i,\mathrm{rms}}(x))^2}{p_0^2}\right). \tag{10}$$

Note that $L_{\mathrm{tot}}(x)$ is not the same as $\mathbb{E}[L(x)]$. The former is defined from the expected mean-square pressure and corresponds to the conventional way of reporting average SPL from incoherent sources, whereas $\mathbb{E}[L(x)]$ is the strict statistical mean of the random decibel values. In the case where the sources contribute with comparable strength, $\mathbb{E}[L(x)] \approx L_{\mathrm{tot}}(x) - 2.5$ dB.

The spread of $L(x)$ around its mean depends on how unevenly the sources contribute at the receiver position x. When many sources contribute with comparable strength (for example, far from the wind farm) and their phases are independent and uniformly distributed, $P(x)$ is approximately exponentially distributed. In this case the distribution of $L(x)$ has a standard deviation

$$\mathrm{sd}(L(x)) = \frac{10}{\ln 10}\sqrt{\frac{\pi^2}{6}} \approx 5.57 \text{ dB}, \tag{11}$$

independent of the mean. If one or a few sources dominate, for example very close to a wind turbine, the distribution departs from exponential and the spread of $L(x)$ is significantly smaller. In particular, in the immediate vicinity of a turbine the SPL will be almost entirely determined by that single source, and the phases of the other turbines become irrelevant. Hence, inside the wind farm and near individual turbines, the standard deviation $\mathrm{sd}(L(x))$ is close to zero.

Remark 1. Later in the paper we compare the expected SPL values $L_{\mathrm{tot}}(x)$ from simulations to measurements from real wind farms. One could argue that the measurement is done with a specific phase combination, and therefore we should try to find that combination in the simulations as well. However, we argue that any specific interference pattern will be highly affected by temporal variations in the sources and atmospheric parameters, which are diminished since the measurements take place over several minutes. We emphasize that the simulation results we present are not snapshots of the SPL at any given time, rather they should be viewed as averages over all possible phase combinations under the assumptions of our model. In reality, local variations of the SPL in both time and space will be significant.

2.2. Wind modeling

The effect of wind is modeled by replacing $c(x)$ and $\rho(x)$ in (1) with the *effective speed of sound* and the *effective density* [43], defined as

$$c_{\mathrm{eff}}(x) = c(x) + \hat{s}(x)\cdot \mathbf{V}(x) \quad \text{and} \quad \rho_{\mathrm{eff}}(x) = \rho(x) - \frac{2\rho_0}{c_0}\hat{s}(x)\cdot\mathbf{V}(x), \tag{12}$$

where $\hat{s}(x) = \frac{x-x^*}{|x-x^*|}$ is the unit vector in the sound propagation direction, $\mathbf{V}(x)$ is the wind vector, and $c_0 = 340.3$ m/s and $\rho_0 = 1.225$ kg/m^3 are atmospheric reference values. This approximation is valid when most of the sound propagates along $\hat{s}(x)$, which is true if we solve for one source at a time and if both the source and the receiver are located close to the ground [9,44].

Remark 2. The approximation in [43] is valid under the assumptions that variations in density and speed of sound remain moderate, and that the wind speed is much smaller than the speed of sound. These conditions are satisfied for the problems considered in the present study. For a more general and accurate treatment of 3D time-dependent wind effects, one must instead employ the linearized Euler equations in 3D, as demonstrated in [7,45].

2.3. Model data

To obtain useful and trustworthy results from simulations it is crucial to use real-world data. In our model, the coefficients we need to specify are the speed of sound $c(x)$, the density $\rho(x)$, the attenuation $\beta(x)$, the wind $\mathbf{V}(x)$, the effective flow resistivity $\sigma_e(x)$, and the source position x^* and amplitude A. We use elevation data provided by *Lantmäteriet* [17] (1 m resolution) to construct Ω. The upper limit is set at 5 km for all simulations.

For large-scale outdoor simulations, it is particularly important to incorporate atmospheric data into the model. In the present study, we use MEPS atmospheric data from *The Norwegian Meteorological Institute*, which provides all the atmospheric data we need with one hour temporal resolution and 2.5 km spatial resolution with 65 height levels up to approximately 10 km. The atmospheric attenuation (damping) coefficient is defined as a function of temperature, pressure, humidity, and frequency [46]. The speed of sound and density are computed from the temperature, pressure, and humidity data according to the formulas presented in [47].

The effective flow resistivity σ_e for the ground boundary condition is highly dependent on the type of ground surface in the computational domain. In this work we distinguish between two different types, hard and semi-hard. We use land cover data from Naturvårdsverket [48], which categorizes the entire surface of Sweden into several ground classes. We set $\sigma_e = 200{,}000{,}000$ Pa $\cdot$ s/m^2 for obviously hard surfaces (water, asphalt etc.) and $\sigma_e = 500{,}000$ Pa $\cdot$ s/m^2 for the rest (forest floor, farming fields etc.). These choices are fairly conservative, possibly resulting in too low ground attenuation. But investigating the uncertainties involved in modeling the ground boundary solely based on data available from satellite imagery and airplane laser scanning is beyond the scope of this study.

We model the wind turbine in each simulation as a point source located at the hub. The coordinates of each turbine and its hub height are obtained from the original sound emission calculations (the basis for the permit application of the wind farm).

In the present paper we focus on sound propagation for the frequency $f = 1$ Hz, which is the lowest frequency we can measure with the current equipment. Ideally, the infrasound measurements should go down to 0.1 Hz to capture the BPF from the new larger wind turbines, expected to be between 0.2–0.5 Hz. We will use measurements on real wind farms to determine the source amplitudes A at 1 Hz, so that the measured SPL values match the simulated SPL values as well as possible. The sound power levels we report should be understood in the context of our sound propagation model, which is a simplification of reality. First, we make the assumption that all turbines are point sources located in the hub (no directivity) and that they all emit the same sound power. The second major uncertainty is the atmospheric and ground data, which have a limited resolution and accuracy. However, as we show in Section 7.3, the influence of the atmosphere is relatively small at the distances where we perform the measurements. A more detailed analysis of the directivity of wind turbines in the infrasound region and the amount of uncertainty from the atmospheric data is out of scope in the present study.

Remark 3. By combining accurate sound measurements, current atmospheric data, and our simulation tool, the sound power levels of the sources can be determined across the entire low-frequency range (under the assumptions of our model). High-frequency sound can also be analyzed with this technique, but would naturally be confined to much smaller domains, due to the large atmospheric and ground absorption.

2.4. Energy method

For linear problems, the energy method can be used to prove stability of PDEs, and hence it is important for well-posedness [49]. Let

$$(u,v)_\Omega = \int_\Omega uv\,d\mathbf{x} \quad \text{and} \quad (u,v)_{\partial\Omega} = \int_{\partial\Omega} uv\,d\mathbf{x} \quad \forall u,v \in \mathbb{R}, \tag{13}$$

denote L^2-inner products over the domain and its boundary, respectively.

To simplify the upcoming analysis we collect terms and write the PDE as

$$\begin{aligned} u_{tt} &= a\nabla\cdot(b\nabla u) + \alpha u_t + S(x,t), && x\in\Omega, \quad t>0 \\ \gamma_1\, u + b\mathbf{n}\cdot\nabla u + \gamma_2 u_t &= 0, && x\in\partial\Omega,\ t>0, \\ u = u_t &= 0, && x\in\Omega, \quad t=0, \end{aligned} \tag{14}$$

where $a = a(\mathbf{x}) = c(\mathbf{x})^2\rho(\mathbf{x})$, $b = b(\mathbf{x}) = \frac{1}{\rho(\mathbf{x})}$, $\alpha = \alpha(\mathbf{x}) = \beta(\mathbf{x})c(\mathbf{x})^2\rho(\mathbf{x})$, and $\gamma_1 = \gamma_1(\mathbf{x})$ and $\gamma_2 = \gamma_2(\mathbf{x})$ determine the boundary condition. With this general boundary condition, we can treat both first-order outflow boundary conditions ($\gamma_1 = 0$ and $\gamma_2 = \frac{b(x)}{c(x)}$) and impedance boundary conditions ($\gamma_1 = \frac{b(x)p\omega}{c(x)}$ and $\gamma_2 = \frac{b(x)}{c(x)}q$). In (14) we have also included the homogeneous initial conditions.

Source data does not influence stability [49], hence we set $S(t) = 0$ in the following stability analysis. Multiplying the PDE (14) by u_t and integrating over the domain Ω gives

$$\begin{aligned} \left(u_t, \frac{1}{a}u_{tt}\right)_\Omega &= (u_t, \nabla\cdot(b\nabla u))_\Omega + (u_t, \beta u_t)_\Omega \\ &= -(\nabla u_t, b\nabla u)_\Omega + (u_t, b\mathbf{n}\cdot\nabla u)_{\partial\Omega} + (u_t,\beta u_t)_\Omega \\ &= -(\nabla u_t, b\nabla u)_\Omega - (u_t,\gamma_1\, u)_{\partial\Omega} - (u_t,\gamma_2 u_t)_{\partial\Omega} + (u_t,\beta u_t)_\Omega, \end{aligned} \tag{15}$$

where the boundary condition has been substituted in the last step. Rearranging terms leads to

$$\frac{d}{dt}E = -2(u_t,\gamma_2 u_t)_{\partial\Omega} + 2(u_t,\beta u_t)_\Omega, \tag{16}$$

where E is an energy given by

$$E = \left(u_t, \frac{1}{a}u_t\right)_\Omega + (\nabla u, b\nabla u)_\Omega + (u,\gamma_1\, u)_{\partial\Omega}. \tag{17}$$

For E to be a valid mathematical energy it must be non-negative, which is guaranteed if $a > 0$, $b \geq 0$, and $\gamma_1 \geq 0$. Stability is obtained if the energy is non-growing, i.e., if the right-hand side of (16) is non-positive, which is guaranteed if $\gamma_2 \geq 0$ and $\beta \leq 0$. These conditions are all fulfilled for the physical parameters used in our model. For linear PDEs, stability in combination with the correct number of boundary conditions is a sufficient condition for well-posedness [49].

Remark 4. The source term plays a crucial role in the model, although it does not influence stability or well-posedness, for which it is usually assumed to be zero. In the simulations, we retain a nonzero $S(t)$.

3. Discrete model

To retain space, we omit details on the spatial discretization. In short, we first compute a coordinate transformation of the domain Ω to a unit cube reference domain using linear transfinite interpolation. Then, we discretize the reference domain into an equidistant Cartesian grid and approximate all spatial operators using the well-documented SBP-SAT finite difference method. For details, we refer to [6,7,14–16,50–52]. For the wind farm simulations, we use second-order diagonal-norm SBP finite difference operators (derived in [15]) and sufficiently many grid points to obtain 10 points per wavelength relative to a wave speed of 330 m/s, in all directions.

The SBP-SAT method leads to a provably stable second-order ODE system given by,

$$\begin{aligned} \mathbf{v}_{tt} &= \mathbf{D}\mathbf{v} + \mathbf{E}\mathbf{v}_t + \mathbf{F}(t), && t>0, \\ \mathbf{v}(0) &= \mathbf{v}_t(0) = 0, && t=0, \end{aligned} \tag{18}$$

where $\mathbf{v} \in \mathbb{R}^N$ is the semi-discrete solution vector (time-dependent), N is the total number of grid points, $\mathbf{D}$ and $\mathbf{E}$ are negative semi-definite $N\times N$ matrices, and $\mathbf{F}(t)$ is the discretized forcing function (see [7,16,51] for details). In the present study, we utilize second, fourth, and sixth-order accurate diagonal-norm SBP finite difference operators, described in [15].

Remark 5. In [53] it was shown that a stable approximation of the wave equation in second-order form, using diagonal-norm SBP finite difference operators of second-, and fourth-order accuracy, yields convergence rates of order 2 and 4, respectively. This is verified in Table 1.

3.1. Temporal discretization

For time-stepping we use the following second-order explicit two-step method:

$$\frac{\mathbf{w}_{n+1} - 2\mathbf{w}_n + \mathbf{w}_{n-1}}{h^2} = \mathbf{D}\mathbf{w}_n + \mathbf{E}\frac{\mathbf{w}_{n+1} - \mathbf{w}_{n-1}}{2h} + \mathbf{F}(t_n), \quad n = 1,2,\ldots, \tag{19}$$

where h is a constant temporal step size, $t_n = hn$, $n = 0,1,2,\ldots$, and $\mathbf{w}_n$ is an approximation of $\mathbf{v}(t_n)$. Written as an iterative formula, we get

$$\left(\mathbf{I}_N - \frac{h}{2}\mathbf{E}\right)\mathbf{w}_{n+1} = (2\mathbf{I}_N + h^2\mathbf{D})\mathbf{w}_n - \left(\mathbf{I}_N + \frac{h}{2}\mathbf{E}\right)\mathbf{w}_{n-1} + h^2\mathbf{F}(t_n), \tag{20}$$

where $\mathbf{I}_N$ is the $N\times N$ temporal step size, that, due and the is an approximation of used, the matrix $\mathbf{E}$ is diagonal and hence $\left(\mathbf{I}_N - \frac{h}{2}\mathbf{E}\right)$ is easy to invert.

To retain second-order accuracy for all time we need to compute the initial time steps with second-order accuracy as well. The first time level is given by the initial data, i.e., $\mathbf{w}_0 = \mathbf{v}(0)$, but the second time level requires some more careful consideration, here we use the modified difference approach. Consider the first order approximation of the first derivative and its truncation error

$$\frac{\mathbf{v}(t_{n+1}) - \mathbf{v}(t_n)}{h} = \mathbf{v}_t(t_n) + \frac{h}{2}\mathbf{v}_{tt}(t_n) + \mathcal{O}(h^2). \tag{21}$$

Using the ODE (18) to substitute the term $\mathbf{v}_{tt}(t_n)$ we get

$$\frac{\mathbf{v}(t_{n+1}) - \mathbf{v}(t_n)}{h} = \mathbf{v}_t(t_n) + \frac{h}{2}(\mathbf{D}\mathbf{v}(t_n) + \mathbf{E}\mathbf{v}_t(t_n) + \mathbf{F}(t_n)) + \mathcal{O}(h^2). \tag{22}$$

which we use to compute a second-order accurate approximation of the solution at t_1, as follows:

$$\mathbf{w}_1 = \mathbf{v}(0) + h\mathbf{v}_t(0) + \frac{h^2}{2}(\mathbf{D}\mathbf{v}(0) + \mathbf{E}\mathbf{v}_t(0) + \mathbf{F}(0)). \tag{23}$$

With homogeneous initial data, we have $\mathbf{w}_0 = 0$ and $\mathbf{w}_1 = \frac{h^2}{2}\mathbf{F}(0)$.

The stability limit of the time-stepping formula (20) can be shown to be proportional to the smallest distance between two adjacent grid points. In this work, we determine the stability limit experimentally and, unless specified otherwise, choose the time step to be 50 % of the stability limit.

4. Implementation details

The numerical method is implemented in a custom code using C++ and CUDA for GPU acceleration. All pre- and postprocessing are done in Matlab (grid generation, reading data, constructing coefficient vectors, plotting etc.). We call the whole software package SoundSim360.

The simulations presented in this paper are performed on a single Nvidia RTX A6000 GPU, with 48 GB of internal memory and 10,752 CUDA cores. All simulations are done in single precision (the results with double precision are identical). The implementation is done in a matrix-free fashion, which means that only a handful of copies of the solution vectors have to be stored in memory (the spatially dependent coefficient and time-stepping vectors). As a reference for the performance of the GPU implementation, generating a noise map over a $15 \times 15 \times 5\,\text{km}^3$ area, such as in Fig. 12, requires roughly 12 min of computation (24 simulations—one per source—at about 30 s each). A Matlab code using sparse matrices on a standard CPU would take roughly 20 hours to produce these results. In general, the Matlab implementation takes between 70 and 100 times longer compared to the GPU implementation, depending on the specific problem. Also, the matrix-based implementation utilizes significantly more memory and requires more preprocessing to assemble the matrices.

5. Verification

Before we turn to simulations with real-world data, we verify the accuracy and implementation of the numerical method by performing two verification tests. First, a comparison against a well-known benchmark problem and then a convergence study with physically relevant data.

5.1. Benchmark

We consider two of the 10 Hz benchmark problems presented in [54], referred to as Case 2 and Case 4. These problems consist of a single harmonic point source at $z = 5$ m, a flat topography, and a non-constant speed of sound profile. For Case 2 the speed of sound profile is defined as

$$c(z) = c_0 + 0.1z, \tag{24}$$

where $c_0 = 343$ m/s and $z \geq 0$. This profile gives rise to significant downward refraction on all heights. The Case 4 profile is defined as

$$c'(z) = \begin{cases} 0.1, & 0 \leq z < 100, \\ -0.1, & 100 \leq z < 300, \\ 0, & z \geq 300, \end{cases} \tag{25}$$

and $c(0) = c_0$. With the Case 4 profile there is downward refraction for the first 100 m, then upward refraction until 300 m and then a constant atmosphere. The density is set to $\rho = 1.205$ kg/m^3 and the attenuation to $2.3 \cdot 10^{-3}$ dB/km (negligible for the distances considered). The normalized surface impedance (at $z = 0$ m) is set to $\hat{Z} = 38.79 + 38.41i$.

We simulate Case 2 and Case 4 using SoundSim360 and compute the transmission loss at $z = 1$ m for both cases as follows:

$$\text{TL}(r) = -20 \log_{10} \frac{p_{rms}(r)}{p_{free}}, \tag{26}$$

where $p_{rms}(r)$ is the RMS of the computed pressure field at distance r from the source and p_{free} is the RMS of the free-field pressure at 1 m distance (spherical symmetry). The upper limit of the computational domain is chosen sufficiently high to ensure it does not affect the transmission loss on the ground. In both cases, we apply our discretization method using 6th-order SBP operators with 20 grid points per wavelength (relative to 330 m/s wave speed) and a time step at 1 % of the stability limit. In Fig. 2 we plot the transmission loss up to $r = 10000$ m for both Case 2 and Case 4. Based on visual comparison, our results agree with the benchmark provided in [54].

To ensure that our reference solutions are accurate, we also simulate the problems with 10 points per wavelength and a time step at 2 % of the stability limit. We then find that the solutions are equal to approximately five decimals compared to the solutions in Fig. 2. Since the discretization is provably consistent and stable, the Lax equivalence theorem applies which guarantees convergence [55]. Hence we can conclude that the results in Fig. 2 are accurate.

5.2. Convergence study

Although the benchmark in Section 5.1 is a good test of refraction and boundary condition implementation, it does not take into account all the relevant physics for long-distance simulations. It is a two-dimensional problem in cylindrical coordinates, and it does not test 3D atmospheres or the effects of topography, for example. To further verify our method, we perform a convergence test on a 3D problem more closely related to simulations with real-world data. Unfortunately, closed-form analytical solutions to the second-order wave equation with general coefficients are difficult to derive, especially for complicated geometries. Instead, we use a synthetically generated reference solution.

Consider the domain $x, y, z \in [0, 1600] \times [0, 1600] \times [H(x, y), 800]$ m^3 presented in Fig. 3. The elevation (ground level) is given by

$$H(x, y) = H_c e^{-\frac{(x-x_c)^2}{r^2} - \frac{(y-y_c)^2}{r^2}}, \tag{27}$$

i.e., a Gaussian profile of height $H_c = 100$ m, centered at $[x_c, y_c] = [900, 700]$, with width $r = 200$ m. A point source with $f = 1$ Hz is located at $[x_s, y_s, z_s]$, where $x_s = y_s = 800$ m and $z_s = H(x_s, y_s) + 125 \approx 185.65$

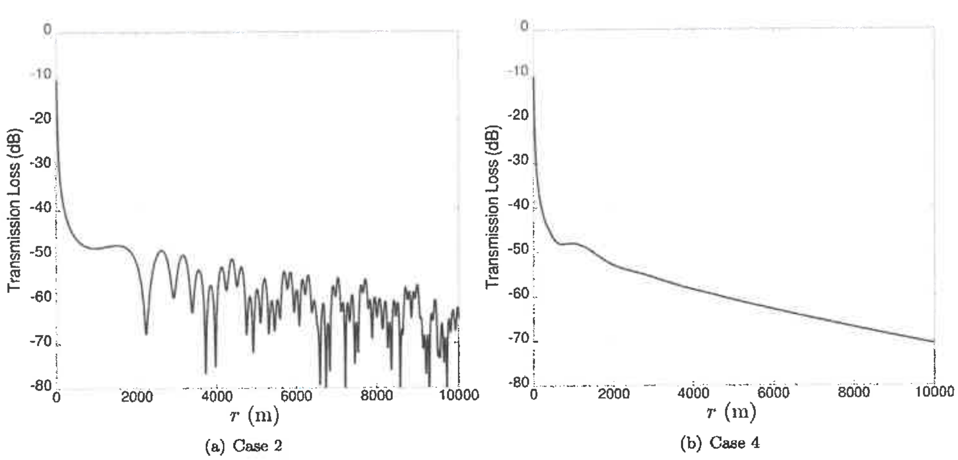


Fig. 2. Transmission loss at 1 m as a function of distance for (a) Case 2 and (b) Case 4 speed of sound profiles.

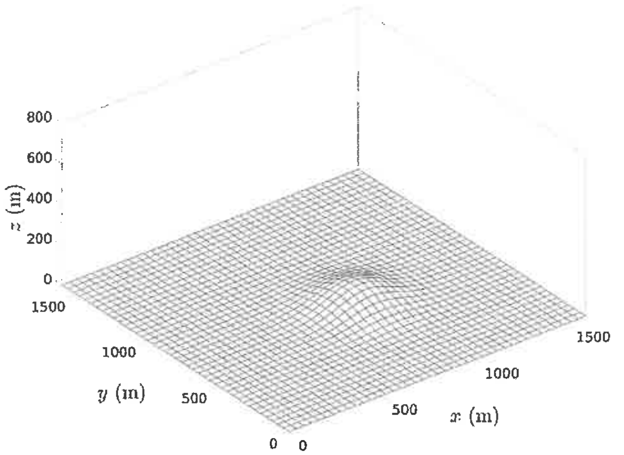


Fig. 3. Computational domain (showing only grid points at the ground).

m. The medium parameters (wave speed, density, and attenuation) are given as functions of elevation (distance from the ground), presented in Fig. 4. These profiles are derived from a typical night-time profile fitted to a fourth-degree polynomial (to guarantee smoothness).

The reference solution is obtained by simulating until $t = 1.8$ seconds using sixth-order operators on a grid with $901 \times 901 \times 451 \approx 366 \cdot 10^6$ degrees of freedom (DOF), see Fig. 5.

The time step is chosen as 1 % of the stability limit to guarantee that the temporal error is negligible. As in Section 5.1, we verify that this reference solution is sufficiently refined by comparing it to the solution on a coarser grid and find the differences small. Thus, this high-resolution reference solution can be used as a substitute for analytical solutions when comparing to less accurate approximations. Here we evaluate the convergence behavior of second and fourth-order SBP operators on grids with 3x, 6x and 10x larger spatial step sizes.

We evaluate the accuracy of the schemes in terms of the relative L_2-error, given by

$$e_p^{(N)} = \frac{||v_p^{(N)} - v_{ref}||_2}{||v_{ref}||_2}, \tag{28}$$

where $v_p^{(N)}$ is the solution of order p with N DOF and v_{ref} is the reference solution limited to the smaller grid. For two solutions with different numbers of DOF N_1 and N_2, we estimate the convergence rate as

$$q_p = \frac{\log\left(\frac{e_p^{(N_1)}}{e_p^{(N_2)}}\right)}{\log\left(\frac{N_1}{N_2}\right)^{1/3}}. \tag{29}$$

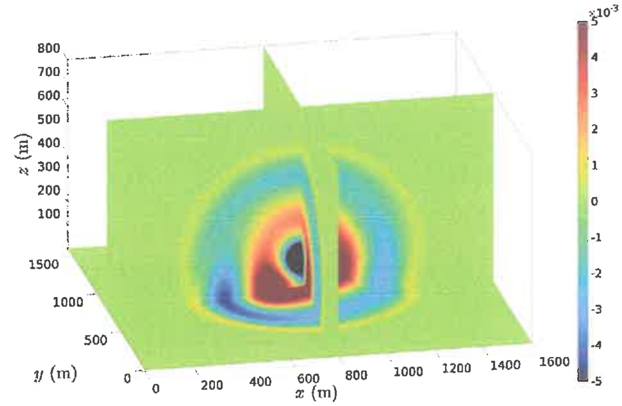


Fig. 5. The reference solution (at $t = 1.8$).

Table 1
Errors and convergence rates of second and fourth order accurate SBP operators relative to a high-resolution reference solution obtained with sixth order SBP operators.

DOF	$\log_{10}(e_2)$	q_2	$\log_{10}(e_4)$	q_4
3.8e5	−0.56	–	−0.54	–
1.7e6	−1.03	2.17	−1.01	2.16
1.4e7	−1.81	2.59	−2.23	4.07

In Table 1 the convergence rates for second and fourth-order accurate SBP operators are presented, showing that we obtain the expected convergence rates as the grid is refined.

6. Infrasound measurements

The importance of the atmosphere cannot be overemphasized when considering sound propagation, but also the sound power levels generated by modern wind turbines. There is a huge contrast between daytime and nighttime atmospheric conditions, particularly in forested regions [56] where many of the new wind farms in Sweden are located. There is also a seasonal variation in the atmospheric conditions [9], particularly over the Baltic Sea [57], affecting offshore wind farms as well as land-based wind farms.

Measuring infrasound differs fundamentally from measuring audible sound and requires carefully calibrated low-frequency instruments. The equipment used in this study is described below, in Section 6.1. Due to the large size of the source (wind turbines) and the long wavelength of 1 Hz sound (several hundred meters), receivers should not be placed

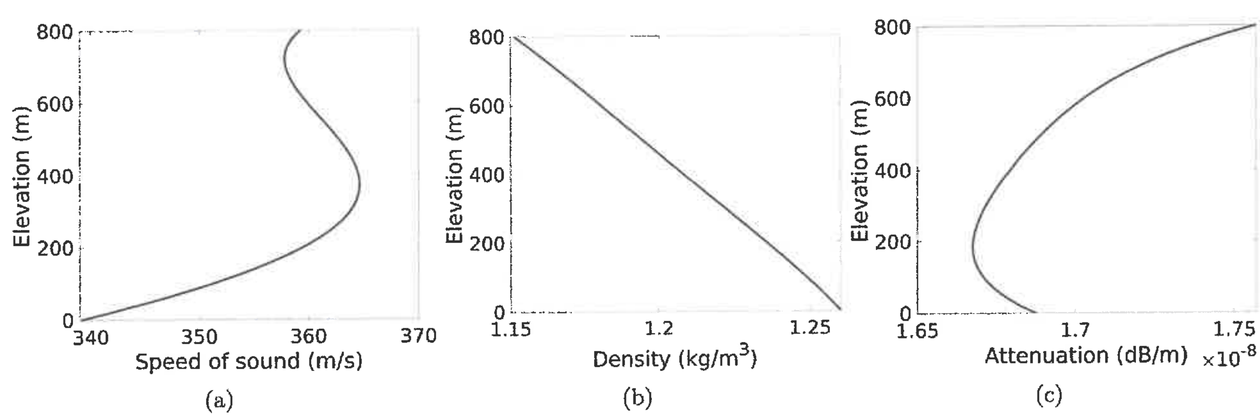


Fig. 4. Atmospheric data used for the convergence study: (a) speed of sound, (b) air density, and (c) acoustic attenuation.

Fig. 6. Infrasound measurement at Målarberget December 16, 2024.

in the immediate vicinity of the turbines, where the point-source approximation is less valid. Conversely, measurements should also not be taken too far away to ensure that the recorded signal originates from the wind farm of interest and to minimize modeling errors associated with atmospheric effects. Accordingly, the measurements were performed approximately 500 m to 2 km from the nearest turbine.

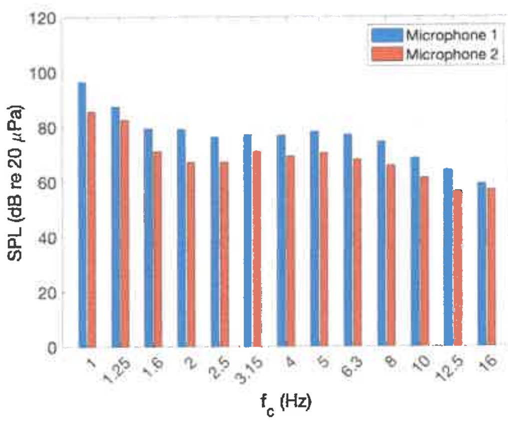
Table 2
The measured SPL at 1 Hz one-third octave band, Målarberget wind farm.

Measurement	Microphone 1	Microphone 2
2023–10-26 (13.00 CEST)	96.3 dB	85.6 dB
2024–10-23 (11.00 CEST)	91.6 dB	99.3 dB
2024–12-16 (12.00 CEST)	115.5 dB	–

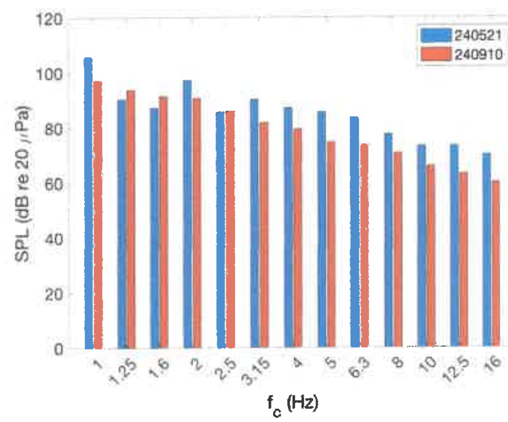
Infrasound around 1 Hz has distinct properties compared to audible sound above 100 Hz. It is less sensitive to uncertainties in ground and atmospheric attenuation, as well as to turbulence in the atmospheric boundary layer or vegetation, due to its long wavelength. Modern wind turbines are strong emitters in this frequency range, producing levels well above typical background levels as shown in Fig. 8. These properties justify our measurement strategy and support the subsequent analysis of turbine sound power levels.

6.1. Infrasound equipment

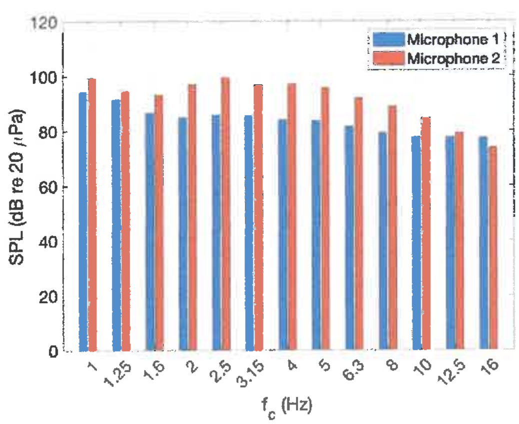
Measuring infrasound down to 1 Hz accurately requires instruments that are demonstrably calibrated. A relative calibration can be carried out in a vault such as one of the CTBTO-certified infrasound stations. We performed the calibration at NORSAR relative to one of their Hyperion microphones at their station in Elverum. In the present study, a 65 mm Lidström microphone manufactured by Gargnäs Electronics in Sweden was used as a sound pressure sensor, calibrated at NORSAR. The



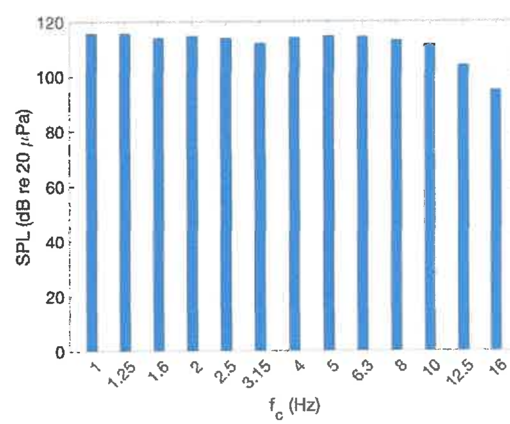
(a) Målarberget 2023-10-26



(b) Lervik 2024-05-21 and 2024-09-10

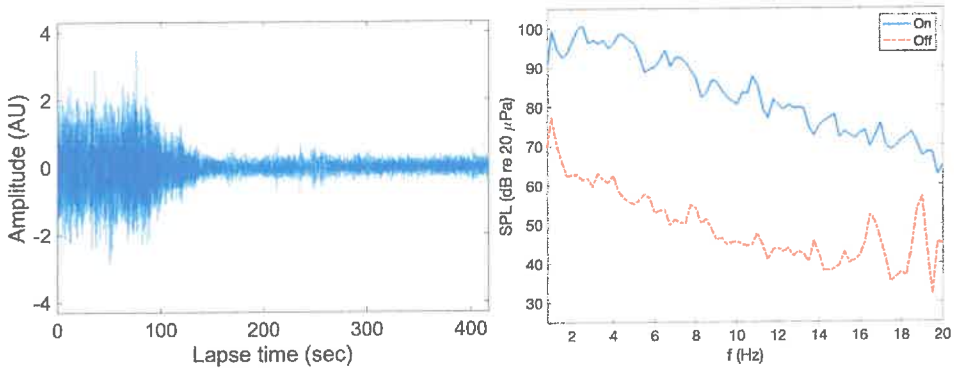


(c) Målarberget 2024-10-23



(d) Målarberget 2024-12-16

Fig. 7. Infrasound measurements (one-third octave band, center frequencies f_c 1–16 Hz) at Målarberget wind farm: (a) 2023-10-26 (13.00 CEST), (c) 2024–10-23 (11.00 CEST), (d) 2024-12-16 (12.00 CEST); and (b) Lervik 2024–05-21 (15.00 CEST), 2024-09-10 (15.00 CEST). Figs. 9–16 show the weather data.



(a) Pressure fluctuations

(b) Sound pressure dB

Fig. 8. (a) Time history of pressure fluctuations, (b) continuous pressure spectrum at Målarberget 2024-10-23, Microphone 2 location. With the plant On and Off. The turbine-on case is estimated from lapse time 10–60 s, while the turbine-off case is taken from lapse time 276–373 s of the time series.

Lidström microphones were developed in the early 1980s in Sweden, to detect for example helicopters. It is designed explicitly for low-frequency sound detection, and is well-suited for capturing infrasound pulses down to 1 Hz. A detailed description of the microphone's design and performance can be found in [58]. The data acquisition system was configured with a sampling frequency of 1060 Hz and, to enhance data reliability, the microphone was shielded from wind interference using a specialized metal windscreen, effectively reducing unwanted wind noise. In Fig. 6 the Lidström microphone is used to measure infrasound at Målarberget on 2024–12-16, and the results from that measurement are shown in Figs. 7 and 14. The SPL in dB is relative 20 μPa.

Remark 6. Ideally, the infrasound measurements should go down to 0.1 Hz to capture the BPF from the new larger wind turbines expected to be between 0.2–0.5 Hz. However, the Lidström microphone is only accurate down to 1 Hz. In a future project, we will use more sensitive infrasound microphones, such as Hyperion, to measure infrasound down to 0.1 Hz accurately.

6.2. Measurement results

We have conducted measurements at Målarberget wind farm three times: 2023–10-26 13.00 CEST, 2024–10-23 11.00 CEST, and 2024–12-16 12.00 CEST, and at Lervik wind farm twice: 2024–05-21 15.00 CEST and 2024–09-10 15.00 CEST. We used two microphones at different locations at Målarberget wind farm on 2023–10-26 and 2024–10-23, and one microphone on the other occasions. The locations of the measurement points in relation to the wind turbines can be seen in Figs. 12, 13, 14, 17, and 18.

Målarberget wind farm consists of 27 wind turbines of Vestas V150-4.2 MW type with a hub height of 125 m (total height is 125 + 75 = 200 m) and began operating in 2021. Lervik wind farm consists of 7 wind turbines of SG170-6.6 MW type with a hub height of 115 m (total height is 115 + 85 = 200 m) and began operating in 2024.

The results from the measurements, in terms of dB relative to 20 μPa, are shown in Fig. 7. For completeness, we show the results up to

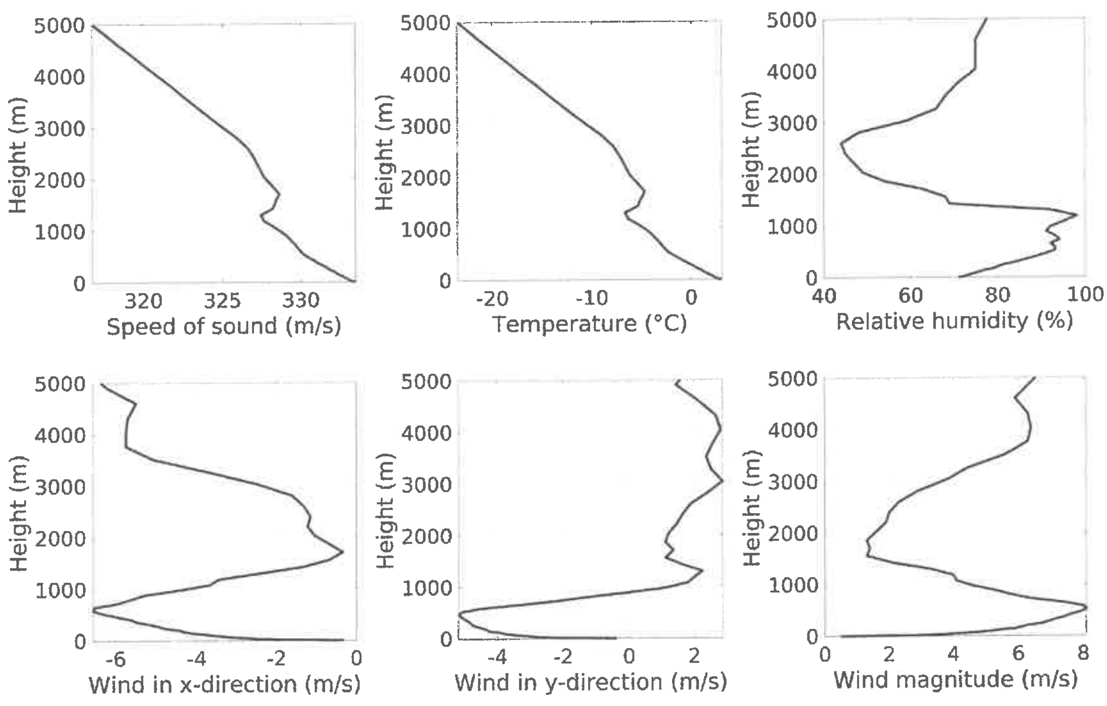


Fig. 9. Weather data (speed of sound, temperature, relative humidity and wind in x- and y-directions) in the center of Målarberget wind farm 2023–10-26 (13.00 CEST).

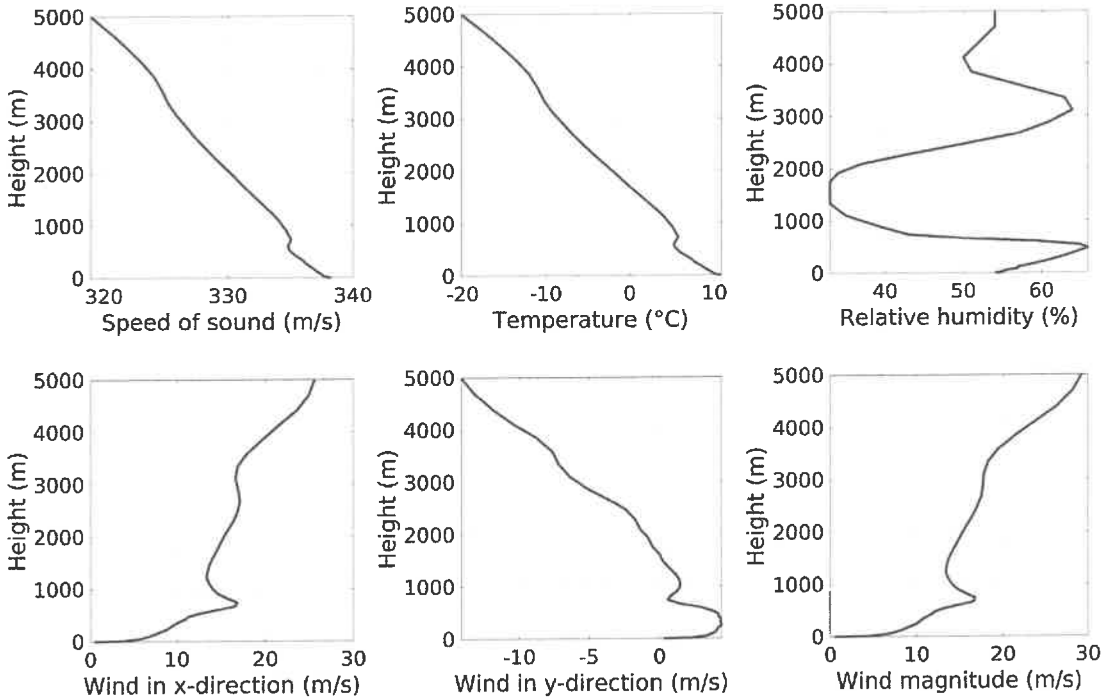


Fig. 10. Weather data (speed of sound, temperature, relative humidity and wind in x- and y-directions) in the center of Målarberget wind farm 2024–10-23 (11.00 CEST).

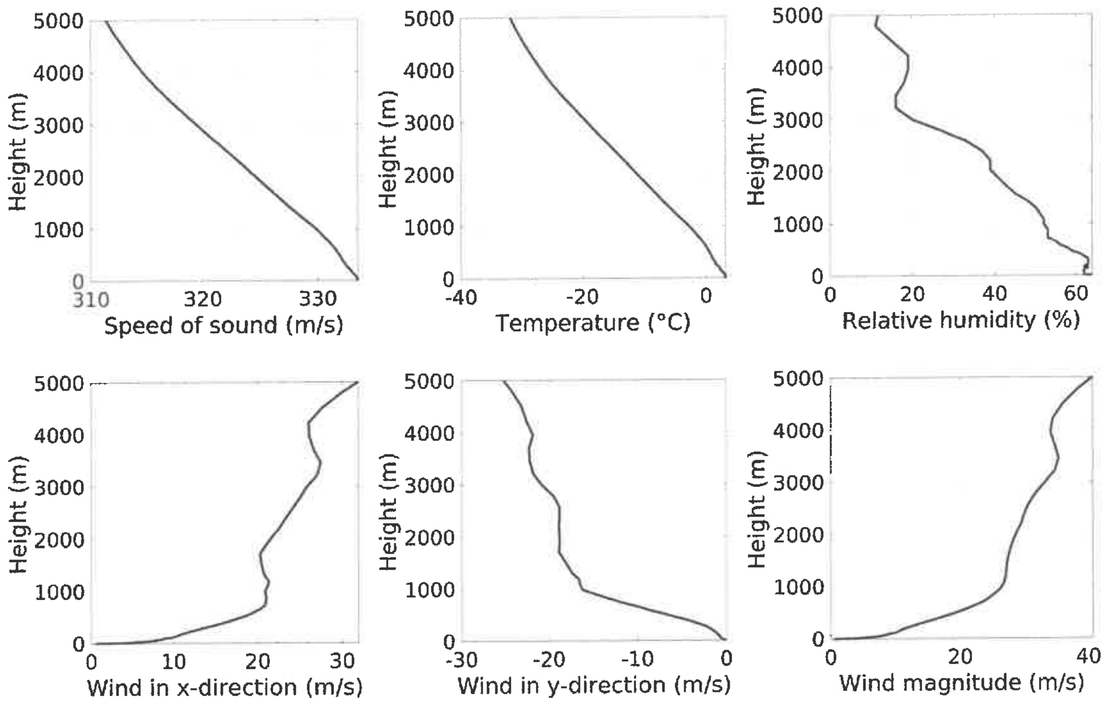


Fig. 11. Weather data (speed of sound, temperature, relative humidity and wind in x- and y-directions) in the center of Målarberget wind farm 2024–12-16 (12.00 CEST).

the 16 Hz one-third octave band, but we will focus on the 1 Hz band in the upcoming sections.

To ensure that the measured infrasound levels were not caused by background noise, we conducted continuous measurements at the Målarberget wind farm on 2024–10-23 during a complete shutdown of the facility. Fig. 8 shows the measurement data recorded at microphone position 2 on that date, capturing the period as the turbines gradually came to a stop. The recording started at 11:50 CEST and covers the transition from full operation to complete shutdown. Approximately 80 s into the measurement, the turbines began to slow down, reaching a full stop after about 150 s. During operation, the signal exhibits higher energy levels, whereas following the shutdown, the amplitude decreases rapidly and stabilizes at a substantially lower background level. These observations confirm that the increased infrasound is directly attributable to the operation of the wind turbines.

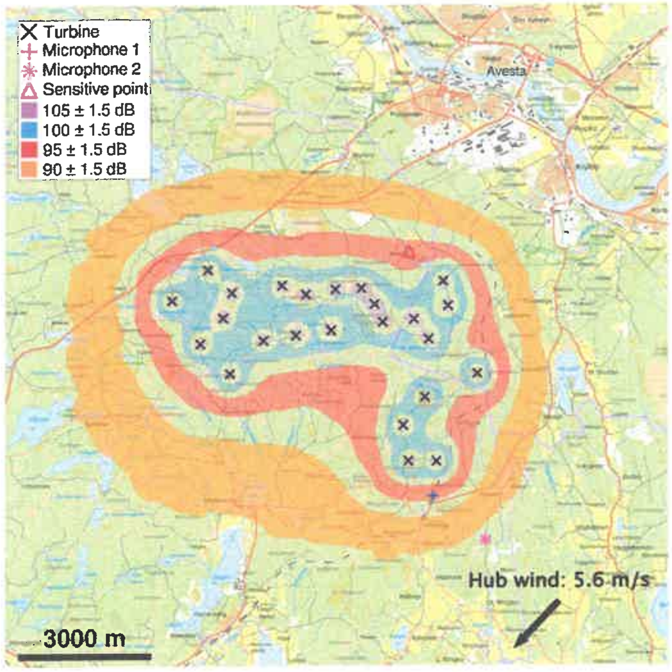


Fig. 12. Infrasound (1 Hz) simulation at Målarberget 2023–10-26 (13.00 CEST), based on two measurements (microphone 1 (96.3 dB) and microphone 2 (85.6 dB)). Here showing the simulated dB levels. The sensitive point means a nearby home (94.7 dB). Map from Lantmäteriet [59]. Weather data is presented in Fig. 9.

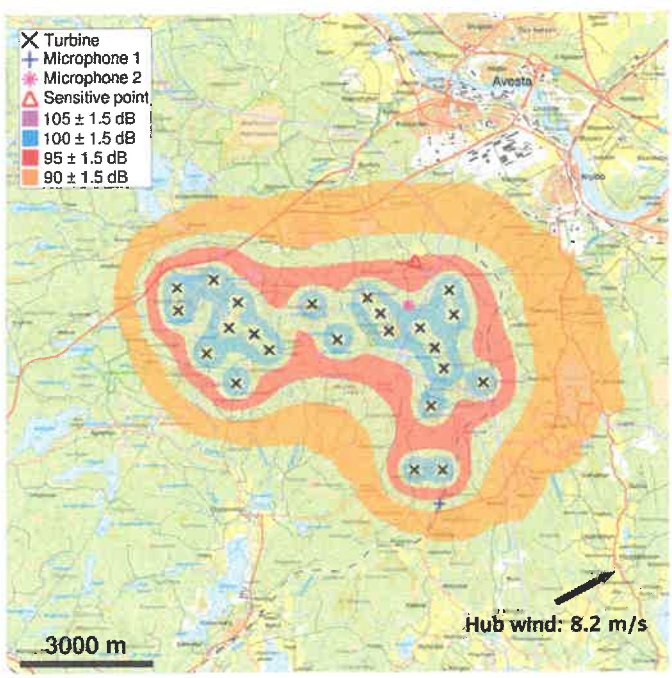


Fig. 13. Infrasound (1 Hz) simulation at Målarberget 2024–10-23 (11.00 CEST), based on two measurements (microphone 1 (91.6 dB) and microphone 2 (99.3 dB)). Here showing the simulated dB levels. The sensitive point means a nearby home (93.8). Map from Lantmäteriet [59]. Weather data is presented in Fig. 10.

7. Simulation of infrasound

The first main focus of the present study is to validate the simulation tool against accurate infrasound measurements. The second main focus is to map the sound power levels in the infrasound regime for a few modern types of wind turbines and examine the influence of the atmosphere. In the present study we will only consider the 1 Hz infrasound.

To compute the sound power levels of the wind turbines at the time of a specific measurement, we do the following:

1. Load topography and ground type data for the area of interest.
2. Load atmospheric data for the specific time of the measurement.
3. Load active turbines at the time of the measurements (often some turbines are shut down for maintenance).
4. Solve the optimization problem

$$\min_{A} \sum_{r}^{N_r} (L_{\text{meas},r} - L_{\text{tot},A}(\boldsymbol{x}_r))^2, \tag{30}$$

where N_r is the number of receiver points, $L_{\text{meas},r}$ is the measured SPL at receiver point $\boldsymbol{x}_r$, and $L_{\text{tot},A}(\boldsymbol{x}_r)$) is the total simulated SPL (defined by (10)) at receiver point $\boldsymbol{x}_r$ with amplitude A.

The sound power level in decibels is then computed from A using the standard free-field definition. Since we assume that all sources are equal, solving (30) is straightforward. Increasing the sound power levels of the

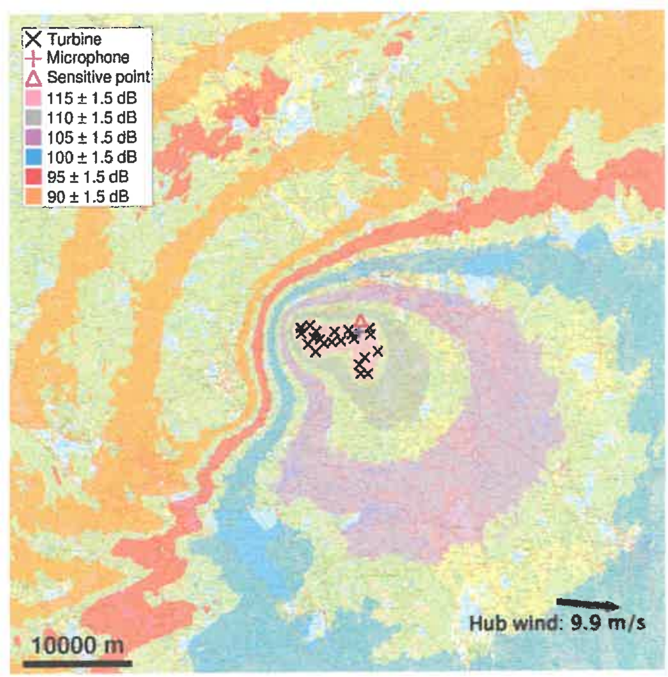


Fig. 14. Infrasound (1 Hz) simulation at Målarberget 2024–12-16 (12.00 CEST), based on measurement (115.0 dB). Here showing dB levels. The sensitive point means a nearby home (112.1 dB). Map from Lantmäteriet [59]. Weather data is presented in Fig. 11.

Table 3
The computed sound power levels and simulated SPL at 1 Hz one-third octave band, at Målarberget wind farm.

Measurement	Sound power level	Microphone 1	Microphone 2	Sensitive point
2023–10-26 (13.00 CEST)	155.0 dB	94.2 dB	87.6 dB	94.7 dB
2024–10-23 (11.00 CEST)	153.7 dB	92.8 dB	98.1 dB	93.8 dB
2024–12-16 (12.00 CEST)	172.6 dB	115.5 dB	–	112.1 dB

sources simply amounts to increasing $L_{tot,r}(A)$ by the same amount, thus only one simulation with each source is needed for each measurement.

7.1. Simulation of infrasound at målarberget wind farm

The measured 1 Hz SPL at the receiver points for the three separate measurements is presented in Table 2. Based on the measurements, we solve the optimization problem (30) for the sound power levels as described in Section 7 and compute (simulate) noise maps over the whole region.

A subset of the weather data we use (speed of sound, temperature, relative humidity and wind in x- and y-directions) in the center of Målarberget wind farm at the time of the measurements is shown in Figs. 9–11.

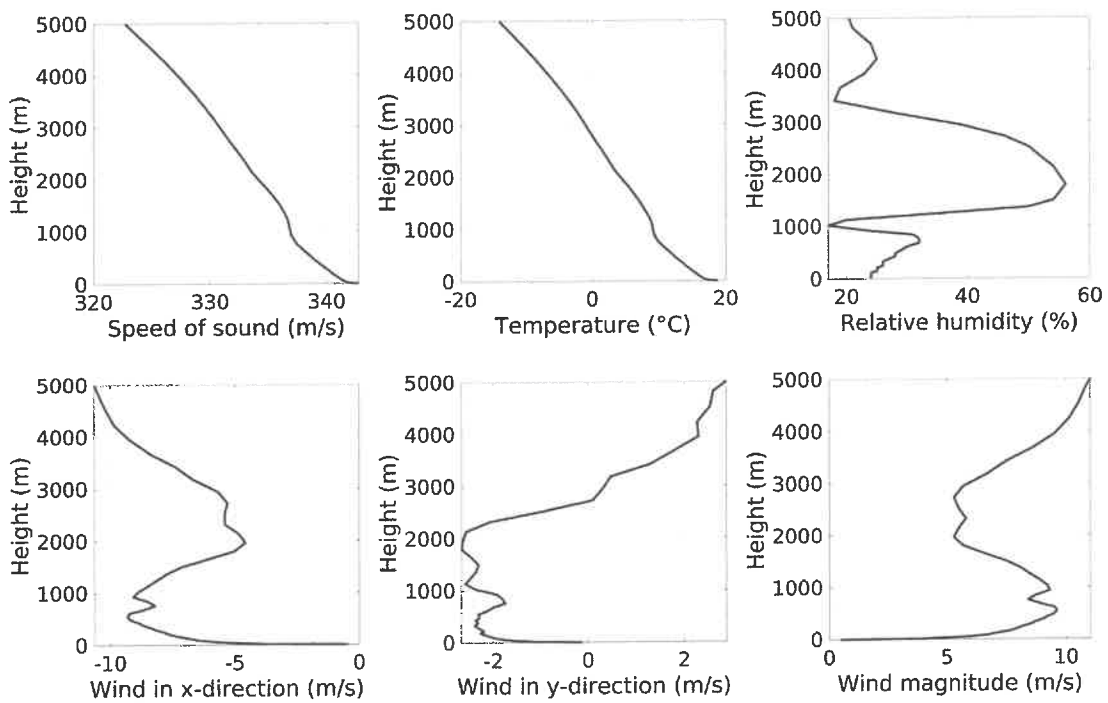


Fig. 15. Weather data (speed of sound, temperature, relative humidity and wind in x- and y-directions) in the center of Lervik wind farm 2024-05-21 (15.00 CEST).

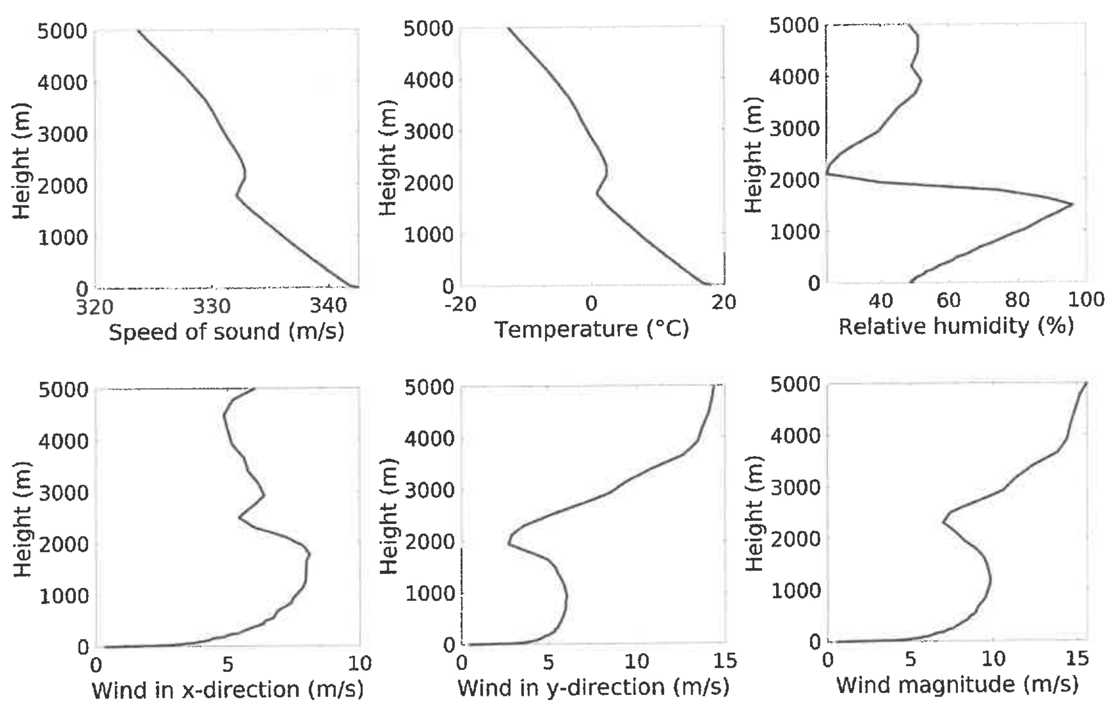


Fig. 16. Weather data (speed of sound, temperature, relative humidity and wind in x- and y-directions) in the center of Lervik wind farm 2024-09-10 (15.00 CEST).

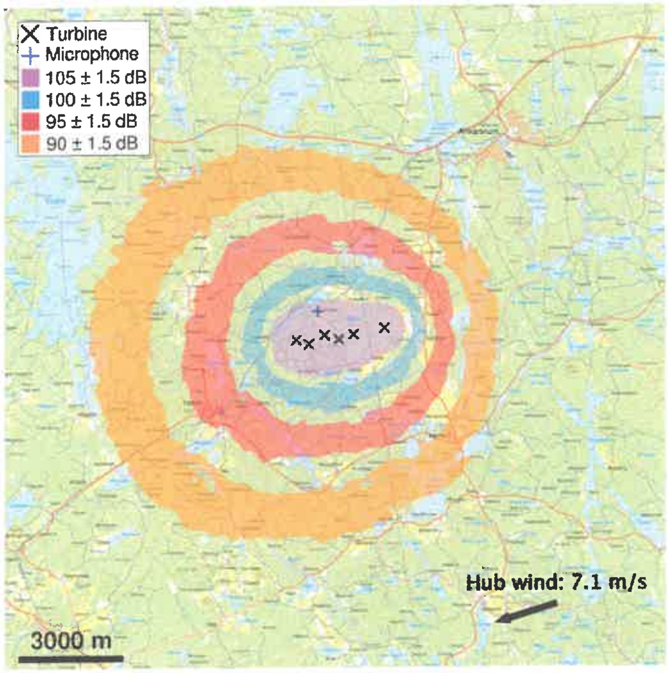


Fig. 17. Infrasound (1 Hz) simulation at Lervik 2024–05-21 (15.00 CEST), based on measurement (105.6 dB). Measurement location at a nearby home. Here showing dB levels. Map from Lantmäteriet [59]. Weather data is presented in Fig. 15.

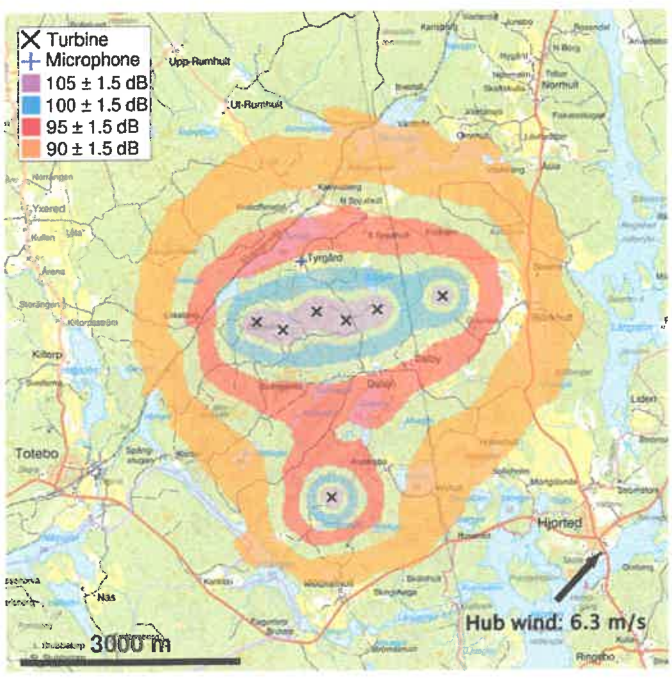


Fig. 18. Infrasound (1 Hz) simulation at Lervik 2024–09-10 (15.00 CEST), based on measurement (97.1 dB). Measurement location at a nearby home. Here showing dB levels. Map from Lantmäteriet [59]. Weather data is presented in Fig. 16.

The noise maps based on the inferred sound power levels of the sources are presented in Figs. 12, 13, and 14, one for each measurement. Note the different spatial scales in the figures. In the noise maps we have included the wind direction and strength at the hub, as well as the locations of the measurement points and a sensitive point (indicating

Table 4
The measured SPL at 1 Hz one-third octave band, at Lervik wind farm, along with the determined wind turbine sound power levels.

Measurement	Microphone	Sound power levels
2024–05-21 (15.00 CEST)	105.6 dB	164.5 dB
2024–09-10 (15.00 CEST)	97.1 dB	156.2 dB

the position of a nearby home). The computed sound power levels and simulated SPL (at the points of interest) are presented in Table 3.

7.2. Simulation of infrasound at lervik wind farm

We perform the same procedure for the Lervik measurement data as described in Section 7.1. The weather data at the center of Lervik wind farm for the two measurements are shown in Figs. 15 and 16. The noise maps based on the inferred sound power levels are presented in Figs. 17 and 18, including the location of a nearby home (the measurement point). The SPL at 1 Hz one-third octave band at the receiver point for each measurement is presented in Table 4, along with the inferred wind turbine sound power levels determined using SoundSim360. Note that in the cases with only one receiver point, the measurements and simulations match exactly.

7.3. Simulation of infrasound at tvinnesheda and and karskruv wind farms

In wind farm permit applications, it is standard practice to assume a simplified atmosphere with tailwind conditions in all directions. In reality, however, the atmosphere is far from constant, and its strong influence on sound propagation (at least for audible sound) is well established. To illustrate the importance of atmospheric conditions for infrasound propagation, we use SoundSim360 to compute the SPL at 1 Hz around the Tvinnesheda and Karskruv wind farms (outside the city of Åseda, Sweden) for four different atmospheric profiles. The atmospheric parameters, given as functions of elevation, are shown in Fig. 19. Weather data were obtained on 2023–03-31, close to the spring equinox, from the center of the Målarberget wind farm: the *day* profile corresponds to 16:00 and the *night* profile to 04:00. For both the daytime and nighttime atmospheres, wind speeds were scaled to 8 m/s and 1 m/s at 10 m height, respectively, yielding four distinct atmospheric profiles.

The Tvinnesheda wind farm consists of 47 Vestas V150-4.3 MW wind turbines, and the Karskruv wind farm consists of 20 Vestas V150-4.5 MW wind turbines. Both turbine types have a hub height of 116 m and a total height of 116 + 75 = 191 m. Tvinnesheda and Karskruv began operation in 2022 and 2023, respectively. Fig. 20 shows the simulated SPL for daytime and nighttime atmospheric profiles, with wind scaled to 1 m/s and 8 m/s at 10 m height. The sound power level (at 1 Hz) is fixed at 153.7 dB, determined from measurements conducted on 2024–10-23 at the Målarberget wind farm. Five sensitive points (A-E) corresponding to nearby residences and towns at various distances from the wind farms are included. The SPL values (1 Hz) at these points are listed in Table 5 for the four different atmospheric profiles, together with the distance to the nearest wind turbine. The results demonstrate that atmospheric conditions can significantly affect the SPL (at 1 Hz) in the far field. The largest variations occur between the daytime atmosphere with 1 m/s tailwind (at 10 m height) and the nighttime atmosphere with 8 m/s tailwind: at sensitivity point A, the difference is 3.8 dB, whereas at point E it reaches 14.5 dB.

Remark 7. Note that the measured sound power levels at the Målarberget wind farm span 153.7–172.1 dB (see Table 3). Using a sound power level of 172.1 dB instead of 153.7 dB increases the SPL at the sensitive points by 18.4 dB compared to the values listed in Table 5. The nighttime atmospheric profile, featuring an 8 m/s tailwind at 10 m height, corresponds to a highly refractive atmosphere (see Fig. 20) that induces waveguide behavior, in stark contrast to the daytime profile

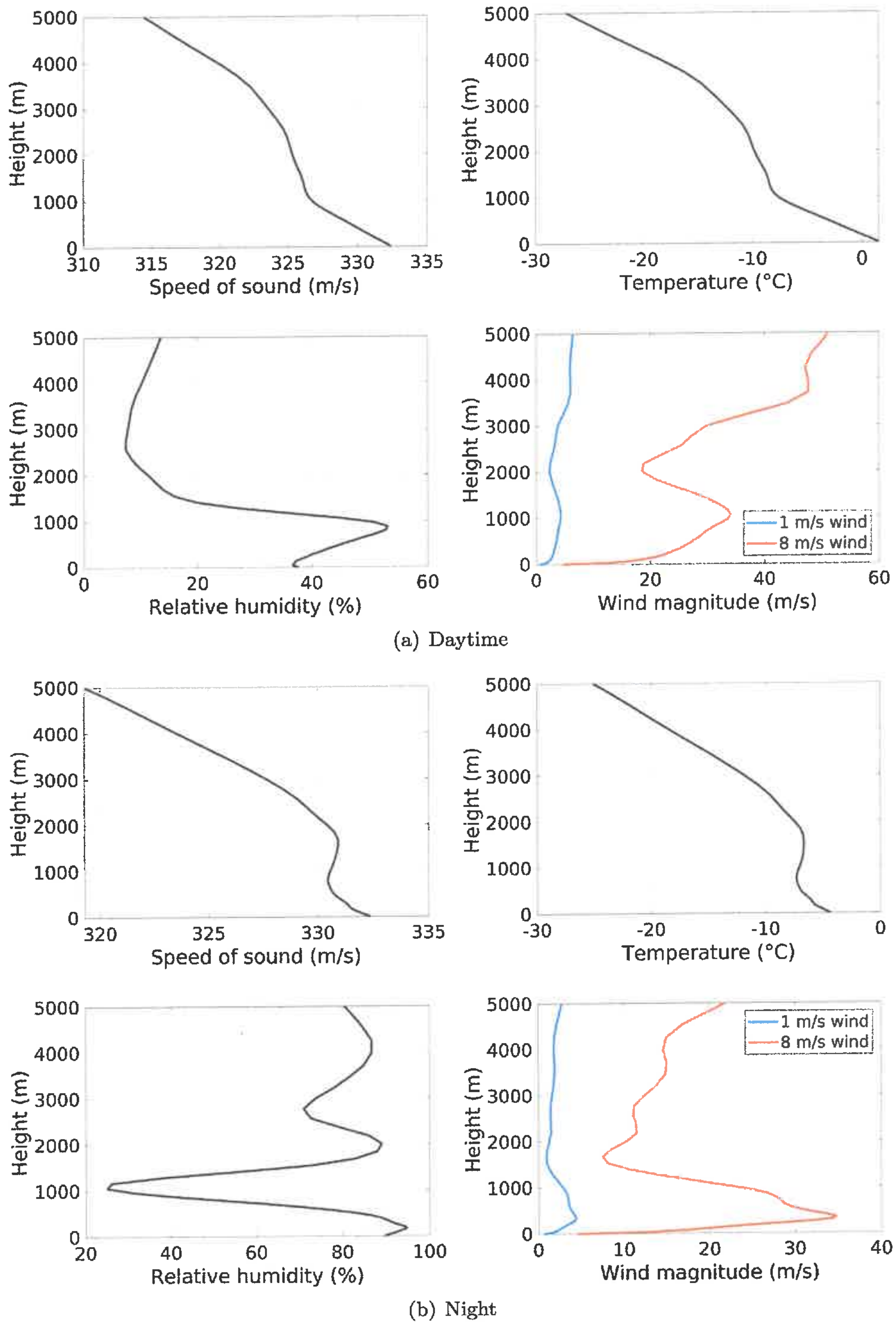


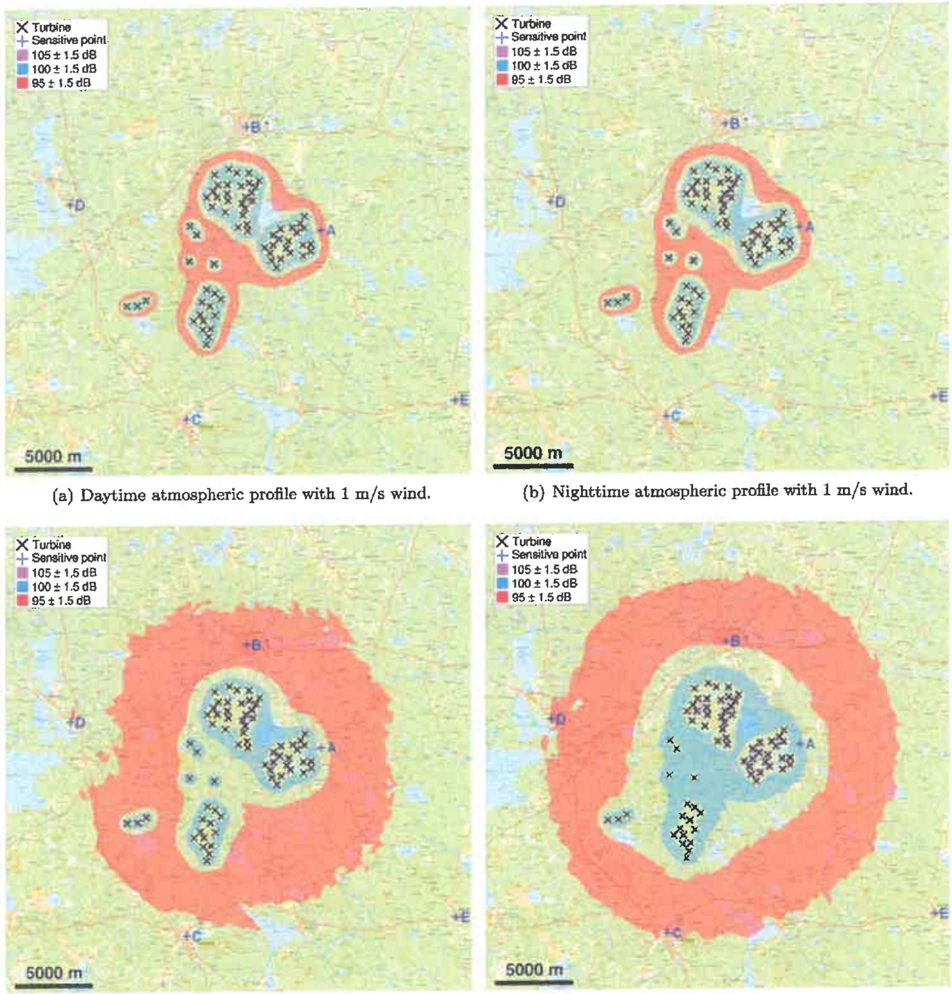
Fig. 19. Weather data showing the difference between (a) daytime (16.00) and (b) nighttime (04.00) March 31 2023 at the location of Målarberget wind farm. Wind speeds were scaled to 8 m/s and 1 m/s at 10 m height, respectively.

with a 1 m/s tailwind at 10 m height, which exhibits much weaker refractive effects. The daytime profile with an 8 m/s tailwind at 10 m height also induces waveguide behavior, which explains the slow decline in SPL.

8. Conclusions

We have presented a high-fidelity simulation tool for low-frequency sound propagation in large and complex three-dimensional domains. The method has been verified against benchmarks and validated with infrasound measurements from several modern wind farms, demonstrating both reliability and accuracy. The results emphasize the crucial role of realistic atmospheric data, which must be incorporated to obtain trustworthy predictions of sound propagation over long distances.

This study also shows that modern, large-scale wind turbines generate infrasound levels substantially higher than those reported for older, smaller turbines. These findings enhance the understanding of the acoustic characteristics of contemporary wind turbines and provide valuable guidance for environmental assessments and policy-making.



(a) Daytime atmospheric profile with 1 m/s wind.
(b) Nighttime atmospheric profile with 1 m/s wind.
(c) Daytime atmospheric profile with 8 m/s wind.
(d) Nighttime atmospheric profile with 8 m/s wind.

Fig. 20. SPL at 1 Hz around the Tvinnesheda and Karskruv wind farms under different atmospheric conditions (a)-(d). Daytime and nighttime profiles are considered, with wind scaled to 8 m/s and 1 m/s at 10 m height, respectively. SPL values at five sensitive points (A-E) near residences and towns are listed in Table 5. Maps are from Lantmäteriet [59].

Table 5
Simulated SPL at five sensitive points (A-E) around the Tvinnesheda and Karskruv wind farms for daytime and nighttime atmospheric profiles with wind speeds of 1 m/s and 8 m/s at 10 m height. Corresponding weather data are shown in Fig. 19. Distances from each point to the nearest wind turbine are included.

Atmosphere	Point A	Point B	Point C	Point D	Point E
Day profile 1 m/s	95.2 dB	88.7 dB	82.6 dB	81.2 dB	76.7 dB
Day profile 8 m/s	97.5 dB	94.6 dB	92.9 dB	93.3 dB	91.1 dB
Night profile 1 m/s	95.8 dB	90.2 dB	85.1 dB	84.1 dB	80.1 dB
Night profile 8 m/s	99.0 dB	96.3 dB	93.5 dB	93.6 dB	91.2 dB
The nearest turbine	1085 m	2924 m	5005 m	7478 m	13,460 m

Future work will focus on extending measurement capabilities using highly sensitive infrasound microphones, such as Hyperion, to capture frequencies down to 0.1 Hz, as well as investigating the directivity of wind turbine noise in the low-frequency regime.

Finally, low-frequency sound propagation in urban environments will be addressed, particularly with respect to transmission through building facades under high outdoor noise levels, which may represent a potential environmental health risk. These developments will further strengthen the applicability of SoundSim360 in environmental acoustics and its relevance for assessing potential health impacts.

CRediT authorship contribution statement

Ken Mattsson: Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Gustav Eriksson:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Leif Persson:** Writing – review & editing, Investigation, Data curation. **José Chilo:** Writing – review & editing, Resources, Investigation, Data curation. **Kourosh Tatar:** Writing – review & editing, Resources, Investigation, Data curation.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Ken Mattsson reports that financial support was provided by Swedish Research Council. Ken Mattsson also reports that financial support was provided by Swedish Research Council Formas. Gustav Eriksson reports that financial support was provided by Swedish Research Council Formas. Gustav Eriksson also reports that financial support was provided by Swedish Research Council. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Gustav Eriksson was supported by the Swedish Research Council (grant 2021-05830 VR) and FORMAS (grant 2022-00843). Ken Mattsson was partially supported by the Swedish Research Council (grant 2021-05830 VR), and FORMAS (grant 2022-00843).

We thank the team at NORSAR for the opportunity to perform the microphone calibration especially Jon Magnus Christensen and Tormod Kvaerna.

Data availability

Data will be made available on request.

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Summary: Ontario's Green Energy Policy vs. Social Justice

By Tom Thompson / Dec 2025

Policy Goals vs. Reality:

- **The Promise:** The GEA (2009) sought to make Ontario a green energy leader, create jobs, lower emissions, and boost manufacturing through feed-in tariffs (FITs).
- **The Problem:** While boosting renewable tech, the policy failed to account for uneven impacts, favoring urban centers and marginalizing rural areas with large projects.

Social Justice Conflicts:

- **Unequal Burdens:** Rural communities near wind farms experienced negative effects (health concerns, aesthetic blight, property value loss), creating "sacrifice zones" for the broader green agenda.
- **Exclusionary Benefits:** Green energy initiatives, including community projects, often favored wealthier, more connected groups, increasing existing divides between communities and excluding marginalized populations from ownership and benefits.
- **"Not In My Backyard" (NIMBYism):** Resistance wasn't just irrational self-interest; it stemmed from real, unaddressed concerns about distributive justice and power imbalances, challenging elite-driven energy planning.

Key Tensions & Findings:

- **Policy Design:** High-level goals struggled with local implementation, creating public backlash over costs and unequal distribution of impacts.
- **Power Dynamics:** Centralized energy institutions and industry networks often sidelined community voices and true participatory planning, hindering a truly just transition.
- **Need for Justice:** Studies highlight the necessity for redistributive policies, stronger community engagement, and explicit strategies to address practical capacity gaps to ensure green energy benefits everyone, not just the privileged.

In essence, Ontario's green push revealed a critical gap: climate goals were pursued without adequate consideration for social equity, leading to localized injustice that undermined broader public support and highlighted the need for a more inclusive, justice-focused approach to energy transition.

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Scientific Research Publishing

Open Journal of Social Sciences, 2021, 9, 447-486
https://www.scirp.org/journal/jss
ISSN Online: 2327-5960
ISSN Print: 2327-5952

Ontario's Green Energy Policy vs. Social Justice

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How to cite this paper: Whiteley, A., & Dumbrille, A. (2021). Ontario's Green Energy Policy vs. Social Justice. *Open Journal of Social Sciences, 9,* 447-486.
https://doi.org/10.4236/jss.2021.91033

Received: December 22, 2020
Accepted: January 26, 2021
Published: January 29, 2021

Abstract

Objectives: To explore the development and implementation of Ontario's Green Energy Act and the outcomes on social justice and risk of harm to Ontario residents. To provide examples of government actions taken to achieve its goals and the occurrence of consequences, whether intended or unintended. **Methods:** In Ontario, many legal cases have been filed due to concern regarding the impact of industrial wind turbines on people and the environment. The contents of this article have primarily been taken from the documents filed during an Application for a Judicial Review that examined the process of approval of industrial wind turbines in Ontario. References to support the content of this article also include: evidence derived from other legal cases, government communications including records obtained by Freedom of Information requests, peer reviewed literature, and other sources. **Results:** Evidence is presented that suggests the government erred by creating an inflexible policy/statute that ensured that industrial wind turbines would be approved, erected and become operational at any cost. It provides examples of government actions taken to achieve this position that are contrary to widely held fundamental principles of administrative law and governmental legitimacy. Recommendations are provided for mitigating some of the outcomes of a government policy and preventing impacts on social justice from happening again.

Keywords

Green Energy Act, Wind Turbines, Judicial Review, Natural Justice, Access to Justice

1. Introduction

By 2000, climate change was increasingly becoming a concern and energy policy became a focus, with increased consideration of renewable energy such as wind turbines.

In 2009, the government of Ontario, Canada enacted the Green Energy Act (GEA) with the intention of making "Ontario a global leader in the development of renewable energy" through fostering the growth of renewable energy projects. The government sought to remove barriers and promote opportunities to stimulate renewable energy development and a green economy (A Green Energy Act for Ontario 2008; Green Energy and Green Economy Act, 2009). This policy resulted in several statutes of general application being amended or interpreted to reduce impediments to the approval and construction of wind turbine facilities. The government thought that these actions would lower electricity costs, lower carbon emissions, establish a manufacturing industry capable of exporting technology, and create 50,000 jobs (Runyon, 2009; Environmental Defence, 2016). These expectations have not been achieved (Gallant, 2016; Ontario Society of Professional Engineers Report, 2012).

Residents living in the areas where industrial wind turbine (IWT) projects were planned expressed concerns regarding the impact of the turbines on people and the environment; where they were operational people voiced complaints.

This paper addresses the questions: How did such a noble policy of reducing a carbon footprint go so far amiss, and what have been the long-term impacts of these actions on citizens, businesses, and our legal framework? The approach taken was to explore why and how the Green Energy Act (GEA) came about, and what appropriate mitigation might be for those impacted by the more than 2600 IWTs (CanWEA, 2020) that are operational in Ontario. It includes a summary of governance issues and evidence of the extent of government efforts that were associated with the creation and enactment of the GEA and its guidelines. Examples of the harmful impacts of the impugned statutory test on human, plant and animal life, and on the social, economic and cultural conditions that affect the lives of residents in rural communities across Ontario are also discussed.

This is the second article in which we explore Ontario's GEA. The previous one reproduced a letter from one of the authors, lawyer Alan Whiteley, to the government that was written to prevent future Acts and policy decisions from making similar mistakes. It provides recommendations of changes in order to modernize the justice system to avoid impacts on access to justice, citizen rights and animal protection. The GEA with associated changes to Acts and policies was used as an example (Whiteley et al., 2021). Similarly, McRobert et al. (2016) described unfairness in the approval system outlined in the GEA, and noted that such an process likely contributed to environmental, social and procedural injustices. The process has been characterised by other lawyers, social scientists and others as top-down, and centralized, causing complaint, conflict and problems (Broekel & Alfken, 2015; Colton et al., 2016; Krogh, 2011).

2. Methods

References to support the content of this paper include: documents derived from an Application for a Judicial Review that include sworn Affidavits by Ontario residents, evidence and transcripts from Ontario Tribunals, other court cases, government records including documents obtained by Freedom of Information (FOI) requests, written communication with government officials, and peer-reviewed references. To increase clarity, the documents that are based on the Application for a Judicial Review are augmented by additional references.

The Supreme Court of Ontario—An Application for Judicial Review

The primary reference source for this exploration was documents supporting a Judicial Review (*Court File No.* 15-2162). The case was submitted by the County Coalition for Safe and Appropriate Green Energy (CCSAGE Naturally Green), a not-for profit group of concerned citizens who were represented by lawyer Alan Whiteley. CCSAGE submitted an Application for Judicial Review of the process by which a Renewable Energy Approval (REA) was issued in Prince Edward County, Ontario, in 2015. In 2019 the case was updated and submitted to the Ontario Superior Court to more specifically have the GEA declared discriminatory and thus unconstitutional (CCSAGE vs Ontario (AG); Court File No. CV-19-0154-0000). The purpose of the Application was to request that the Supreme Court of Ontario respond to the following questions:

- Is the REA that was issued to construct an IWT project the result of institutional bias in the GEA and/or operational bias by the various Ministries?
- Was the implementation of the GEA an infringement of natural justice and a denial of rights created under the Charter of Rights and Freedoms, in that residents of rural Ontario are discriminated against as turbines will never be located in urban communities?

The Judicial Review record includes over 50 sworn affidavits prepared by individuals from across the province. These addressed issues such as the GEA's removal of power from Municipalities and the lack of meaningful account of the impact on health, endangered species, and the local economy including tourism, property and business values. After 4 years the file was withdrawn as resources to conduct the case were depleted.

3. Ontario's Green Energy Act

The documents submitted during the Application for a Judicial Review give evidence that industry proposed, advised on, and recommended modifications of the policies that would govern it, i.e., those that would later be used in the GEA. It was only clear well after the fact that this direct collaboration between the government and industry went on for over many years.

For example, in 2001, a Wind Power Task Force that included representatives from seven Ontario Ministries and a consortium of wind energy developers, engineers, and investors was initiated and led by the industry's voice on wind energy. IWTs were touted as a reliable renewable energy source and as new technology to combat global warming. The stated purpose of the task force included proposing regulatory policies for wind power and examining opportunities for industry/government co-operation (Ontario Newsroom, 2012). A report with recommendations for the promotion of wind power was compiled by the Task Force (Ontario Wind Power Task Force Industry Report and Recommendations, 2001) and was part of the Ministry of Natural Resources (MNR) Environmental Bill of Rights (EBR) posting (Environmental Bill of Rights, 2003). The industry commented on topics such as the wind company's rental charges and length of the royalty holiday and lease period for turbines on Crown land. The ministry amended its report to reflect these comments (Environmental Commissioner of Ontario Annual Report, 2004-2005).

In 2003, in response to government's request for a new mechanism for developing renewable energy, an industry group—the Renewable Energy Task Team (RETT)—in collaboration with government officials, drafted a policy on Standard Offer Contracts. The subsequent report stated that an objective was to "make a proposal for regulating policies for wind power" and focused on the Power Purchase Agreements, i.e. the money paid out to proponents. The contracts were recommended to be long term, tax exempt, and have expanded incentives (Renewable Energy Task Team, 2002).

By 2009 the Premier was ready to act on his goal of making Ontario a world leader in "green" energy production, and to achieve this with minimal interference from the public and from municipal governments. Like other global political leaders of the time, the former Premier of Ontario considered that the wind industry could contribute to a green energy policy and the rules that would govern it (CBC News Report, 2009; National Wind Coordinating Committee in the US, 2007).

The centrepiece of the Premier's ambitious plan was the GEA. Passed in 2009, the GEA was comprised of 65 pages of clauses amending 20 statutes of general application including the Municipal Act, the Ontario Heritage Act, the Planning Act, the Public Lands Act, the Electricity Act and the Environmental Bill of Rights Act (Green Energy and Green Economy Act. Acts Affected, 2009b; McRobert et al., 2016; Ontario Hansard 25 Feb 2009). Other statutes such as the Endangered Species Act were subsequently amended, and extended the reach of the GEA even further. The resulting policy changes enabled wind turbine facilities to be installed across rural Ontario in contravention of municipal by-laws, official plans and property assessment rights and most fundamentally, in contravention of the duty of care the government owes to the public to address health and safety concerns.

The new legislation and the implementation guidelines it gave rise to were for the express purpose of streamlining the approval process for IWT facilities and to reduce, and wherever possible, eliminate impediments that would cause delays in the construction of these facilities. They reflect a number of the proposals made by organizations with wind energy interests such as the Green Energy Act Alliance, a coalition of wind power interests including the Ontario Sustainable

Energy Association, trade associations, developers, manufacturers and environmental groups (Canadian Institute for Environmental Law and Policy, 2009; Ontario Green Energy Act Alliance, 2009; The Ontario Sustainable Energy Association, 2003).

Soon after the passing of the GEA Ontario residents began expressing concerns (Legislative Assembly of Ontario, 2009d; Gallant, n.d.). Ontarians, particularly in rural areas where the wind turbines were to be erected, were vocal in their opposition to this policy. Many filed appeals of the government's Renewable Energy Approvals—the process that approved a wind turbine project. These appeals were held before an Environmental Review Tribunal (ERT), a restrictive requirement of the GEA (Green Energy and Green Economy Act, 2009a; Wilson et al., 2020; Krogh et al., 2019).

While there were over 50 appeals launched, very few were successful (Wilson et al., 2020). This was due to the high evidentiary threshold and the onerous legal test put in place by the government that required proving causality before the project was erected and became operational: appellants were required to prove in an ERT that in the future the project "will cause" serious harm to human health or serious and irreversible harm to plant life, animal life or the natural environment (Green Energy and Green Economy Act, 2009a). There were many obstacles in even filing an appeal, one of those being that appeals of Renewable Energy Approvals were cost-prohibitive, with legal fees ranging from several thousand to millions of dollars (Wilson et al., 2020). In fact, it has been suggested that participant and intervenor funding be available for participation in approvals, and policy and planning processes related to Ontario laws such as the Green Energy and Green Economy Act (McRobert, 2011). This would improve public access to justice.

Outside of the Tribunal hearings, Ontario residents expressed their concerns regarding other impacts including the infringement on the rights of rural property owner such as enjoyment of their property, and ability to develop their own land (Morrison, 2012; Spencer, 2015; and see Section 6.2).

It was not long before opposition to the GEA spread throughout the Province. Not only Ontario residents were voicing concerns; analysts tracking energy production and hydro rates were also starting to take note of the increasing electricity costs (Gallant, 2016; Gallant, n.d., and Section 6.5). And there was evidence of increased carbon emissions resulting from the requirement for back-up generation due to the low capacity and operational intermittence of wind turbines (Ontario Society of Professional Engineers Report, 2012; Rosenbloom, 2004).

Any opposition or criticism was seen as an impediment to the development of energy projects, with some people characterizing these concerns as anti-environment, NIMBYism (Not in My Backyard) and bananas (Build Absolutely Nothing Anywhere Near Anything) (Clarke, 2012; Smith & Klick, 2007; Casey, 2019; Ontario Environmental Review Tribunal, Case Nos.: 10-121 and 10-122).

The Premier was complicit in the use of such derogatory terms, stating that while it is okay to object on the basis of "safety issues and environmental standards" that "NIMBYism will no longer prevail" (Ferguson & Ferenc, 2009).

While achieving a position of "green energy at any cost" (Wente, 2016) is considered contrary to widely held fundamental principles of administrative law and governmental legitimacy (Shain, 2011, Whiteley et al., 2021), the government remained adamant throughout its time in power that these actions were urgently needed to reduce carbon emissions and would have demonstrable additional benefits including lowering electricity costs, establishing a manufacturing industry capable of exporting technology, and creating 50,000 jobs (A Green Energy Act for Ontario: Executive Summary, 2008; Runyon, 2009; Wikipedia, 2009; Environmental Defence, 2016).

The government's insistence on "green energy at any cost" is believed to have eventually led to the decisive and humiliating defeat of the Liberal party in the 2018 provincial election (McGrath, 2018; Toronto Star, 2018).

4. Implementation of the Green Energy Act

Evidence indicates that the GEA was implemented by a top-down approach, with the government dictating the direction and strategy in partnership with industry. Upper levels of government provided targets and priorities to senior managers who made clear to staff that implementation of the GEA was of the highest priority. A letter from the Minister of Natural Resources to an industry association obtained through a freedom of information request stated:

> The Ministry is also aligning its resources to provide support for renewable energy projects. MNR is focusing staff resources on reviewing and approving Feed-in-Tariff projects, resulting in the approval of over 75 per cent of natural heritage assessments submitted to the Ministry… I am pleased that MNR staff have been meeting regularly with representatives of CanSIA and CanWEA and their member companies to work with the industry to satisfy the REA submission requirements. (Freedom of Information Request, 2010a)

The review process became a box-ticking exercise for projects to which these ministries had inadvertently become promoters and partners. During a Remedy Hearing, evidence was presented that government staff commented to a pre-GEA proponent that having to complete an Environmental Assessment (EA) was a "regulatory glitch" that should not delay the proponent's schedule, and that the mandatory EA was an "administrative exercise", "just a formality" and "no big deal" (Freedom of Information Request 2010b).

Additional evidence of reviewing partiality was revealed when, although a staff expert herpetologist was hired to assist the government in the implementation of the Endangered Species Act and in the development of provincial policy and regulations for species at risk herpetofauna, including the Blanding's Turtle, neither the hiring of a government staff expert nor his advice was disclosed at any time during a Tribunal that was held in 2013. This information only came to light during the Remedy Hearing (August 2015), when a Tribunal Order revealed the extent to which the advice of this government expert was not considered during the review and approval of a proposed wind turbine project at Ostrander Point. During testimony under oath, when this government expert was asked what advice he gave to the ministry he stated:

> As such, it is reasonable to conclude that road mortality at the site could result in the eventual loss of the population (Crowley, 2015).

Appendices 1 and 2, derived from affidavits provided to the Supreme Court of Ontario during that Application for a Judicial Review, provide additional specific examples of where removal of quality controls on technical reports and greatly reduced impediments to construction and operation of IWTs have negatively affected the health of the environment and put public at risk.

These examples reveal the top down approach and reduction of impediments to constructing and operating the IWTs. By 2018, of the 80 applications for REAs to construct IWTs including those approved prior to enactment of the GEA, only two had not been approved and two were revoked by ERTs.

The government was acting as a protector of the environment while promoting and approving energy projects, a situation that lends itself to a conflict of interest.

5. Evidence of Governmental Preferential Treatment

There is evidence that the GEA and its associated regulations affected established policies, practices and procedural processes that were in place to protect the health of people and the environment. This created legal inconsistencies.

5.1. Improper Purpose

The creation of the GEA and the related changes subsequently made to established regulations demonstrated improper purpose, a legal term for an action whereby government alters results or prevents normal procedures from occurring (Law Insider).

For example, in 2009, the Premier of Ontario stated that the purpose of the proposed Act was to stop special interest groups and municipal governments from trying to block green energy projects for anything other than safety or environmental concerns (CBC News Report, 2009). Key components of the Act involved removing municipal governments from the decision making process, streamlining approvals and guaranteeing and prioritizing connection of wind energy facilities to the electricity grid, and allowing only restricted appeals of a wind energy project (Green Energy and Green Economy Act, 2009a). With the passing of the GEA, the Environmental Protection Act was modified to make exemptions for "green energy" projects. These established legal inconsistencies such as those related to a ministry's Statement of Environmental Values. (*See* 5.2

Regulatory Capture and Institutional Bias)

5.2. Regulatory Capture and Institutional Bias

Regulatory capture occurs when a public authority charged with regulating an industry in the public interest comes to identify the public interest with the interests of the industry, rather than the interests of the general public (Kenton, 2018). The GEA-related policies, practices, and procedures giving advantage to or favoring industry over the public demonstrated apparent institutional bias.

An early occurrence of regulatory capture was when Ontario moved towards a law promoting green energy, and the wind industry and its members took part in the formulation of the law by providing the government with their recommendations to shape the policy that would govern it.

By the end of 2008, some residents described harmful effects from operating wind turbines (Ontario Municipal Board, 2007). Community groups began forming to express the concerns that more health effects would appear if proper standards were not in place (Wilson et al., 2010). As noted by a renewable energy industry group, an Act was needed so that "the forces of status quo not be allowed to block wind projects." (Legislative Assembly of Ontario, 2009c). The proposed GEA and the use of wind power was being promoted by various groups (Canadian Institute for Environmental Law and Policy, 2009; Green Energy Act Alliance, 2009; The Ontario Sustainable Energy Association, 2003).

As well as giving input into the GEA, industry and associated member groups had provided recommendations that were incorporated into the technical guidelines that governed implementation of the GEA. For example, in October 2008, Ontario published its "Noise Guidelines for Wind Farms", that defined how far from a household or other structure a wind turbine could be sited. As described below, the draft guidelines were modified after the recommendations were received (A Green Energy Act for Ontario, 2008; Tomlinson, 2009). McRobert et al. (2016) commented that the implementation of the GEA is "…an Act that creates an unfair and incoherent process for renewable energy approvals".

Based on court documents, recommendations beneficial to industry but detrimental to rural residents were consistently applied by the authors of the Act. On numerous occasions, Appellants perceived that health-related expert witnesses testifying on their behalf before the Environmental Review Tribunal were ignored or derided by government lawyers (Environmental Review Tribunal, 2011). Members of professional associations contributed to the forward movement of the industry by dismissing or discounting the complaints of serious harm to health from residents.

Documents show that the government referred to proponents rather than the public as their "clients". (Incident Reports obtained by WCO. Under CLIENT on the forms, the MOE/MOECC/MECP lists the power operator). There were also concerns regarding support of the wind power industry by insiders of the Liberal Party of Ontario (the elected provincial government) (Wind Concerns

Ontario, 2020).

These actions indicate that the government considered "public interest" to be that of the wind turbine industry and perhaps voters in urban areas rather than those most affected.

The policies, practices and procedures related to and leading up to the GEA, that gave advantage to or favored industry over the public also demonstrated apparent institutional bias. Concerns about regulatory bias in the renewable energy sector by government agencies can be found as early as 2004-2005 in supplemental report by Ontario's Environmental Commissioner that commented that:

> ...members of the public could question the independence of MNR in setting the policy in the first place and also question whether MNR is able to act as a legitimate rule enforcer and applicant elevator when it comes to reviewing applications for the use of Crown land for wind power purposes because it is also actively promoting this industry. (Environmental Commissioner of Ontario. Annual Report Supplemental 2004-2005)

In 2009, the Ontario government issued Regulation 359/09, linked to EBR 01-6516, that set out the process for the Renewable Energy Approval (REA) under the Environmental Protection Act of Ontario. In the initial draft released for comment on June 10, setbacks of 550 metres from all receptors were proposed along with property line setbacks of turbine hub height plus blade length. The applicable setbacks would increase with the number of turbines and the sound level rating of selected turbines (Ontario Newsroom, 2009a, 2009b). The wind industry immediately objected to these guidelines, arguing that they would "jeopardize over three-quarters of all 'construction ready' wind projects in Ontario". In a letter sent to Ministers Smitherman and Gerretsen, the Canadian Wind Energy Association warned that "Of the 103 'shovel ready' wind projects in the province, 96—and fully 48 per cent of all proposed turbines—will be affected by the new rules". And 79 of the projects, representing 2591 MW, will be "rendered immediately non-viable" or require a "back to the drawing board redesign" (Hornung, 2009). As an alternative, they recommended a property line setback of the IWT blade length plus 10 metres, with the set-back only applying to "non-partici- pating receptors" (the terms of reference adopted by the wind industry and government to designate those not financially benefitting financially from hosting wind turbines on their property) (Environmental Commissioner of Ontario Annual Report, 2004-2005). The adjusted guidelines met these recommendations.

The wind industry also lobbied against proponents having to address low-frequency noise and infrasound. A Minister of Environment proposed that as a condition of approval for wind turbine projects, proponents would be required to monitor and address any perceptible infrasound (vibration) or low frequency noise as a condition of the Renewable Energy Approval (Perry, 2009). The Canadian Wind Energy Association took exception to the proposed requirement

(CanWEA Supplemental Submission, 2009). Despite the government's prior commitment to include requirements for low frequency noise (Hornung, 2009) and the evidence indicating that IWTs generate a broad spectrum of noise including low frequency noise (LFN) and infrasound that may be inaudible (Engel, 2011; Krogh et al., 2019; Wilson et al., 2020), the government removed the requirement to monitor and address LFN/infrasound. Ontario's noise guidelines are limited to monitoring of dBA audible noise. At the same time, communication from the Ministry of Environment in 2009 advised that regarding the ability to monitor compliance, there was:

> No scientifically accepted field methodology to measure wind turbine noise to determine noncompliance with a Certificate of Approval limits. (Bardswick, 2009)

Both noise measurement companies and those living near IWTs raised concerns regarding emissions of LFN/infrasound (Ontario Municipal Board, 2007; Walker et al., 2012; Wilson et al., 2010).

By 2010, the government was aware that the setbacks were inadequate to avoid adverse health effects. Government records obtained through a Freedom of Information request stated that:

> It appears compliance with the minimum setbacks and the noise study approach currently being used to approve the siting of WTGs (wind turbine generators) will result or likely result in adverse effects contrary to subsection 14(1) of the EPA. (Hall, 2010)

and that instead of the noise limit established by the noise guidelines:

> …the setback distances should be calculated using a sound level limit of 30 to 32 dBA at the receptor, instead of the 40 dBA sound level limit. (Jeffery et al, 2014)

The content of the GEA and the associated regulations contains apparent inconsistencies with the Statement of Environmental Values (SEV) of various ministries. In Ontario, each ministry is mandated through the Environmental Bill of Rights (EBR), section 7, to prepare and adhere to their SEV. These represent promises made to the public that all actions and policies by each ministry will consider and integrate social, economic and scientific aspects in their decision-making processes. For example, the SEV of the Ministry of the Environment included directions to:

- use a precautionary, science-based approach in its decision-making to protect human health and the environment (consistent with s. 11 of the Environmental Bill of Rights);
- evaluate cumulative effects in decision making;
- assess social and economic impacts to a community;
- be transparent about decision making;
- base decisions on best available science, in all decision making. (Statement of

Environmental Values, 1993)

While these values are consistent with the Environmental Protection Act, the GEA overrode many of the important protections. In order to enable IWT approvals and implementation when contrary to these principles, the government effectively gave IWTs an exemption by reducing the scope to which Environmental Review Tribunals (ERTs) could base decisions.

The GEA imposed a single legal pathway to appeal an REA: through an ERT that had limited jurisdiction that was inconsistent with the applicable SEVs. The legal test for health as defined in the GEA was that the wind turbines "will cause" serious harm to human health or serious and irreversible harm to plant life, animal life or the natural environment. The Tribunals were not permitted to consider health related or environmental cumulative effects, economic viability, social or economic impacts, the Precautionary Principle or the "more likely than not" provision. In effect the benchmark for a successful challenge was set so high as to make challenges almost impossible. Contrary to the provisions of the ERT, the following has been stated regarding "proof of causality" for human health and the environment:

> … prudent public health actions do not and should not require 100% proof of harm. In fact, precautionary and preventative actions are specifically justified at a point in time before scientific proof is established. If the growing weight of evidence is positive (although all studies need not report positive effects) then it may be essential to take preventative actions and implement policies that are protective of public health, safety and welfare rather than wait for absolute certainty.
>
> … environmental quality acts… require that assessments use a standard of "potential for a significant impact on the environment which is a relatively low level of certainty (10% to 30%)" (Sage & Carpenter, 2012)

The GEA required that an application to appeal a wind turbine project had to be filed within 15 days after the issuance of the Renewal Energy Approval, a very tight timeline for the public to organize a community appeal and to raise funding, hire legal representation and acquire expert witnesses—all the more so when the public had no way of knowing when the Renewable Energy Approval was about to be issued and for which project. Further, since government was a proponent of the process, challenges of an REA were considered a challenge to the government. As such, community groups were generally forced to legally challenge both their government and the industry provider as "partners". Government lawyers demonstrated having a collegial and close working relationship, with the lawyers representing their wind developer clients. These conditions for securing a hearing under the GEA scheme appear prejudicial to those who appealed the siting of the turbines and highly favourable to the proponents and their expert witnesses.

By 2009, the process was in place: the required burden of proof (causality) was established and the appeal timeline minimized. The government began rapidly approving IWT projects. Once started, the process continued unabated until just before the 2018 election: between 2010 and 2018, more than 50 appeals were held (Wilson et al., 2020). By then, government records obtained by Freedom of Information records documented the problems experienced by those living near IWTs (Wilson et al., 2020; Krogh et al., 2019). Many municipalities passed resolutions of being "unwilling hosts" to an IWT project after the Premier vowed to not impose such projects on places unwilling to take them (Martin, 2013) (The Premier pulled back on this vow). To ensure continuation of the "green" energy production, Bill 135 was proposed in 2015. It was intended to amend the GEA to prevent an incoming government from being able to cancel projects on a discretionary basis at a relatively low cost; the Bill did not pass.

To sum up, in the creation of the GEA, its regulations and guidelines, and modifications to related Acts, the government worked closely with the wind power industry. Policy makers failed to establish and apply rules and standards that were protective of residents and of the natural environment.

5.3. Evidence of Differential and Discriminatory Treatment

In addition to the indication of differential treatment provided above, there are perceptions of differential treatment related to the processing and awarding of IWT contracts. For example, the requirement to adhere to the commercial operation date was altered on separate occasions by the Ontario Independent Energy System Operator (IESO). (The IESO is considered independent: it is governed by a board whose directors are appointed by the government of Ontario.) In February 2011, the Ontario Power Authority (OPA) (originally licensed by the Ontario Energy Board but later merged with IESO) offered that all Feed-in-Tariff (FIT) contracts that had not yet reached their Commercial Operation date may have an extension of up to one year. Regarding project delays, in June 2013 the OPA advised contract holders that it would not act upon its right to terminate a contract should they need more time to meet the requirement in their Notice-To-Proceed.

Discriminatory treatment is also built into the process. Due to large land use requirements for IWT projects (SaskWind, 2020), IWT projects in Ontario are located in rural Ontario, often against local by-laws and the will of the municipality and community (Martin, 2013). The statutory provisions and regulations effectively restrict IWTs to rural areas, and potentially create a divide between the residents of rural and urban/suburban Ontario. With the lower population density in rural compared to urban voting areas, this can hamper the rights of residents of rural Ontario to advocate for, enact, rely on and claim the benefit of sound land use planning principles or environmental protection legislation: these factors amount to a form of discrimination.

Urban communities have been able to resist electrical generating stations on political grounds. For example, when the government had two firm contracts to build gas-fired generating stations in the urban areas of Mississauga and Oakville, the urban residents objected loudly and the government relocated those gas-fired stations to rural Ontario, at a change cost of an additional $1.1 billion (Morrow, 2015). When the government contracted to purchase power from a proposed IWT array to be erected in Lake Ontario off the Scarborough Bluffs (east of Toronto), they declared a moratorium when urban residents objected, exposing taxpayers to a damage award of $28 million (Jones, 2017; Talaga, 2011).

Despite the thousands of noise and other complaints and requests for government action (Krogh et al., 2019; Wilson et al., 2020) rural residents living near IWTs have not benefitted from a responsive government in the same way residents living in urban areas have benefitted.

6. Outcomes of the Green Energy Act

The implementation of the GEA in Ontario has resulted in reported negative outcomes related to a range of issues such as: effects on health, safety, social well-being and the economy, right to a fair tribunal, and loss of property rights,. At the same time, there has been no evidence that the assumed benefit in reduction of greenhouse gases has occurred.

6.1. Effect on Health Protection

6.1.1. Incident Reports/Complaints and Gaps in Research and Knowledge

Government records document that neighbors living near IWT facilities filed over 4500 noise complaints/incident reports between 2006 and 2016. In the majority of cases, there have been limited field responses to the complaints (Sage & Carpenter, 2012). Compliance audits are a requirement of the REA, yet the government has a backlog of these audits. As responses by the government to complaints do not occur until the results of noise audits are known, resolution of the complaints can be delayed for many years.

Although Health Canada logs, analyses, interprets and acts on adverse reaction reports associated with medications and medical devices (Government of Canada), neither Health Canada nor the provincial health ministry have provided a similar vigilance monitoring program for IWTs. The regulatory authority for IWT complaints in Ontario is the Minister of the Environment (Stachura, 2018). There is no indication that these complaints are analysed or shared with the Ontario health ministry.

There were gaps in health protection. Prior to launching the GEA in 2009, the Ontario government did not conduct health studies to determine whether the 550 m minimum setback from residences would protect the health of people living near the IWTs. Setbacks were established using computer models based on dBA sound; excluded were other types of noise such as the tonal quality and cyclic variation of the IWTs (Hall, 2010) and low frequency noise/infrasound. Limiting consideration of a single turbine rather than including all those that surround a home limits the ability to consider cumulative effects. These limitations were generally not supported by the government's field observations (Hall, 2010) or its Acoustic Consulting Report (Ramakrishnan, 2007). Unconsidered was the evidence that in addition to audible noise, operating IWTs emit tonal and cyclic (amplitude modulation) noise, and infrasound/low frequency noise (ILFN). ILFN can disrupt the normal functioning of the middle and inner ear and that of other sensory organs, and can lead to nausea, impaired equilibrium, disorientation and elevated blood pressure and is easily transmitted into buildings, causing psycho-acoustical annoyance and sleep disturbance for some residents (Acoustic Group, 2014; Alves-Pereira et al., 2019; James, 2012; Punch & James, 2016). Despite the limitations on the setback requirements that were defined as mandatory to protect the health of adjacent residents, exceptions have been made to allow reduced setback requirements through issuing an Amended REA in breach of the approved conditions and contravening the Environmental Protection Act (Vineland Power Inc., 2014; EBR Nos. 012-4601, 012-4493).

In 2010, the Chief Medical Officer of Health (CMOH) identified that there was a research gap associated with low frequency noise. At the same time, the CMOH issued an opinion denying a direct causal link between IWT noise and adverse health effects but did not address the role of an indirect pathway to adverse effects (Chief Medical Officer of Health Report, 2010). An Ontario Tribunal Decision stated that:

> The Tribunal has found above that "serious harm to human health" includes both direct impacts (e.g., a passer-by being injured by a falling turbine blade or a person losing hearing) and indirect impacts (e.g., a person being exposed to noise and then exhibiting stress and developing other related symptoms). This approach is consistent with both the WHO definition of health and Canadian jurisprudence on the topic. (Environmental Review Tribunal Case Nos. 10-121, 10-122, 2011)

Despite the CMOH report having been produced 10 years ago, the Ontario government continues to rely on it. Yet the World Health Organization (1999), in a review funded by the Ontario government (Howe, 2010), an Australian Tribunal Decision (Krogh et al., 2011), and other literature (Abbasi et al., 2016; Jeffery et al., 2014) comment on IWT-related adverse effects on residents living near IWTs.

The CMOH report has been referenced during the issuance of REAs (Renewal Energy Approval, 2012, 2014, 2018), and during judicial proceedings. (e.g., Ontario Superior Court of Justice, 2014, Court File No: 2055/14; ERT Case No.: 13-084-13-087 and Court File No: 2056/14 ERT Case No.: 13-097/13-098; and Environmental Review Tribunal Case Nos. 10-121 and 10-122, 2011) In response to an internal initiative to update the 2009 report in 2013, the CMOH stated that based on reviewing an updated literature review and comments from staff and local medical officers of health:

> I am of the opinion that my position as stated in my CMOH report remains

the same. (Freedom of Information Request, 2013)

To date, there is no evidence an update to the CMOH report has been publicly released.

In addition to complaints related to the components of noise/vibrations from IWTs, some individuals have reported being susceptible to electrical sensitivities due to high frequency ground current and transient and harmonic signals and electromagnetic/radio frequency energy related to IWT infrastructure and operational requirements (Havas & Colling, 2011; Krogh & Harrington, 2019).

The government has been aware that many adverse health complaints had been received from those living near IWTs (Krogh et al., 2019; Wilson et al., 2020), and that district officers were unable to demonstrate compliance with applicable standards (Hall, 2010; Krogh et al., 2019; Pearce, 2010; Wilson et al., 2020). The setbacks have not worked as expected and have not been altered to adjust for the increased size and capacity of newer IWTs. After years of complaints and submitted incident reports the government has failed to take any step to remedy the unauthorized pollution emitted by IWTs.

6.1.2. Abandoned homes

Some people living near wind energy facilities have reported adverse health effects and have left their homes (Krogh, 2011; Krogh et al., 2020; Le Coz & Sherman, 2017; Nicol & Seglins, 2011; Pearce, 2010); others contemplate doing so (Krogh et al., 2020). Some families have been billeted by, or have negotiated financial agreements with wind energy developers (Jeffery et al., 2014).

Although the government is aware that adverse effects resulted in people leaving their homes, no acknowledgement has been made or remediation given.

6.1.3. Contamination of Drinking Water

In some areas, well water supply at properties adjacent to IWTs has become depleted and/or unsafe as a result of their construction and vibration. Some wells are reported to have run dry or are producing turbid water (Di Maria, 2017; Wind Concerns Ontario, 2017). In one area, wells have become contaminated with black shale particles known to carry heavy metals such as uranium, lead, mercury and arsenic (RTI Laboratories, 1993a). The particles are smaller than one micron, such that they cannot be removed even by the finest filters and are easily absorbed through the skin. When the government required an IWT developer to perform an analysis on water contaminants, only those suspended particles large enough to be filtered were measured. An analysis commissioned by the well owners that included particles below 1 micron in size gave results many-fold higher than that of the company. It indicated that suspended solids increased 82 times, and that the number of black shale particles increased 14,500 times (from 47 particles/mL in the pre-construction sample to 681,939 particles/mL in the post-construction sample), while that of the company showed that suspended solids increased only 5 times and turbidity increased 13 times compared to pre-construction samples (RTI Laboratories, 1993b). Despite acknowledging the correlation between the pile driving and the spike in well water turbidity (Jacobs, 2017), the government continues to rely on the flawed methodology of the proponent to assert that there was no causation.

Although the government has since made a requirement of an REA that the project "not utilize pile foundations for project infrastructure" (EBR number 013-1675), the vibrations from operating IWTs continue to pollute the ground water.

6.1.4. Risk of Collapses and Fire

In recent years IWTs have snapped in half or thrown blades and other components over 500 m, incidents that threaten both landowners and farm animals. Incidents in Canada that have occurred in Ontario include: Chatham-Kent, Kawartha Lakes, Newcastle, Sault Ste. Marie, Orangeville, and in Nova Scotia: Grand Étang, and Point Tupper (Caithness Windfarm Information Forum, 2020).

The wind industry's publication "WindPower Monthly" published that there were about 3800 blade failures annually (June 2015). Worldwide, there had been over 2000 accidents total and hundreds of IWT fires. Uadiale et al. (2014) commented that due to highly flammable materials within the nacelle and other factors, fire accounts for a "substantial fraction of accidents" in any year—about 10 to 30%. The authors also note that fire intervention cannot occur due to the height of the IWTs. Since fire crews cannot extinguish such fires, in certain conditions the fire can spread to abutting properties. Fire issues have been acknowledged by the Ontario Fire Marshal: training courses for 2013-2014 included training associated with wind turbines and firefighter safety (Sylvester, 2013-2014).

The *Fire Protection and Prevention Act* (s. 76) prevents the abutting landowner from recovering any damages for loss caused by turbines in Ontario.

Although there is an association between fire and industrial-sized turbines, and control of such fires is problematic, this safety issue has not been addressed.

This section describes issues that indicate a failure to regulate to the benefit of the wind industry. There is clear evidence that health protection from IWTs should be reassessed.

6.2. Depreciation, Limited Use, and Loss of Enjoyment of Property

As discussed, the GEA requires a minimum setback of 550m from the nearest "receptor" (i.e. centre of an occupied building) and 100m from the nearest non-participating property line. Even before construction of IWTs is commenced, this setback requirement can prevent owners of abutting lands from being permitted to construct homes on their own lands within 450 m of their property line. IWT manufacturers have advised that workers and children not be allowed within 400 m of an IWT, especially in icy or stormy conditions (Ragheb, 2011). This can leave the abutting lands unfit for purpose and potentially unsaleable.

The government has consistently denied that construction of IWTs has any impact on sale prices of abutting properties. This appears to be based on a report prepared in 2008 by four employees of the Municipal Property Assessment

Corporation (MPAC) (Guerin et al., 2014) who were uncertified as appraisers of land sale prices. The MPAC study used only 5 variables to determine assessed values, none of which included proximity to IWTs. Despite their own study, MPAC is following a policy of reducing assessments of properties adjacent to IWTs while publicly declaring that IWTs have no impact on property values (Gulden, 2014a, 2014b).

Many professional real estate property appraisers have stated that IWTs cause substantial value diminution to nearby properties, and have conducted studies of actual values of specific properties within clearly identified distances from installed IWTs (Appraisal Group One, 2009; Lansink, 2012; McCann Appraisal, 2010). In Ontario, sellers of property have been required to provide full disclosure and must declare the potentiality for the presence of IWTs to the buyer. (Real Estate Clauses Ontario).

The approval of IWTs within proximity to occupied homes can essentially "sterilize" abutting lands, leaving them unfit for purpose and have reduced value, or be unsaleable. The approval of IWTs within proximity to occupied homes is tantamount to a regulatory taking of private property rights.

6.3. Social, Cultural and Economic Effects on Rural Communities

In areas where the economy is dependent on cash flow from outside sources such as migration of retirees and tourists, industrialization by imposing IWTs on a municipality can put at risk the social, economic and cultural conditions of the community (Broekel & Alfken, 2015; Whitmill, 2006).

The requirement to consider "the social, economic and cultural conditions that influence the life of humans or a community", as is stated in the Environmental Protection Act (Part V.0.1), was not a requirement in the REA guidelines. As such, it could not be considered in a statutory appeal to an ERT. Consequently, the impact of the IWTs on the local economy was not considered during the IWT approval process.

The government's renewable energy policies have prejudiced the economies of rural municipalities. The assessed values of IWTs are limited under the Assessment Act (O. Reg. 292/98; Ministry of Finance, 2012): a turbine that costs in excess of $2 million is assessed at $90,000 per MW. This reduces municipal revenue to 9% of the industrial mill rate, and in an assessed value of 3% of assessed value otherwise determined. This is a loss to rural municipalities of millions of dollars in foregone assessment tax.

The government failing to investigate the social and economic conditions in approving turbine projects, failing to require the IWT developer to do so, and prohibiting its consideration in the statutory appeal to the ERT demonstrates that the impact of the REA and the IWTs on the local economy was ignored.

6.4. Protection of Heritage Conservation

In an application for Judicial Review, the Divisional Court held that the government acting under the GEA when issuing an Approval has discretion to exclude and override the policy and purpose of cultural heritage conservation, even when the expressed purpose of the override is to promote the economic viability of the project (Driver et al., 2017). Nowhere is this factor permitted under any applicable legislation. Neither the GEA nor the Environmental Protection Act displaces or takes priority over the Ontario Heritage Act.

The government did not apply the provisions of the Ontario Heritage Act when it conflicted with the GEA in approving the turbine generators.

6.5. Effects on the Costs of Electricity

In 2009, when a former Minister of Energy introduced the GEA in the Ontario Legislature, he told the Standing Committee on General Government "We anticipate about 1% per year of additional rate increase associated with the bill's implementation over the next 15 years." While the basis for this statement is not known, opposition parties criticized the estimates (CBC News, 2009; Legislative Assembly of Ontario. Hansard, 2019a, 2019b). Employees at the Ontario Power Authority (the agency responsible for determining how much the plan would cost) and other organizations were also concerned that these rates were unrealistic (Hill, 2018; City News, 2010). A 2015 estimate claimed that the globally adjusted Ontario energy prices increased about 40% (Gallant, 2016), and the Ontario Auditor General's 2015 Report estimated the cost to Ontario would total $ 170 billion over 30 years (Office of the Auditor General of Ontario. Annual Report, 2015). From 2010 to 2017 the Auditor-Generals of Ontario have issued reports that include critiques of the GEA and the policy of subsidizing proponents of IWT projects (Office of the Auditor General of Ontario. Annual Reports, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017).

IWTs are inefficient producers of electricity and provide intermittent supply that requires back-up power by carbon source factories. Electricity from carbon-free sources that can provide reliable base load is available at half the cost of that payable to developers of IWTs. Strong winds during periods of low demand create severe surplus base load in the grid. As generation and load must match up at all times to protect the grid, and as that electricity is not stored, the surplus is sold off or generation curtailed in order to avoid a blackout. Generators are paid to curtail production; surplus load is sold at a fraction of its costs (Ontario Society of Professional Engineers Report, 2012).

Nineteen gas-fired plants have been commissioned in Ontario since 2003. According to the Independent Electricity System Operator (2020) website, they operate at less than 5% of their potential. This activity appears to be largely when they are backing-up IWTs during windless periods. Similarly, in Germany eleven gas turbines are being installed even though they are generating record amounts of renewable energy in the north, as its grid is challenged to transport all the power down to load centres in the south and the grid requires stabilization (Hede, 2020).

It became clear soon after the GEA was implemented that instead of the predicted reduction of electricity rates resulting from operation of industrial-sized turbines, costs were sky-rocketing and the requirement for gas was increasing. Yet the policy of approval continued. Ultimately, the government suspended expansion of its IWT program stating that there was no demand for the electricity and it would save $3.8 billion in electricity system costs (Ontario Newsroom, 2016).

6.6. Summary of Outcomes of the GEA

The government policy failed to apply rules and standards set up to protect rural citizens. The policy of promoting IWTs at all costs is marked by an absence of meaningful public hearings, token public consultation, an extreme dependence on information provided by IWT developers, a failure to consider cumulative effects of multiple projects, and a failure to consider the impact of IWTs on land values, health of residents or social and economic health of communities.

Under the GEA statutory scheme the relevant ministries in Ontario violated the rights of rural residents, ignoring their interests and their environment by following an inflexible policy of approving renewable energy projects without regard for rural economies or the health and property rights of rural residents. The government's support of the IWT industry affected all stages of the regulatory process:

1) At the rule-making stage, when industry groups advanced their positions;

2) At the technical decision stage, the government adopted technical assumptions that favoured the industry groups;

3) At the enforcement stage, the government has failed to conduct inspections, monitor compliance and prosecute violators.

The damage inflicted includes affecting abutting properties by making them health hazards or blocking them from permissible development, ruining water tables, violating economic interests, and disrupting fragile rural economies. In particular, the impugned statutory provisions have imposed on rural Ontario thousands of IWTs that have:

- been erected in breach of mandatory geographic setbacks and noise limits
- emitted infrasound and electromagnetic pollution that are reported to cause illness in residents
- rendered homes unfit for habitation
- polluted waterways and ground water with soil, shale and toxic minerals
- prevented building in adjacent lands within their setback shadow
- vandalized habitat and species on abutting lands
- opened gravel pits and erected cement batching plants without any environmental studies
- incurred fires, tower collapses and other dangers to residents
- depreciated market value of abutting lands or rendered them unsalable
- prohibited municipalities from raising assessment revenue on the same basis as urban municipalities

- disrupted rural economies and development plans.

The noble policy of reducing a carbon footprint clearly went far amiss. The Ontario IWT experiment has not been realised as expected. For all the costs of going "green", none of the alleged economic and social benefits, including the thousands of presumed permanent jobs, have materialized. There is clear evidence from the rural residents living within 10 km of IWTs reporting adverse health and other negative effects that allowable noise levels are too high and setback distances too close.

7. Repeal of the Green Energy Act: Is There Remediation?

On September 20, 2018 a newly elected government gave notice of the introduction of Bill 34 (2018) to repeal the GEA, stating that it was necessary because the GEA led to "the disastrous feed-in-tariff program and skyrocketing electricity rates…and …took away powers from municipalities to stop expensive and unneeded energy projects in their communities". The government admitted: "the GEA allowed the previous government to trample over the rights of families, businesses and municipalities across rural Ontario" (NetNewsLedger, 2018). The Bill cancelled most projects that were currently under review as well as one that had begun construction (Bill 2, 2018). Some sections of the GEA that gave privileged status to renewable energy projects were not rescinded, but were transferred to the Electricity Act.

Since introducing Bill 34, the government has taken no steps to put restrictions on the many turbines that are out of compliance (e.g. exceeding noise limits) or for which the noise audits are overdue. In some cases, companies have been out of compliance for several years—a situation unknown in other industries with reported health effects. Further, there is increased evidence that establishes that wind energy facilities emit acoustic infrasound and electromagnetic pollution that in animal subjects induce disturbances in the visual field, vascular changes in liver structure, hemorrhagic events in lungs and hippocampus morphology, and in humans cause pericardial and cardiac valve thickening and increased arterial stiffness, producing symptoms that include depression, cognitive dysfunction, sleep disorder, chest pain, nausea, vertigo, stress and heart palpitations (Alvez-Pereira et al., 2019; Bray, 2018; Havas & Colling, 2011; Krogh et al., 2011).

Although the GEA was repealed and the impacts acknowledged by the Ontario government, nothing has been done to alleviate the conditions imposed on those living adjacent to or within operational IWT installations. To date, there remains inadequate mitigation to address the concerns and complaints of the affected public who have lost faith in the government they believed would protect them. The government owes the public a duty of care to protect them from a health risk.

8. Conclusion

This paper presents evidence that the government erred in creating an inflexible policy that ensured that IWTs would be approved and erected at all costs. It is demonstrated how working with industry created bias that favoured industry over the safety and well-being of the public and the environment. The government demonstrated a failure to regulate, to the benefit of the wind industry and associated members, to the prejudice of residents.

With respect to the over 2500 IWTs already in operation across Ontario, the following legal implications must be considered:

- Was the statutory scheme in violation of constitutional rights and international treaties?
- Were the administrative procedures biased and in breach of natural law?
- Were administrative decisions illegally institutionally and operationally biased in favour of IWT proponents?

If the GEA was unconstitutional and/or the statutory scheme was institutionally biased, we question the legality of all IWT projects now established in Ontario.

The IWTs continue to damage communities' economics, human health, land values and environments across Ontario. Taking action to help the citizens impacted by the GEA would begin to repair the damage resulting from this failed policy. A reasonable course of action could include:

- Rigorous on-site testing at the expense of operators and enforcement of mandatory Renewable Energy Approval requirements;
- Renegotiation of Renewable Energy Approvals and FIT (Feed in Tariff Program) contracts to ensure human health and environmental protection; and
- Mandatory remediation for landowners suffering the impact of IWT operations, financed by a compulsory payment from revenues of IWT operators.

Considerations when choosing a renewable energy should include objectives such as: minimal harm to people, animals and their habitat and if this occurs, immediate action by government; reasonable cost, reliability and effectiveness; and possible storage for use when needed. These criteria can be met today by small scale solutions such as residential scale wind turbines and roof storage of solar energy for personal or local community use. With advancements in battery storage, minimal back-up energy would be required. Of note, in Ontario, there is presently an over-abundance of energy, and the electricity supply mix is now approximately 92% non-emitting (Power Advisory, 2020).

Other jurisdictions can learn from these experiences to develop more balanced and effective approaches to addressing climate change and other challenges as we move forward.

Acknowledgements

We acknowledge Alan Whiteley as the lawyer for CCSAGE, a not-for-profit organization based in Prince Edward County with citizen members from across Ontario. He led the CCSAGE legal case against unsafe and inappropriate industrial wind turbines being imposed on unwilling rural municipalities because he believed the law to be wrong. He fought hard against an arbitrary policy that ignored the rights of citizens in the placement of turbines across the province. He argued for compensation for those suffering from living near them. He advised and managed the preparation of the more than 50 affidavits, and prepared the related legal documents supporting the CCSAGE case, met with and advised those concerned and affected across the province, all on a pro bono basis. Prior to his death September 2020, he had concurred with a draft of this paper.

We acknowledge all of the Ontario residents and groups that provided sworn statements, shared their records, and contributed towards this endeavour. We also acknowledge suggestions by Carmen Krogh and Paula Peel in the preparation and submission of this manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendices

The contents of the appendices are extracted from the documents filed during an Application to the Supreme Court of Ontario for Judicial Review. They provide examples of how removal of quality controls on technical reports and other factors have greatly reduced impediments to the approval, construction and operation of wind energy facilities.

Appendix 1: Examples of Changes to Requirements for Approval of IWTs

1. *Excessive flexibility in modification of REA documents*

The government permitted proponents to replace reports after the close of the public review period. These replacements could be so extensive that they could not be considered addenda. e.g. wpd White Pines water reports are dated 7 months after the REA application was deemed complete and 5 months after expiry of the comment period, not allowing the public any input.

2. *Excessive flexibility in approval conditions*

Vague wording within IWT approval conditions allowed IWTs to be built outside the intension of the REA. For example, use of "where possible" in permitted construction windows allowed construction in periods that endanger species at risk. The government justified the activity as being "unavoidable", without further explanation to the public.

3. *Endangered Species Act (ESA) permits readily issued*

As long as certain requirements were met, ESA (Endangered Species Act) permits were issued to authorize a person to perform an activity that isn't otherwise allowed under the ESA (e.g. harm or harass a species at risk, or damage or destroy its habitat). As reported by the Environmental Commissioner, the government never denied an ESA permit to any IWT proponent. Many harmful activities were allowed under a permit system, where proponents were required only to minimize not eliminate or compensate for harm, to the detriment of endangered species. This was a proponent-driven approach, based largely on self-assessment. Increasing the risk to the species, the government made no attempt to ensure routine compliance, to prevent cumulative impacts, or to monitor the effect on species at risk.

Members of the public had no access to the justification of the permit, or the supporting information including the species at risk reports. They could not seek to appeal the government's decisions to grant an ESA permit. As such, it was difficult to hold the government to account.

4. *Differential access to government*

IWT proponents were permitted unfettered access to government staff throughout the entire period of preparation of REA proposals, whereas the affected communities were allowed only a short window to make written submissions.

5. *Lack of meaningful public consultation*

Thousands of members of the public, many having extensive expertise, reviewed and commented on the hundreds of technical reports prepared by the proponents. Relevant concerns about the GEA were expressed. These often in-depth critiques went largely ignored by the government and the proponents, becoming a table of comments and vague assessments of non-relevance or being out of scope. The sham of public review was made even more futile by the exemptions placed on the REA and the ERT review process, and by the government often being a proponent in the ERTs (with industry), having approved each project.

6. *Differential Relationships with Government*

Government lawyers, senior government officials and lawmakers engaged in close relationships with wind companies. This is evidenced, for example, during ERT hearings, when government and industry lawyers sat together and shared both strategies and arguments, at times at the request of the Tribunal (Whiteley A.: author's personal observation).

7. *Advice from the government's own experts was ignored*

Internal experts advised the government about reducing IWT approvals and tightening guidelines, both of which would reduce the number of IWTs in Ontario—these appear to have been ignored. This occurred both regarding IWT project approval and creation of requirements/guidelines. Government ignoring expert advice was concealed during ERTs.

Advice was also not taken when it was recognised that energy requirements were exceeded. In 2012, the Department of Energy and the Ontario Power Authority (now "IESO") considered cancelling certain IWT projects that had not yet been approved but were located within designated Important Bird Areas. The IESO (Independent Electricity System Organization) was having difficulty managing "surplus baseload generation" caused by generation from IWTs during periods of low demand. However, none of the listed projects that were in Important Bird Areas were cancelled—maintaining the inflexible policy favouring renewable energy at all costs.

8. *Limitations placed on the Environmental Review Tribunal (ERT)*

The conditions for securing a hearing under the GEA scheme are highly prejudicial to those who oppose the siting of the IWTs and highly favourable to the proponents. The GEA imposed the legal pathway for appeal through an ERT that had limited jurisdiction. The legal test for health as defined in the GEA, "will cause" serious harm to human health, and serious and irreversible harm to the environment, is not consistent with the Statement of Environmental Values that requires adherence to the Precautionary Principal and is more in scope than the Environmental Protection Act. The GEA required appeal application being filed within two weeks of approval, a very tight timeline for the public to respond.

9. *Untrue/Unsubstantiated Public Communication*

Regarding the value of IWT installations, enticing but false, misleading or unproven narratives were communicated by the government in order to gain public buy-in. A former premier said: "Ontario is moving ahead with its clean energy program, taking immediate steps to ensure the long-term sustainability of renewable energy while creating more jobs, lowering prices and giving communities a greater say", and that: "More than 20,000 clean energy jobs have been created and the province is on track to create 50,000 jobs, while helping build a healthier future for all Ontarians."

These claims have been refuted. The GEA did not create jobs or improve economic growth in Ontario, but rather increased unit production costs, diminished competitiveness, cut the rate of return on capital, reduced employment, and made households worse off. IWT installations have resulted in massive increases in the cost of electricity. From 2007, the government was informed by the Ontario Power Authority and the C.D. Howe Institute that IWTs would not reduce CO_2 emissions. Reports such as the Ontario Society of Professional Engineers Report of 2012 confirmed that the IWTs greatly increased CO_2 emissions because of the requirement for back-up generation due to their low capacity and intermittence. This is particularly the case where back-up technologies are more carbon intensive than the base load technologies, as is the case in Ontario.

10. *Reduced Power for Communities*

The GEA resulted in changes to the Municipal Act, which took away powers from municipalities. The changes allowed IWTs to be erected in contravention of municipal bylaws, official plans and assessment rights against local objections. Municipalities and the public lost their veto power.

11. *Rules, policies, practices, and procedures of the government favoured industry*

Some examples are given below (details are available in **Appendix 2**).

- Guidelines were limited after input from, and to the benefit of industry. For example, noise guidelines have only a requirement for using dB(A) filters to measure emissions by IWTs. They are incapable of detecting infra and low frequency noise ("ILFN"). The short-comings of the dB(A) system of measurement have been well-documented, including in the Vestas presentation in Australia in 2004, the 2017 decision of the Australian Administrative Appeals Tribunal in Waubra, the 1999 WHO Community Noise Guidelines, the HGC Engineering study commissioned in 2010 by the Respondent, and the 2006 publication by the UK Noise Association. The 1999 WHO document states: …if the noise includes a large proportion of low-frequency components, values even lower than the guideline values will be needed because low-frequency components in noise may increase the adverse effects considerably (World Health Organization, 1999). The WHO document also states that when prominent low-frequency components are present (i.e., when the difference between C-weighted and A-weighted noise levels exceeds 10 dB), then measures based on A-weighting are inappropriate.
- Reports required for approval of specific IWT projects, such as sound emission test reports, were accepted by the government after the period for public comment expired.
- Draft REAs were sent to the proponent for comment after the period for

public comment expired (e.g., Sumac Ridge—Township of Manvers), to which the government then often incorporated proponent suggestions in the final REA. No such opportunity was afforded to members of the public or municipal staff.

- Changes to a project were made while the project was under appeal to the ERT and Minister, without informing the public or allowing them to review the new information. Changes were also made after approval, without public consultation (e.g., Niagara Region Wind Farm). In some cases, approval was granted after the project was built and in operation and without any possibility of community input. (EBR Case No. 012-2985, posted 14 Dec 2015)
- The government permitted many projects to utilize outdated noise guidelines through "transitional rules" in order that the IWT developers avoid more rigorous compliance requirements. This was the case even when, at the time that the more rigorous standards were imposed, none of the proponents had chosen a turbine model, were aware of the turbine MW output, or knew the number or location of turbines they would need. (e.g., Otter Creek wind project).
- When the public identified flaws in reports such as Noise Assessment Reports and environmental reports, no action was taken by the government. Even when a citizen-project identified species at risk after the proponent reported that there was no habitat for that species in their studies. The industry studies had failed to meet the minimum requirements as described in the government's "Survey Protocol for Blanding's Turtle in Ontario", yet still the government accepted the proponent's conclusion that the species was not present in the area. (ERT Case No. 15-084)
- When evidence of flawed reports regarding sound emissions were taken to an ERT, it was declared outside the jurisdiction of the ERT to comment. The Tribunal stated that since the government had approved the reports, it must assume that the regulatory limits would be met and it could not consider evidence that the project would exceed those limits. (ERT Case No. 15-053, para 13, posted 17 Sep 2015)
- After an ERT allowed a project to go forward, conditional on the extensive mitigation measures that had been presented to the Tribunal by the IWT developer, the proponent refused to perform any of the promised mitigation measures that were not expressed in the REA. They were said to be unenforceable.
- When a violation of the required setback from a turbine and house was taken to an ERT, the ERT held that it had no jurisdiction to enforce the statutory setback requirement and required the residents to prove that non-compliance would cause serious harm to human health (ERT Case 14-048): notwithstanding that the setback requirements were mandatory and imposed as the minimum measure to protect the health of adjacent residents. At the ERT the government admitted that the setback violation was the fault of the propo-

nent and that the government had exercised no oversight, but "absolutely trusted the proponent".

- When the government was informed that the restrictions imposed by a permit to destroy the habitat of bird species at risk were being violated, no action was taken. The government replied that the proponent had destroyed the habitat before the timing restrictions were operative, so that it was no longer considered habitat for purposes of the permit (e.g., White Pines).
- When the nest of an eagle, a species of special concern, was in the way of a turbine access road (Summerhaven), its preservation was recommended by government's expert and required by the *Fish and Wildlife Conservation Act*. The government granted a ministerial exemption allowing the industry to cut down the tree on the basis that this would avoid significant cost and time delay for the proponent without re-starting the REA process.
- A batching plant for the production of cement for use in the foundations for IWTs towers was built immediately beside a primary school on Amherst Island without an impact study. Initially the government held that the cement plant was not part of the REA and would require environmental compliance approval. After the residents intended to challenge the application for the cement plant, the government amended the REA to add the cement plant as part of the "renewable energy project" (EBR 12-0774) thereby allowing construction and operation of a cement plant without any environmental assessment, without any input from the public and without any opportunity to appeal. Construction of a dock and underwater cable were dealt with in the same way.

Appendix 2: REA Approvals and Reduced Impediments

These provide specific examples of REA approvals during which the government of Ontario reduced impediments to the construction and operation of the IWTs.

1. *Otter Creek—Lambton County*

The project documents for the Otter Creek wind project in Lambton County were deemed complete by the government on 7 July 2017 and opened to public comment for a period of 45 days. The proposed turbines would have "the largest rotor available for an on-shore turbine". The company could not provide sound emission test reports until 3 months after the Technical Review phase as it had not been completed. Thus the modelled noise levels at nearby homes were merely estimates based on estimates of an untested turbine and could not be finalized before the period for public comment expired.

The government permitted the Otter Creek project and many other projects to utilize transitional rules to permit the IWT developers to avoid more rigorous compliance requirements. No further requirements were enforced even though, at the time that there were more rigorous standards were imposed, the company had not chosen a turbine model, they were aware of the turbine MW output, knew the number or location of turbines they would need or knew the turbines' noise emission or setback requirements.

Admitting that earlier noise modelling guidelines resulted in underestimates of noise at nearby homes, the government nevertheless also allowed the developers of the Easter Fields, Nation Rise, Romney and Strong Breeze IWT projects to ignore new guidelines designed to restrict noise impact.

2. *Ostrander Point—Prince Edward County*

Ostrander Point was identified by numerous environmental experts as a sensitive site particularly vulnerable to harm from development of an industrial-scale wind project with its ancillary equipment and roads, but the government accepted a report by the agent for the IWT developer and approved the project, indicating that having to complete the environmental assessment was a "regulatory glitch" that should not delay the proponent's schedule. Prior to approval, the government advised the proponent of the Ostrander Point project that the mandatory Environmental Assessment was an "administrative exercise", "just a formality" and "no big deal".

The government approved the Ostrander Point project on 20 December 2012; a citizen group appealed to the Environmental Review Tribunal (ERT) that revoked the permit on the basis of findings that the project would cause irreversible harm to an endangered species, the Blanding's turtle. The proponent and government appealed to the Superior Court and the citizen group further appealed to the Ontario Court of Appeal, which returned the matter to the ERT to determine whether the proponent could remedy the anticipated environmental harm. At that remedy hearing (2015) the government produced a witness, Joe Crowley, who testified under oath that he was herpetologist engaged by the government to review portions of the original habitat assessment of the REA submission and to provide comments and recommendations prior to the approval of the Ostrander Point project. There had been no information about Mr. Crowley or his review, comments or recommendations in the thousands of documents provided by the government in response to a Request for Information made in October 2010, or at the ERT or the appeal hearings, the subsequent Motion to Stay, or in the final appeal. Documents produced by Mr. Crowley as ordered by the ERT remedy hearing contained a report entitled: *Adult Blanding's Turtle Mortality and Population Decline*, which concluded: "it is reasonable to conclude that road mortality at the site could result in the eventual loss of the population". When the ERT ordered the MNR senior manager overseeing the project to produce documentation during the permit process indicating urgent action was required to avoid jeopardizing the project, Ms. Bellamy failed to produce even the emails that had been secured by the citizen group under a Request for Information.

The people of Prince Edward County paid hundreds of thousands of dollars to protect Ostrander Point through 5 legal proceedings, all of which would have been unnecessary had the government not withheld relevant evidence and breached its statutory duties in order to impose IWTs in an unsuitable location.

3. *Snowy Ridge—City of Kawartha Lakes*

The government issued an REA for the Snowy Ridge project in June 2015; a citizen group appealed to the ERT in July 2015. Their allegation was that the project would exceed permitted noise emissions. Their evidence was that the project's Noise Assessment Report was seriously deficient in five major categories. The ERT struck the evidence of deficiencies on the basis that the ERT must assume that the regulatory limits would be met and could not consider evidence that the project would exceed those limits. If it is assumed that the mandatory noise levels are for the protection of human health, then evidence of potential non-compliance is relevant prior to construction. The practical effect of the ERT decision is that the Snowy Ridge project must be built and then found to be non-compliant with mandatory noise levels before protection of human health can be considered.

In May 2016 the proponent disclosed that significant changes were being made to the Snowy Ridge project while the project was under appeal to the ERT and Minister. The government was aware of the changes at the time, but neither the proponent nor the government advised the citizen group or the ERT of those changes. No one other than the proponent and the government had any opportunity to review or appeal the Snowy Ridge project as built.

4. *Sumac Ridge—Township of Manvers*

The government made no response whatever to the 2874 comments posted to the EBR registry by local citizens. Well after the period for public comment expired, it sent a draft REA to the proponent for comment, which resulted in significant changes to the REA. No such opportunity was afforded to members of the public or municipal staff at the City of Kawartha Lakes. There is no provision in the regulations to permit the proponent to review a draft REA and to have it modified at its behest. The proponent resisted disclosure of documents establishing this collusion and regulatory capture for over two years.

5. *Windlectric Inc.—Amherst Island*

Local residents appealed the issue of an REA for the Amherst Island project to the ERT. The ERT declined the relief requested in reliance on extensive mitigation measures presented by the IWT developer at the hearing to remedy the concerns of the local residents. However, as soon as all legal avenues were exhausted, the proponent refused to perform any of the promised mitigation measures that were not expressed in the REA, as being unenforceable.

At the ERT hearing the proponent stressed that the island roads would need minimal upgrades and widening in three locations only. After the ERT hearing concluded the proponent stated that island roads would suffer "catastrophic failure" if subjected to turbine traffic and proceeded to trench and widen 25 km of island roads without any modification of the REA. Despite the fact that the government's "Technical Guide to Renewable Energy Approvals" mandates that "all activities for all project phases…must be considered in defining the project location" the government refused to require an amended REA on the basis that "construction on a highway…is expressly excluded from the definition of a renewable energy generation facility".

The proponent's environmental impact study reported that there was no turtle habitat within the project location. Citizens mobilized a project which confirmed sitings of 58 Blanding's turtles within the project location. The government accepted the proponent's flawed study in the face of evidence to the contrary and the fact that studies carried out for the proponent failed to meet the minimum requirements as described in the government's "Survey Protocol for Blanding's Turtle in Ontario".

Even without actual sitings of turtles, the presence of waterbodies such as wetlands and river corridors are accepted surrogates for confirming associations of rare species with habitat. The ERT concluded that the proponent did not map the extent of waterbodies on Amherst Island, thereby potentially underestimating available corridors and habitat for Blanding's turtles. Without valid waterbody data, the ERT accepted the proponent's conclusions; it was constrained to do so for want of any probative evidence to the contrary.

The government issued a permit to destroy the habitat of Bobolinks, Eastern Meadowlarks and Eastern Whip-poor-wills provided that it was not done between specified dates. When notified by a resident that the proponent was violating the restrictions imposed by the permit, the government replied that the proponent had destroyed the habitat before the timing restrictions were operative, so that it was no longer considered habitat for purposes of the permit.

The government showed bias towards the IWT company by not adhering to their own guidelines for background studies. The gaps in, and the poor quality of studies conducted for the proponent and the lack of due diligence by the government in reviewing those studies, coupled with the stringent guidelines that dictate limitations in how ERT decisions are made were a large contributing factor to the denial of the appeal by the ERT.

6. *Niagara Region Wind Farm* (*NRWF*)

The government issued the REA for the NRWF in 2014. Ten months later, the IWT developer advised that multiple infrastructure changes were to be made to the project. The government failed to respond to requests by the public for particulars of the changes, and permitted multiple amended versions of the noise modelling document without public consultation.

The proponent relied on section 26(3) 7 of O. Reg. 359/09 and section 5.1 of the 2012 Natural Heritage Assessment Guide for Renewable Energy Projects to avoid investigation surveys of lands affected by the NRWF project, alleging that access was denied by landowners, and adjacent properties did not contain natural features that would warrant investigation. Residents advised the government that several landowners had never been asked for access to their lands, site surveys had not been conducted for 55 of the 80 (68%) proposed turbine locations, and there were numerous natural features on adjacent properties that required investigation. The proponent also failed to provide baseline data required to assess habitat disturbance of identified species. However, the government took no action and accepted the erroneous assertions of the proponent.

A home is surrounded by IWTs and a Transfer Station forming part of the Niagara Region Wind Farm. The studies submitted by the proponent and accepted by the government erroneously identify that property as a vacant property. Despite this egregious error, the government issued an REA authorizing the project. Immediately following commissioning of the project, the homeowner was exposed to vibrations and noise; her health has been adversely affected. Despite numerous complaints, the government has failed to provide any resolution to issues including vibrations, interference with internet, stray voltage, shadow flicker or health impact.

7. *Grand Valley Wind Farm—Dufferin County*

In 2014 the government granted an REA for 16 IWTs. Two weeks after the turbines began operating in 2015, the government issued a new REA which altered the Acoustic Assessment Report and the Application. In breach of the Technical Guide to Renewable Energy Approvals, changes to the project had already occurred; the approval was granted after the project was built and in operation and without any possibility of community input.

8. *HAF Wind Energy Project—West Lincoln Township*

The government issued an REA to the IWT developer in 2013 despite the objections of West Lincoln Township and despite the fact that numerous individuals had identified deficiencies in the application. Among the many errors was the failure to specify a safe route for electricity collector lines in a road allowance adjacent to an old natural gas well. Despite indicating that the line would be installed on the south side of a road allowance away from the natural gas well the proponent installed it on the north side within 2.23 m of the gas well. The gas well inventory relied on by the proponent and accepted by the government indicates that the well was active and in good condition, although it had not been used in over 7 years. The proponent's engineering report stated that they had contacted the two registered owners of the well, who in fact have been dead for decades.

9. *Summerhaven—Haldimand County*

During construction of an access road to the IWTs, the IWT developer encountered a 200 year old cottonwood tree containing the nest of a bald eagle, a bird listed as of "special concern" in the Species at Risk List. The government's expert recommended moving the IWT leaving the tree and nest intact. Although the nest would be protected as per Section 7 of the *Fish and Wildlife Conservation Act*, the government helped the proponent to obtain a ministerial exemption allowing it to cut down the tree on the basis that this would avoid significant cost and time delay for the proponent without re-starting the REA process. The proponent was required to remove the tree within 2 days of the permit being posted on the EBR website: "to get the nest removed by Sunday".

10. *Kent-Breeze Wind Farms-Chatham Kent*

The REA for the project was received in 2010. During the first ERT held under the GEA, qualified experts submitted that the acoustical engineering evidence demonstrated uncertainties, and errors in the noise modeling would lead to residents being exposed to noise in excess of the permitted 40 dBA predicted for the Project. As the government ministry still had no method of accurately measuring IWT noise compliance, there would be no method to ensure compliance with the REA. The evidence before the Tribunal also demonstrated that noise from IWTs is unique, either as a result of amplitude modulation, low frequency sound, infrasound, tonality or a combination thereof. Experts called by both the Appellants *and* Respondents acknowledged that operation of this Project at these levels *would* cause human health impacts.

The approval was not revoked.

Infrasound Impacts at the Cellular Level - Introduction & History

Initial Low Frequency Noise (LFN) Research (1950s to 1970s)

- Key discovery of this period: chronic low frequency noise (LFN) causes cumulative harm to body systems (military & aerospace contexts)
- Workers exposed in aviation and heavy industries experienced nausea, fatigue, sleep disturbances, disorientation, thickening of cardiovascular structures, mood disorders, and neurological dysfunction
- References: Vladimir Gavreau (Wikipedia), NASA: Apollo Space Program

Vibroacoustic Disease Studies (1980s and 1990s)

- Portuguese researchers formalize the concept of Vibroacoustic Disease (VAD)
- Initially discovered in aircraft technicians; linked to fibrosis of cardiac tissue, memory issues, and neurological effects (later included train operators & shipyard workers)
- Effects extended to : cognitive dysfunction, balance disorders, tinnitus, autonomic nervous system dysregulation, irritability, arrhythmias, hypertension, emotional instability, and neurological symptoms
- Early studies found that LFN could cause health effects even when people couldn't hear it - pointing to infrasound below the frequency of 20Hz as the cause.
- References: Mariana Alves-Pereira & her You Tube interview on VibroAcoustic Disease

Wind Turbine Syndrome (2000 to 2010)

- Installations grow across Europe, Australia, and North America; first complaints registered from 2003-2004 included sleep disturbance, headaches, pressure in chest, anxiety, ear pressure, and cognitive fog
- A U.S. Princeton & Harvard trained doctor coins the term: Wind Turbine Syndrome, published a self-funded case series of 10 families living near turbines in 2009. Her work was attacked by pro-wind industry groups but embraced by affected communities and several independent researchers.
- Nina Pierpont, MD PhD book Wind Turbine Syndrome: A report on a natural experiment

From 2010 to Present in Ontario & Alberta

- In both provinces, wind generation grew significantly between 2008 and 2024 resulting in each province having an installed generation capacity of 5500+ MW by mid-2025
- In Ontario, affected people can call the Ministry of Environment's Spill Action Line to report issues related to living near wind turbines; in Alberta, people must try to report and resolve noise issues directly with the corporation operating the wind power plant (WPP).
- In Ontario, reports have been made on numerous symptoms experienced after the WPP began operation. In Alberta, landowners only have the ability to file complaints regarding audible noise.
- Wind project operators are not required to measure inaudible infrasound (below 20Hz) that causes health impacts before gaining project approval.
- By the end of 2018, over 5800 complaints were registered in Ontario with the vast majority left unaddressed after being recorded; Wind Concerns Ontario collected this data through FOIA requests and compiled the results in the report linked below.
- As turbines grow in generation capacity and blade length, the infrasound generated increases exponentially, creating a further need to determine minimum setbacks from people and homes.
- Most electricity-generating equipment can generate infrasound below the level of human hearing. Batteries, inverters, transformers, and substations all require adequate assessment.
- Wind Concerns Ontario report: Response to Wind Turbine Noise Complaints (April 2021)

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Infrasound Impacts at the Cellular Level - The Science In Plain-English

Nobel Prize Research on Sensory Receptors (2000 - 2021)

- David Julius & Ardem Patapoutian discovered the molecular sensors (mechanosensors) responsible for temperature and touch – TRP ion channels (for heat/cold) and PIEZO ion channels (for mechanical force/touch).
- This work solved a centuries-old question: how physical stimuli like heat, cold, and pressure are turned into electrical nerve signals.
- Genetic studies began in the early 2000's and PIEZO1&2 were identified in 2010.
- PIEZO2 channels were found primarily related to sensing touch in 2014 and PIEZO2's role in proprioception (sense of body position) was shown in 2015.
- Between 2016 and 2021, much research was completed to confirm, characterize, and expand the importance of these channels across multiple tissues and systems: hematology, ocular physiology, bone biology, immunology, and chronic disease.
- Typically, the Nobel Prize is awarded only after the key findings have been repeated by others, have shown biological and medical significance across fields, and have received various forms of peer recognition. This is why the Nobel Prize was not awarded until 2021.
- Nobel Prize Research Article published in 2021
  https://www.nobelprize.org/prizes/medicine/2021/advanced-information/

Blood Circulation & Endothelial Cells

- Blood delivers oxygen & nutrients to every cell in the body & moves harmful waste out
- Endothelial cells form an ultra-thin (nanoscopic) protective lining along the inner walls of every artery in your heart and blood vessels of all sizes including capillary microcirculation.
- When blood flows, endothelial cells asborb information through PIEZO ion channels that can, for example, regulate nitric oxide (NO) release to help control how & when arteries dilate.
- The **endothelium** (network of endothelial cells) form a barrier controlling the passage of materials into and out of the bloodstream and it is the foundation to regulate body systems and processes
- Dr. Bellut-Staeck's research: Impairment to the Endothelium & Disorder to Microcirculation..... (2023)

Mechanotransduction & Infrasound

- **mechano**= force **transduction**= converting electrical energy into biochemical signals
- **mechanotransduction**: how forces of physical energy transfer will impact the biochemical activities of cells or individual molecules
- The endothelial lining of blood vessels contains **mechanosensors** (sensors that can register a mechanical force), namely the PIEZO1 & PIEZO2 ion channels.
- Living bodies react differently to natural external forces (wind) than man-made mechanical forces (noise from a turbine); all organisms "feel" and "hear" with these mechanosensor inner receptors.
- When a mechanical force in the low frequency range (below 10Hz) is received, it causes PIEZO ion channels to open or close in response, which can disrupt endothelial cell functions triggering dysfunction & illness.
- Endothelial cell functions include: exchange of nutrients & oxygen, growth & embryology, auto-regulation of blood vessel width & balance of nitric oxide, transport of hormones & medications, homeostasis of fluids, and regulation of the immune system, chronic inflammation & cancer.
- The impulsive, repetitive sound pressure waves of infrasound (above and below ground) are "felt" by mechanosensors in the endothelial cells resulting in **direct & serious** health impacts.
- Dr. Bellut-Staeck's 2025 research in SCIREA's Journal of Clinical Medicine as: A fundamental basis for all living creatures, mechanotransduction, is significantly endangered by periodic exposure to impulsive infrasound and vibration from technical emitters - in particular cardiovascular and embryological functions

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Infrasound

Infrasound
measurements
New model
105dB often exceeded

https://www.youtube.com/watch?v=nDwsd32SDEY

Transcript: Professor Ken Mattsson on Infrasound

My name is Ken Mattsson. I'm a professor in scientific computing at Uppsala University. I have some important things to say that I feel deserve more spreading in the world, and that is this issue about infrasound. Wind turbines emit a lot of infrasound, and the authorities and the industry claim it's harmless. I've seen the opposite. We really need to stop and investigate how dangerous this infrasound is.

Infrasound can potentially spread at least ten kilometers at levels that have been proven to affect people. So I would say a safe distance is most likely five to ten kilometers at least. In animal studies, they've seen that animals move more than five kilometers from wind turbines, which is a strong indication that they don't like infrasound.

We have measurements where people live only six hundred meters from new, modern wind turbines. I should also say that the larger you build them, the more infrasound you will get — and that's something the industry doesn't want to talk about. What I'm saying is: make a real study where you actually test the levels that we record. They are quite high.

I will demonstrate what we have done, what levels we have measured, and also provide some references to new research showing that infrasound affects people well below what you can hear. This is an important message, so please share this data I show you with others — local politicians, authorities, anyone you know. I think this deserves much more attention.

[2:27]

This is a short CV, mainly for the industry, because they believe that I'm a prophet against wind turbines only — and that is not true. I've been working since 2018 as a professor in scientific computing at Uppsala University. I did my PhD in Uppsala, and then worked a few years at Stanford and NASA on air acoustics, jet engines, rockets, and helicopters. I also worked at the Swedish Defense Research Agency with underwater acoustics, developing methods to detect submarines, for example. After that, I spent a year working at a nuclear power plant.

I'm definitely not against green energy, but my personal experience has made me increasingly critical toward wind turbines. My views are based on facts, not ideology or belief.

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In physics, there are many types of waves, and that's what I've been working on for 25 years — partial differential equations. The first two are the Schrödinger equation and the Dirac equation. The new Nobel Prize in Physics was actually awarded for work related to these equations, and I've done research on similar topics, including tunneling effects. I could spend a whole lecture talking about that, or show you some of the fascinating effects from quantum mechanics.

I've also done simulations involving what are called Boussinesq equations, or solitary waves — a tsunami is an example of a solitary wave. And I've worked on Einstein's equations as well. Out in space, you have something called gravity waves, which are also very interesting. But most of my work has focused on acoustic waves. I'd say the majority of my research has been in acoustics, which is a type of partial differential equation — that's what I specialize in: how to model reality using PDEs and how to solve them.

The acoustic wave equation, which forms the foundation of acoustics, is central to that work. If you're interested in acoustics, you have to solve the wave equation — and that's exactly what we've been doing. We use a method called SPT-SUT, which is a finite difference method. You don't have to worry about the technicalities, but it started in 1974 in Uppsala with Professor Engquist, continued with a PhD student there, and then another PhD student in 2004 — that was me. Since then, we've published about forty papers on this topic.

[6:01]
I just want to briefly mention that there is a distinction between the *generation* of sound and the *propagation* of sound. The generation of sound is very, very complicated — to model it, you have to solve something called the Navier-Stokes equations, which is extremely difficult. Then you have the propagation of sound — once it's generated, it travels outward. That part is much simpler, and for that you can use the acoustic wave equation.

What we do is assume that we know the source — in this case, the wind turbine — and how much sound it generates. That's our model. Then we can simulate how that sound spreads through the atmosphere. The key point here is that both the generation and propagation of sound are *highly affected by atmospheric conditions*. I'll show you some examples of that.

One of the biggest lies from the industry is the claim that turbines aren't very loud — they say each has a sound power level of 105 dBA, and that it's constant. That's a big lie. It's not constant. It can vary by more than 20 decibels within a single day, and I'll show you results to prove this. The biggest uncertainty in all of these models is the sound power level itself.

When you look at the simulations provided by industry, they often use data from manufacturers — for example, from Vestas — describing how much sound a new turbine emits. When that data is put into simplified models, it produces contour maps: here's 40 dBA, and since no one lives inside that contour, they conclude it's fine to build. But there are many uncertainties — first, how much sound is actually generated, and second, how it propagates. In both cases, the results aren't very reliable.

Here's an illustration I often show my students. This is a volcano. I've actually done research on volcanoes and infrasound, so this is connected to my work. It demonstrates both the generation of sound — for example, from the eruption — and the propagation of sound through the atmosphere.

One of my main motivations for studying this came about fifteen years ago: traffic noise. At that time, I was working at the Swedish Defense Research Agency on methods to simulate underwater acoustics. We came across some very simplified models, like NOC 2000, which I'll talk about more later. We tested them — and they didn't work at all. In Sweden alone, traffic noise costs roughly seventeen billion kronor annually due to cardiovascular disease and reduced productivity, not to mention the decrease in property values and other impacts.

When it comes to wind turbine noise, it's treated differently; there are separate rules. This is something I presented to the Swedish Environmental Protection Agency in 2012. We did a careful evaluation of these simplified models. The blue line here represents our model, which we can prove is correct. This example was a benchmark problem where we compared our model to two different parabolic-equation methods published in 2010, and the results were quite similar.

Then we compared those results to ray-tracing methods — highly simplified approaches that assume sound behaves like rays, which is only valid for high-frequency sounds, around 1,000 hertz. In this benchmark case, the source was a helicopter at 50 hertz — a low-frequency sound. The terrain in the model includes small hills, and what's shown is the *transmission loss*, meaning how much the sound is reduced as a function of distance.

[11:43]
You see, these ray-tracing methods don't work at all. I spent four hours with three of my PhD students trying to convince the agency not to use Nord 2000 for low-frequency sound. They didn't want to listen. We met with them again three years ago, and they still didn't want to listen — they never will. This is clear proof that the Nord 2000 method, which is one of those simplified models, doesn't work.

A colleague of mine at the university did long-term measurements on wind turbines back in 2014 and proved that the Nord 2000 model fails when compared with real-world data. It consistently underestimates by roughly five to seven decibels at one kilometre distance.

Now, let's talk about infrasound. Volcanoes emit large amounts of it, and by detecting that infrasound, you can model a volcano and even anticipate when it might erupt — just by listening for those deep, inaudible vibrations. Nuclear explosions also generate significant infrasound, as do high-speed trains and wind turbines.

There is a global infrasound network called **CTBTO**, which monitors nuclear explosions and other atmospheric phenomena. One of the network's stations is located in Norway, in Älvbyrum. We've been there twice. The people who operate those stations truly understand infrasound and how to measure it properly. Unless you've been there and calibrated your own instruments against theirs, you can't measure it accurately — and as I said, we've been there twice.

[13:55]
And the careful calibration. So, you're all familiar with electromagnetic waves — and how we give them different names depending on their frequency: radio waves, microwaves, up through X-rays and gamma rays. These are all electromagnetic waves, just at different frequencies. The visible spectrum — what we can actually see — is just a very narrow part of that range.

When it comes to acoustic waves, we have a similar situation. There's audible sound, which is roughly between 20 and 20,000 hertz. Then there's *infrasound*, which is everything below 20 hertz. You can't hear it in the normal sense — you can only sense it. And then there's what's called *low-frequency sound*. In Denmark, that's defined as 10 to 160 hertz; in Sweden, about 31 to 200 hertz. It's something you can partly hear, but infrasound, you primarily *feel*. Some people can hear it faintly, but for most, it's a physical sensation rather than an audible one.

There are many human activities that generate infrasound, and many natural ones as well. Volcanoes, as I already mentioned, produce strong infrasound, but so do tornadoes, storms, and earthquakes. Even meteor explosions and the northern lights can create infrasound. Some animals also communicate using these very low frequencies.

However, infrasound from wind turbines is very different from natural infrasound. This is what it looks like when you measure it — pressure as a function of time. It appears as a series of implosions, because every time a turbine blade passes the tower, there's a pressure drop — an implosion. In the frequency spectrum, it looks like a pattern of small explosions or implosions. This is *not* what natural infrasound looks like — not at all.

You can't hear infrasound from wind turbines, but that doesn't mean you can't perceive it. If you could hear it, it would be like a dripping faucet — that irritating, repetitive sound that keeps you awake at night. Natural sounds like ocean waves, by contrast, make you *want* to sleep with the window open. I think that's a very fitting comparison — though I'm not sure of the right English word for it.
(Transcriber's note: He appears to be searching for the word "analogy.")

[16:39]
This was a really good YouTube video that came out a few years ago — *Infrasound Affected by Industrial Wind Turbines*. It's about people who have done extensive work in this field, and in this particular video. These are some of the common questions I get, such as: how is infrasound generated, how far can it travel, how much of it is lost into the ground and the atmosphere? I'll show you that. Also, how it interacts — how it penetrates buildings and affects people — and then, how important the atmosphere is, not only for propagation but also for the generation of these sounds.

If you want to answer these kinds of questions, you have to simulate everything with *extreme precision*. And that's exactly what we've done. The solution is something we call **SoundSim 360**. It's a software system that is very, very accurate and can solve many types of problems in acoustics. It represents about twenty-five years of research, so it's not something trivial you could develop using AI. There's real physics built into it.

Now, these are some of the challenges in infrasound research and regulation, including low-frequency sound, not just infrasound. The biggest challenge, I think, is the resistance from both industry and authorities to absorb the research that already exists. They simply don't listen. What's particularly odd is that they still use **dBA measurement** for low-frequency sound — I'll explain what that means in a few slides.

Much of this depends on the **Nord 2000** model. In Denmark, they use something even simpler, called the Danish model — just a basic low-frequency model. We have something similar in Sweden, called the **Naturvårdsverket calculation model**, an ISO-based approach for low-frequency noise with many parameters. Nord 2000 is also based on low frequency with numerous parameters — and depending on who uses it, you can "tune" it. You can get almost any result you want, which makes it very user-dependent.

Authorities also claim that you can't measure infrasound — that it's not possible to measure this kind of sound. They say, "We don't believe in that; we only believe in Nord 2000 simulations." That's a real misuse of science — a distortion of research.

This next example is from a conference paper. It involved two 2-megawatt turbines located near a house, about 650 meters away. The person living there complained about it — which, of course, made him unpopular and dismissed by others: "No, no, no, it's all in your head." But the researchers, **Tomas and Bertil**, carried out long-term measurements. First, they wanted to establish the background noise — the levels when the turbines were turned off. That background was between **30 and 35 dBA**.

[20:49]
Roughly. So this is a two-week measurement. I don't know if you can see it, but if you follow this green line here, that's the dBA variation over the two-week period. This line here is the legal limit — forty. Almost all the time, the levels are much higher. Up here, it reaches sixty. You can see the variation clearly — how the sound levels change with time. And this is a legitimate measurement.

Since they were allowed to build this, Nordproducer must have said that it was well below forty. But it's *never* below forty. Well — here. This is from January, six o'clock in the evening at **Lagerstorp**. You can see the meter up there — it's close to sixty. And this measurement was done correctly: shielded from wind and everything.

This next one is half an hour later at **Snyggebo**, also where people live, one kilometre away. Notice the light as well — imagine living here. The first thing I reacted to was actually the light. But it's sixty decibels — sixty dB. You hear this pulsating sound. This isn't the infrasound; this is something called *amplitude-modulated sound* that happens in the evening. It's sixty. The difference between thirty-seven and sixty, if you understand decibels, is enormous.

All right — so this is a simulation that we did based on those measurements. According to Nord 2000 here, it gave thirty-seven point six at these two locations. But if we put this into our own software and use the real atmospheric data from that exact time, to match the data the sound power level has to be one hundred twenty-eight decibels — not one hundred six — to fit the data.

The atmosphere does affect propagation, but not that much. It might add about five decibels, but not twenty-five. The rest comes from the source. So these turbines aren't generating one-oh-six at that time — it's one-twenty-eight. And he did some measurements earlier that same day — then it was around forty-two or forty-three. So it can vary *a lot* during the day.

[24:17]
Okay, that was all. This is the building where we are sitting. I'm sitting here. This is Ångström, Uppsala University. We had a rock concert here in August, so we wanted to simulate that. This is 50 hertz. I just want to mention the physics here. If you want to simulate this, you really have to simulate it correctly, including the buildings, the ground, and the atmosphere. We have something called diffraction. Low-frequency sound bends around the corners. It also bends in the atmosphere. If you don't get that into the model, you can't simulate it.

Okay. We made a comparison with Nord 2000. In Sweden they have decided to use Nord 2000 for everything. This is 31 hertz. Here you see the sound levels. The dark areas are the buildings. The sound is two meters above the ground. Look at the difference here — here and not here. Nord 2000 has no diffraction. This is 63 hertz, low-frequency sound. Low-frequency sound is completely off. This is the difference. The sound is lower than Nord 2000. Red means more than 30 decibels error — too little. Blue is 20. Here you see the effect of using a good method. Near wind turbines, there aren't so many houses. Here it's more objective why it doesn't work.

This is indoors — 200 hertz, 50 hertz. You can see 50 hertz through doors and openings in doors. This is the building where we are sitting. Here we put the source outside — 1 hertz, 100 hertz. One hertz is very relevant when it comes to wind turbines. This is transmission loss — how much of the sound is reduced. You can't see the doors here. Infrasound just goes through. There are no protections against it.

This is a submarine outside Gotland. I want to show that you can also do sound in the sea. It's very important to include the sediments at the bottom, because the sound also goes down into the seabed. This could be ships, boats, wind turbines in the sea. They generate a lot of infrasound and low-frequency sound. The reason we wanted to develop a meter was to validate the model — to make sure that it's correct. You have to do that against measurements. So we went out to make measurements.

[28:23]
With this equipment, it's called LeadStrom. This is a highly accurate piece of work. It can measure infrasound only down to one hertz. So we took this to DTU to have it calibrated against their Hyperions. So it's very accurate at one hertz. Unfortunately, it cannot go below one hertz, and the highest levels are below one hertz. But then you need even more accurate equipment, like Hyperions, and we have bought two of them. And yesterday we

did the first measurement with them, so I actually had time to put it on the last slide. So it's really new.

All right. So this is what the Swedish Environmental Protection Agency says in 2025: no special models are needed to calculate the infrasound from wind power, and this has been found in several studies to have no impact on humans. And then they list their references. Two of the references are to their own reports, and these reports are not scientific reports — they're like, you can't even see the data.

Here are two real articles, eleven here. If you read this, it's like — yeah, it doesn't say anything. "Available scientific research does not provide a definite answer about the question whether wind turbine sound can cause health effects which are different from those of other sound sources. Wind turbines do stand out because of their rhythmic character, both visually and aurally."

This study has not done measurements. There are no medical studies — it just goes through old studies. Then there's this Finnish study that they like to show, saying it's the proof that infrasound is harmless. Okay, what did they do? For ten minutes, they exposed roughly thirty people to seventy-three-decibel infrasound at one hertz — seventy-three decibel. In total, if you sum everything up, it's ninety decibel — for ten minutes. Håkan was not invited to that study.

Here are some more references that I dug up, but I'll leave that for Håkan. An interesting study is from 1985, where they actually did some testing on humans. They found that ninety-five-decibel infrasound hit pressure. Then there are some new studies that show between eighty and ninety decibel, the brain picks this up, even though you can't hear it.

[32:13]
So those are really interesting studies. And I should mention that in this report, the people who did these measurements got sick while doing them — they got really sick. The same thing happens to me and Kourosh when we go out. That's the reason why I'm standing here. Every time I go out and measure infrasound, I get sick. The day after, I get a terrible migraine, and then I can't sleep for a few days. That's when I started to think, well, okay, some people say that infrasound can be dangerous or affect people. And then I found this out through Håkan. And after that, I started to dig into the literature.

Every time I go out and measure, the same thing happens. So for me, this isn't a belief or a religion — I *know* it affects people. Not everyone, but it definitely affects me and Kourosh and some others I've spoken to. They report the same thing. So for me, it's a little bit personal. Otherwise, I wouldn't be standing here talking about it.

Okay, so here are five serious deficiencies. What needs to be done is a study that actually exposes people to the *true* levels. And it has to involve many test subjects — not just thirty, but probably a thousand. You also have to include someone like Håkan in the study, someone who knows about the brain. You have to include people who are migraine-sensitive. And it has to be *long-term exposure* — not ten minutes. That's ridiculous.

Also, the infrasound from wind turbines is *pulsating*. It's not natural infrasound. Personally, I believe it's that pulsating nature that makes it affect us more than the actual level — that's my personal belief. And in many of these studies, you see higher levels indoors than outdoors because there are vibrations involved too. So this is probably very complicated. Okay.

[34:58]
So this is from one of the measurements in December. It was very cold and very windy. This is a wind farm in Målaberget — twenty-seven turbines. You can see a few of them here. Here's the equipment — we have four of these LeadStrom units, and this is a windshield. This is what a windshield looks like for infrasound. It's made of metal.

All right, this is from a measurement we did in October last year. We captured the moment when they turned the turbines off, because the industry says you can't measure it — that you're only measuring the background. Okay? So this is when it's *on*. What you see here is the amplitude of the sound, roughly speaking. Then they turn them *off*. And this is when they're *off*. On, off — in the same recording.

These are the decibel levels for off and on. So yes, it *is* the wind turbines that generate the infrasound. You have seventy-eight decibels at one hertz from just the wind. And in their Finnish tests, they exposed for seventy-three. But when the turbines are on, it's ninety-nine decibels at one hertz. That's a big difference — twenty decibels. So yes, infrasound is caused by wind turbines, but you also have some infrasound from the wind itself — just much lower, much lower.

Okay, so this is something called "Peshband," which is how you represent sound sometimes in frequency bands — one hertz up to twenty hertz — showing how much energy you have in each frequency band. So you have on and off, and then you can decide how to represent those levels.

You have something called dBA, dBC, dBG, and then you have something called dBZ, which is with *no weighting* — it's just like dB. So if we sum all the infrasound from one to twenty hertz, we get one hundred six decibels when they're on and seventy-nine when they're off.

In dBA, that becomes twenty-two when on, and minus two point eight when off. So you can trick the numbers by using different weightings. But this dBA — if you look at, for example, one hertz, how much do you remove when you do the summation? You remove one hundred fifty. So if the wind turbine emits one hundred fifty, it becomes zero. That's how it works.

So dBA — you can't use it for low-frequency sound or infrasound. dBC isn't very good either. dBG is often used, but it's also not good for really low infrasound. It's useless.

[39:09]
That doesn't say very much. So, yeah, don't use that. So this is from the measurement — the first measurement we did at Målaberget 1. These are the measured values. Here are two locations where we did the measurements — measurement and calculation. So there's a deviation between what we measure and what we simulate, around two decibels.

Here we have a resident — I spoke with him. He's not feeling well, and he's very worried. Here he has around ninety-five decibels at one hertz. So everything here is at one hertz. One year later, we have two different locations — again, measurement and calculation — and here the deviation is around one decibel. So I would say that's quite good, considering there are some uncertainties.

Okay. So what we do is measure, then take the real atmospheric data from that exact time and feed it into the model. Then we look at how much sound is emitted from each wind turbine to fit the data. If we really solve the physics accurately, we see that the sound level here is around one hundred fifty-four decibels; here it was one hundred fifty-five. This was in October last year. This one was in December, two months later. We measured one hundred fifteen instead of ninety-nine.

Here it was much higher — it was windier, it was cold, so yes, much higher. Here you can see the wind level; it was also blowing hard. And here you can see the atmospheric effects — the sound propagates in the direction of the wind. The box to the right shows much higher levels because of the wind effects.

Here you can look at night and day — typical day, night, and day. This is the day; this is the night. What happens is that the atmospheric layers are compressed — that's physics. This is also the reason why you get this amplitude-modulated sound in the evening. When the blades pass through these layers close to the ground, you get this disturbing sound. When you see something like this, it means that the sound is bending down. And here, it bends down even more.

[42:32]
Here we see an effect at 1 Hz, 5 Hz, 50 Hz, 500 Hz. This is a wind turbine, 120 meters long.

Here we use the assumption that the water level is the same for all frequencies — not in reality, just to show the effect of the ground and the atmosphere. Here we use a real atmosphere, day and night atmosphere, 8 meters per second. This is how the sound at 2 meters above the ground looks — how much is lost. This is infrasound — it's not lost very much. The yellow is 500 Hz, so after 2 kilometers it's more or less lost. For example, when you have this night atmosphere, you get this kind of spreading. So day atmosphere, night atmosphere with more wind — it becomes quite different how the sound spreads and how much is lost. You have losses in the ground and in the atmosphere.

This is how the sound looks if you visualize it. This is 5 Hz, this is 50 Hz. At night the sound is trapped, it stays here. But it's also lost to the ground and the atmosphere. Higher frequencies are lost a lot. Infrasound not at all. This is a place called Åseda. That's where Kenneth lives. He has a damn migraine all the time. He can't live there. He asked us to visit and make measurements. The industry refused to cooperate — that was an interesting episode. We did simulations for him.

This is a typical day, a typical night — 8 meters per second. They have the same wind turbines as in Målaberget. We can use it at certain power levels. This is what you get. Here in the village we have Åseda — it's actually quite a large town. At all these locations we have small towns. These are the infrasound levels at those locations. Kenneth has 99 here. This is if it were only 1 meter per second — then it doesn't travel as far compared with 8 meters per second. It's the same sound power level. The sound power level itself also depends on the atmosphere. The industry will never explain that. When it's windier, the sound propagates farther, but the level is also higher.

The last image is from Lervik, where Kjell-Åke lives. This is from his house. These turbine levels are quite large. The sound power level is 85 meters.

[46:36]
6.6 megawatts. He has seven of them. This is last year in May. We recorded 105 decibel where he lives. This is what it looks like if we simulate it. This is a few months later. It was different weather. It was only 97 at that time.

This is an animation of this. We did this just to show the politicians because they like to have something that looks nice. It's the same simulation — it just looks nicer. This is a big simulation of how infrasound is propagating.

The last slide I added just before I went up there. I got it actually two hours ago. We did a measurement yesterday with the new equipment that we bought. We bought Hyperions, what CTBTO are using. We went in July to have them calibrated. Yesterday, we did the first recording with them because the problem with this LeadStrom is that it can't go below one hertz. The highest level is below one hertz.

This is what we got. Sorry, this is from Leif — he doesn't know how to produce nice plots. The yellow one is LeadStrom. Here it's at one hertz, then it drops. The other lines are the Hyperions. The highest level is at 0.63 hertz, the blade passing frequency. It's roughly 128 decibels at that frequency. This is roughly one and a half kilometers away. I should say there are like 60 wind turbines close to this area.

This is preliminary results. Still, the highest level is below one hertz. Of course, we need to do more validation of this. How much higher it is, we don't really know. This is an indication that it might be quite high, actually. You will hear more about that later.

Thank you very much for listening.

Dr Håkan Enbom, M.D., Ph.D, E.N.T. specialist, otoneurologist, Copenhagen 8 Oct 2025

https://www.youtube.com/watch?v=teMrW8Kd4xU

Here's the English translation of your Swedish audio text:

" Infrasound Affects the Brain"

Then we sit in Persons, HSB. About 30% of a population — and that's quite a lot. A third of Denmark's or Sweden's population belongs to the group that is a bit more sensitive than the rest of the population. So it's not a small portion we're talking about.

When we describe these people who are a bit more sensitive than others, we're talking about individuals who have special characteristics. They are capable people, driven people, ambitious people who like order and structure — meticulous people. And they are also more sensitive.

They have a nervous system that is quicker and functions better than other people's nervous systems. That means they are also more sensitive to sound. More sound-sensitive — often they are also more prone to motion sickness. In fact, all of the sensory organs are a bit more alert in these individuals.

We talked about infrasound, and I'd like to briefly introduce infrasound. It's a sound that you can't hear, right? But also a sound that is very penetrating. It meets no obstacles. These walls here — it passes straight through them, and it goes straight through our bodies. It even passes through the skull bone. Strangely enough.

And it has a long range — it spreads far. Enough said about that.

Who am I then? I'm an otoneurologist — that's a special kind of training where you start as an ear doctor and then add education in neurology. I worked for several years in a neurophysiological laboratory before I obtained that specialty.

I also did research for several years in Lund, in Örebro, and in Helsinki, among other places. I wrote a dissertation a little over 30 years ago — about how all of our sensory organs and the brain work together to control balance, that is, postural control.

It's quite remarkable that we humans can stand on two legs, isn't it? We really should be walking on four like other animals. But we have very good postural control — and that's the function I studied a long time ago.

History.
So, what does an otoneurologist actually do? What does a neurologist organize? Well, I work with the part of the nervous system that sits in all the other parts of the spinal cord —

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what's called the brainstem, the area below the brain. From that region come the twelve cranial nerves, including those connected to the face, and these are the nerves that control hearing, balance, vision, smell, and taste — but also swallowing, the sensations in the mouth, and the feelings in the face. All those nerves in that area — that's my field as an otoneurologist.

My workspace is a laboratory in a regional or university hospital, where one examines and studies the function of these different nerves.

But then, why on earth am I here today? I don't actually work with infrasound. It's actually a bit of a long story.

About twenty years ago — or maybe fifteen — I was going to test a new technique for treating tinnitus in people who were sound-sensitive, those who are HSPs — Highly Sensitive Persons. Tinnitus is normally caused by hearing loss, a hearing injury, and that hearing injury results in tinnitus. Usually, people get used to it after a year or two, or they manage to push it into the background and forget it somewhat.

But this group of Highly Sensitive Persons has a more sensitive nervous system and finds it hard to get used to the tinnitus tone. They can also develop tinnitus without any hearing damage — and that's what distinguishes this group. It was that group I wanted to try a new kind of treatment with at that time.

The usual treatment for ordinary tinnitus is simply to wait and see — to see if the brain adapts after a year or so. And if the tinnitus is too distressing, one tries to dampen the nerve activity in some way with medication that has a calming effect — for example, medicine for anxiety or depression, or medication for epilepsy, which has properties that reduce the activity in the nervous system.

These aren't exactly pleasant medications to take — especially not if it's a child who has tinnitus. Because, in fact, quite a few children can develop tinnitus. And for those children, taking medicine that causes side effects is certainly not ideal.

These individuals are highly sensitive. They're not only sensitive to light and sound — they're also sensitive to medication. And that's a dilemma, because it means they more easily experience side effects.

I had planned to start using this new technique in a location that was quiet and free from disturbances. At the university facilities, there was a lot of traffic noise, rumbling, and other sounds. So we arranged for a space out in the countryside, a bit outside of Lund, where we thought we could carry out this method.

But it turned out that just 500 to 800 meters from that location, they were planning to build a wind turbine. And that wasn't exactly ideal. That's where it all began — I had to start thinking, can we stay here, or do we need to move?

I read up on the literature and quickly realized that it probably wouldn't be a good idea to stay. So we had to relocate the project.

The articles that existed at that time were not very many. The ones that had been written mostly came from people who thought they saw a connection — but without a solid scientific basis. It started with Nina Pierpont, and later we have Jeffery's articles, but several have shown that many people living near wind turbines feel unwell in one way or another.

However, there were also many other articles from that period examining the effects of wind power, and they couldn't demonstrate any harm or impact on humans — even if, as Professor Mattsson said, those studies might not have been of particularly high quality.

In any case, I wrote an article in *Läkartidningen* (the Swedish Medical Journal) in 2013, where I pointed out that this particular group — those who are highly sensitive and those with migraines — are a risk group. Even if other people tolerate exposure from wind turbines well, according to the studies done, there is still a group of people — perhaps 30% of the population — who have increased sensitivity, and that should be taken into account.

But it wasn't. The article was ignored, and I forgot about the matter and moved on to other things — until about a year ago, when Professor Mattsson contacted me. He had read the article and thought that maybe there was something we could revisit.

And so, now the old rusty horses are trotting again.

Over the past year, I've gone through the literature, and you can actually find quite a few real gems. If you look at those yellow highlights, you'll see that in just the past ten years, many new articles have appeared on the effects of infrasound on humans. That's what I'll be summarizing and presenting today.

To make it a little more exciting, I'll start by teaching about the nervous system. Welcome!

The nervous system is powered by the body's sensory cells. Without sensory cells, everything would be dark, everything would be empty — we wouldn't function, we wouldn't feel anything. So, at the most fundamental level, all of our sensory cells — vision, hearing, balance, touch, proprioception, everything — are the engine that keeps us alive. The engine of the nervous system.

All the information from our sensory organs travels up through the spinal cord, up to the brainstem, and then on to the brain. In the brain, that information is processed — we think, we form our perceptions, our memories. And from that information then comes a reaction — in the form of a movement, a spoken word, or some other activity.

We're now talking about my area — the brainstem — which I like to call the reptilian brain. I call it that because it's actually the most primitive part of the nervous system. Even the dinosaurs, many hundreds of thousands of years ago, had a reptilian brain.

This area contains many vital basic functions: breathing, blood pressure regulation, the wakefulness center — the reticular formation — which is incredibly important for our level of alertness, appetite, sexuality, and many fundamental reflexes. Reflexes that allow us to stand upright at all, reflexes that let us walk, neck reflexes, eye reflexes — reflexes that allow us to glance to the side while still fixing our gaze on an object, like a hunter tracking prey.

Above this area lies the large brain — the cerebrum. And within the cerebrum is another area called the emotional brain, or the limbic brain — the limbic system. This is the region where our emotions are formed: pleasure, anger, anxiety, discomfort, love, joy. It's our emotional center, you could say.

And part of this center — the amygdalae down here — is an area that can specifically be affected by infrasound, as has been demonstrated. It's precisely this area that produces feelings of anxiety, fear, or discomfort when it is activated.

Infrasound is a type of sound that humans cannot hear, so it's often said to be insignificant. But even if we can't hear it, infrasound waves still reach the brain and activate different centers — for example, the amygdalae. These waves can enter directly through the skull bone, since the slow vibrations can penetrate and influence the brain's own waves.

You might know that in EEG testing, electrodes are placed on the skull to measure the brain's electrical waves. Those waves come from the outer part of the brain, the cortex. But those cortical waves, in turn, are regulated by brain waves generated in the brainstem and midbrain — especially the thalamus. These deeper brain waves are much slower and similar in frequency to infrasound waves. That means there's a possibility that they can interfere with each other.

The second way infrasound affects the body is through sensory cells in the inner ear — not the ordinary hearing cells, but those belonging to the secondary line of auditory cells. These can be affected and can in turn activate the amygdalae in particular.

In a very recent study from this year, researchers examined the damaging effects of infrasound on laboratory animals. At levels of 120 to 140 decibels, one can begin to speak of actual damage occurring in brain cells. These are levels produced by wind turbines at close range — though the question remains, where exactly does the threshold lie? That threshold is what must be determined when constructing wind turbines.

However, infrasound can give rise to other effects even without causing physical damage. I mean, one can become irritated, one can become stressed — and that's a significant functional impact even if no injury occurs.

When there's increased activity in the brainstem as a result of heightened sensory input, the first thing you tend to notice is a sleep disturbance. When brainstem activity becomes too high, it affects the reticular system. This type of sleep disturbance usually means that one sleeps much more lightly — waking up at the slightest thing and never reaching deep sleep.

Effects on the neurotransmitter systems — such as depression and anxiety — are common problems that can arise quickly when exposed to infrasound. And excitation of the amygdala, as I mentioned earlier, produces anxiety — so anxiety is something people can easily develop when exposed to infrasound.

Fluctuating infrasound is also a very strong trigger for migraines. If we look at this picture — the lighting is quite pleasant in itself — but when it's pulsating, it creates a quality that's very unpleasant. And it's precisely this pulsating quality in the infrasound from wind turbines that is disturbing and causes discomfort for many people.

As I said, anyone can be affected by infrasound — it's not that they can't. If the infrasound is strong enough, it's dangerous. But it's especially this group of highly sensitive people who are at risk of being affected.

The symptoms that usually appear first are what we call *annoyance* — that is, irritation — then *sleep disturbance*, *anxiety*, *depression*, and an increased risk of developing *headaches* or *migraines*. And, as we'll come to later, *migraine-related disorders*.

About 30% of the population is therefore born with increased sensitivity — it's genetic. These are the people who have heightened sensory sensitivity and may develop migraines. But not all of them do. Many who have this genetic disposition for sensory hypersensitivity can go their whole lives without ever experiencing a migraine headache.

However, if they were to face an extreme situation — for example, a sudden divorce or a deeply distressing emotional event — they could develop ocular migraine or migraine headaches as a response to that sudden surge in sensory tension.

So, these individuals are born with a more finely tuned nervous system. They're born with extra-sensitive sensory cells — the very engine of the nervous system is more reactive. And that increased sensitivity applies to all sensory cells — not just sight and hearing, but also emotions, and proprioception (the sensors in the body's muscles that detect posture and movement). It also includes pain receptors, and receptors for cold, heat, and chemicals. All of these are more sensitive.

This means that even relatively minor stimulation produces a signal — compared to a normal person without that heightened sensitivity in the nervous system. A person with increased sensory sensitivity will always have a slightly elevated flow of nerve signals from all sensory organs up to the brainstem. The brainstem and brain are therefore constantly under a kind of increased "pressure" of neural activity, you could say.

As mentioned, a bit more than a quarter of the population has increased sensitivity. But this is also relative — not everyone has the same degree of it. The majority have a mild increase in sensitivity and may not even notice it much. Others have a lower level, while around 13–15% have *very high* sensitivity.

That means this group of people — when near a wind turbine — may begin to experience symptoms after just a few hours of exposure.

...symptoms after just a few hours of exposure. This group might not experience discomfort for a week, a month, or even a year. Another group might not develop symptoms until after being exposed to this stimulation for one, two, or three years.

So, the degree of sensitivity varies within the population, which means that not all people with increased sensory sensitivity are affected in the same way — there are differences. Experiencing negative effects from infrasound depends on three factors:

1. The degree of individual sensitivity — what kind of person you are.
2. The strength of the sound — how intense it is and how far away you live.
3. The duration of exposure.

Those three factors must all be taken into account when assessing the potential harm of infrasound.

Returning to the brainstem — we talked earlier about the center called the *formatio reticularis*, which regulates wakefulness. That means that if the brainstem is affected, the first symptoms that appear are increased alertness — an elevated level of physical or mental activation — and disturbed sleep, because the person remains in a more wakeful state.

There is also an effect on the centers in the brainstem that regulate neurotransmitters, primarily noradrenaline and serotonin. An increase in activity within that system — particularly noradrenaline — as you know, causes higher stress when adrenaline secretion rises. So, increased activity means that a person will have a higher stress level when exposed to too much sensory stimulation from infrasound in the brainstem.

Serotonin is a bit complex. One might think that an increase in serotonin levels would make people calmer and more relaxed. But it's actually a complex reaction — involving both the midbrain and the thalamus — that can lead to the opposite effect: increased anxiety and a higher risk of depression.

I should also mention that right here in the brainstem, this increased inflow of sensory input and its effect on neurotransmitters also influences personality. So, those who happen to be born with a truly fine and sensitive nervous system — HSPs, Highly Sensitive Persons — have the good fortune of possessing a special kind of personality. And it's a good personality.

Many famous people throughout history have had high sensitivity or migraines. They're often driven, ambitious individuals who stand out in history. What makes these people special is that they tend to be very industrious — they take initiative, they're energetic, meticulous, and well-organized. They like order and structure. No mess in drawers, no papers scattered around — everything should be in order. They have a need for control.

They also tend to learn easily. Some in this group have what's called a photographic memory — they only need to look at a page once to remember it. It's quite fascinating.

They're also highly empathetic — and often worry a lot. They frequently come to clinics concerned about small things. And sleep problems are common among them.

These individuals — the HSPs we're talking about — have a higher flow of nerve signals from all of the body's sensory cells from birth. But then, there are other contributing factors...

...that put extra strain on the nervous system — what we call *trigger factors*. These increase nerve activity even further. They include different forms of stress. We usually distinguish between *emotional stress* — such as, for example, a painful divorce or a boss who gets angry and says, "You're fired tomorrow because you're useless" — and *sensory stress*.

Sensory stress was shown in that earlier image — flickering light, or, for example, a classroom full of children yelling and throwing erasers. Flashing lights and fluctuating sounds are especially powerful triggers.

When you suddenly experience an increased sensory load — a trigger — and you're already operating at a high level of brainstem activity, there's a threshold somewhere. And when you cross that threshold, that's when you get a headache — a migraine.

It's often said that migraines begin with what's called an *aura*. That's when you've crossed that limit — when too much nerve activity reaches the brain. Then, a kind of chain reaction of nerve activity starts somewhere in the brain. Most often it begins in the back of the brain, where the visual center is located — which is, so to speak, closest to the brainstem.

This burst of activity is perceived by the person with migraine as something happening with their vision: zigzag patterns, or moving bands of color in the visual field, or a blurry spot — like trying to wipe away a smudge on your glasses that won't go away.

The aura is caused by that increased activity constricting the blood vessels in that particular area of the brain. That region then receives too little oxygen and blood flow, and that's what triggers the symptoms. And that's not good — not good at all.

This impaired situation quickly triggers a cascade of reactions in the brain that lead to the migraine headache. I won't go into detail — it's far too complex — but in brief: that vessel constriction triggers the release of a substance from the nerves surrounding the blood vessels called *CGRP*, which strongly dilates the vessels again.

So the constriction is quickly counteracted, and the blood vessels expand again — but the dilation becomes a bit too strong. When the vessels widen too much, they leak slightly — some of the fluid from the blood seeps out. That leakage around the vessels irritates the surrounding nerves and makes one even more sensitive.

If you were already sound-sensitive, you become even more so. If you were light-sensitive, you become even more light-sensitive during this phase.

I usually say it's a bit like getting a sunburn. If you lie on the beach all day and sunbathe your back, your back turns red — not because of the tan, but because the blood vessels under the skin dilate as much as possible to protect against ultraviolet rays. But when they dilate that much, fluid leaks from the blood vessels, and you can even develop blisters filled with fluid on the skin.

Even without blisters, there's an increased amount of fluid around the blood vessels in the back, making the area very sensitive. When you try to lie down at night, it feels like lying on needles.

And that's roughly what happens when the blood vessels in the brain dilate strongly during a migraine. The dilation naturally subsides again once the migraine attack has passed — but that's the process.

At the same time as this vessel dilation, or *exhalation*, there's a reactivation from the brainstem up to the brain. Each migraine attack increases the activation of the midbrain, leading to what we call *increased arousal*. Increased arousal is, in fact, a defining feature of people with migraines — they have a higher general level of brain activity, so to speak.

Now, let's look a bit at the symptoms and associated effects. It starts with what we call the aura, when the blood vessels constrict — this causes the various visual phenomena we talked about earlier. But there can also be completely different symptoms: numbness in the face, loss of sensation or strength in an arm — dramatic and unpleasant sensations.

There may be effects on hearing, or an unpleasant smell experience — *olfactory hallucinations*. A person might suddenly smell something like burnt rubber. They go to the doctor and say, "I smell burnt rubber — what's wrong?" The doctor might ask, "Are you having hallucinations?" Few people think it could actually be related to migraine — unfortunately.

Here's an example: a woman in her 30s comes into the emergency department with sudden dizziness, nausea, and vomiting. At the same time, she's numb on one side of her face. It looks like a stroke is in progress. So, an emergency brain scan is done, along with imaging of the blood vessels in that area — to see if something has happened.

Thank goodness — no stroke. But when they looked at the blood vessels, they saw — aha! — good circulation overall. Yet the vessel supplying the cerebellum... what's going on there?

This is what it looks like, actually, on the underside of the brain. The blood vessels rise upward and branch out, and this particular vessel — the one supplying the cerebellum — showed disturbed circulation. When blood flow to the cerebellum is disrupted, you get ischemia.

Two days later, they repeated the examination. The woman had become almost immediately symptom-free after the imaging procedure — no treatment was necessary. And what did they find two days later? The circulation had normalized again — it was only temporary, a brief spasm in the vessel.

And here you can see that something did happen in the cerebellum — but not an infarction. Rather, a fluid increase, swelling — similar to when you get a hard hit and the skin swells a little, like after a slap on the cheek. It passes — it's temporary. The woman was completely fine and could go home.

The next stage in the migraine phase is when the blood vessels dilate. Pulsating, dilated vessels cause the headache — typically a one-sided headache, the classic symptom described in textbooks as a migraine headache.

It depends on which part of the vascular network is affected by spasm or poor circulation. The headache may be located in the forehead on both sides, or quite commonly, in the neck. It's also not unusual to experience pain in the cheeks — exactly the same kind of pain as from sinus inflammation. In fact, many supposed sinus inflammations are actually undiagnosed migraine attacks.

The stomach can also be involved. There's something called *abdominal migraine*, which presents solely as stomach pain. And many women with migraines have recurring digestive issues. The same system involved in migraine also affects the gastrointestinal tract — particularly by slowing gastric motility. This slower emptying of the stomach can, in turn, lead to increased problems with reflux.

The third phase brings longer-lasting and more uncomfortable effects. One of the most common is increased sleep problems. For those living in environments near wind turbines, that's often one of the first things noticed — sleep disturbances.

Then comes an intensification of sensory symptoms: greater sound sensitivity, and more frequent motion sickness. It becomes unpleasant to drive to work because of the sensations.

Different forms of dizziness can also be triggered. A particularly uncomfortable form is called *PPI* — postural dizziness with anxiety, you might say. People suddenly feel as if the ground is swaying, everything feels unstable, and they simultaneously experience a surge of anxiety. They're often deeply distressed when seeking help for these symptoms.

That type of dizziness is caused by hyperactivity in the body's muscles — the *proprioceptors*, which are the sensory cells that generate muscle tension and detect the degree of stretch in tendons and joints.

The increased sensitivity causes a completely different inflow of information from the body about how one stands and moves — and that's what creates that strange feeling.

Mental fatigue — what is that? It occurs when there's irritation or inflammation around the blood vessels that affects a larger part of the brain. The first thing you notice is that you don't function as well — you feel tired, even if you sleep at night, you're still exhausted during the day.

As you get older, over the long term, if migraine headaches are frequent and poorly managed, the risk of vascular impairment increases. People with migraines tend to have slightly constricted blood vessels. They often have cold hands and feet. What's called *Raynaud's phenomenon* is much more common among people with migraines.

This tendency toward constricted vessels means that, over time, the risk increases for both heart attacks and strokes. A person who has suffered a lifetime of severe headaches and dizziness in older age may actually be showing signs of poor circulation — and an increased risk of what's called *vascular dementia*.

This is especially true if other risk factors are present — and I'm thinking particularly of *smoking*. What upsets me most today is the new nicotine snuff being marketed — it delivers extremely high doses of nicotine, which constrict blood vessels, worsen circulation, and gradually make the vessels stiffer over time.

It's mainly women now who have begun using this white snuff and who also suffer from migraines. In 30 years, we'll see a rapid increase in the incidence of heart attacks and strokes in that group. I view this white snuff as a potential public health catastrophe waiting to happen.

Highly sensitive people are exceptionally capable individuals — driven people who contribute greatly to society, people society should protect and value. Yet these individuals are affected by various forms of *sensory disturbance*. And I'm not just talking about infrasound — I mean telephones, mobile phones, TV screens, computers, sound systems, ventilation noise from air conditioning — the entire soup of sensory input that overwhelms people with sensitive nervous systems.

One can choose whether to listen to someone on a mobile phone. One can choose whether to sit under a noisy air conditioner or in a building with flashing lights. But if you live near a wind turbine, you can't choose whether or not to be exposed to that influence. It's a factor that is very difficult to avoid — and one that can be harmful in the long term.

It's a catastrophe that will eventually affect society.

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These individuals are affected by various forms of sensory disturbance. I'm not just talking about infrasound — I'm talking about telephones and mobile phones, TV screens, computers, sound systems, and ventilation noise from air conditioning — the entire mix of sensory input that overwhelms people with sensitive nervous systems.

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It's a factor that is very difficult to avoid — and one that can be dangerous in the long term.

What can happen in the long term, if one has a growing tendency toward migraine — headache after headache after headache — is that inflammation becomes chronic. One then develops what's called *chronic migraine*, and that's no small matter.

This inflammation, as we discussed earlier, drives increased pain sensitivity. That heightened sensitivity, in turn, gives rise to what's called *fatigue* — that is, brain fatigue. And that brain fatigue — we hear people say, "I'm burned out," or "I've hit the wall." It takes a very long time to recover.

Chronic fatigue and pain together — it's one of the worst things that can happen, to develop chronic migraine. You become more or less disabled. The natural abilities that you're normally good at in everyday life deteriorate more and more. Memory worsens — you forget things: *What did he say? What did he look like? Who was he talking to? And what was it he said?*

Focus disappears. It becomes difficult to concentrate again. Reading, listening to information from a boss — it's too much. You can't keep up with anything. Eventually, you end up at home — you can't even go to work. You can hardly clean your house or move around.

And this is a person who once functioned perfectly well — with one of the best nervous systems in the world: smart, efficient, organized. To end up in that kind of situation is dreadful. And, of course, no one wants that.

A bit about infrasound and the brain, before I wrap up.
Infrasound — you can't escape it. It's constantly there, like a background layer.

And how far does this "layer" actually extend? Is it only around wind power installations, or is it a layer that spreads across all of Europe — or smaller than that?

I think it...

Wind power installations — or is it, rather, a kind of blanket that spreads across all of Europe, more or less? I think that's something we really need to reflect on — whether this is a form of sensory stress that, in the long term, is harming society as a whole.

I mentioned earlier that infrasound affects the sensory cells in the ear. It can also pass through the skull bone and influence the brain's slow-wave activity.

The risk of developing migraines is a product of *intensity* and *exposure*. Those who are highly sensitive develop symptoms quickly. Those who are less sensitive — it might take a year before anything appears. But then perhaps it comes in the form of a depressive or anxious episode.

How on earth could anyone link that to infrasound? Especially among young people — there we see an increased risk of anxiety and depression. And, as I said, burnout from chronic migraine, as well as a higher risk of suicide. The risk is elevated — I don't know how much, but it exists.

There's also an increased risk of heart attack and stroke, premature aging, and dizziness.

And the most insidious and troubling thing about all this is — how can one even know that it's the infrasound causing it?

Infrasound travels far — you can't hear it. So how could I possibly know that it's *that* causing the problem? It's therefore very difficult for someone experiencing symptoms to connect them specifically to infrasound. It's a hidden factor.

To summarize: infrasound can affect us — it can influence the brain both directly and indirectly. The degree of impact depends, of course, on the sound level and on how long one is exposed. It can trigger headaches, sleep disturbances, anxiety, and depression even after short-term exposure.

But if we look at the long-term effects, they are far more numerous. They include problems with migraine-associated conditions that affect the heart and increase the risk of stroke.

And there are no existing guidelines — and that's what I want to emphasize: society needs to work toward developing them.

And that is why Professor Mattsson and I have taken part in this work.

Thank you for your patience. Thank you for listening.