

PUTTING INTO PERSPECTIVE THE RISKS TO PUBLIC HEALTH AND SAFETY POSED BY WIND TURBINE INSTALLATIONS

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ABSTRACT

This paper evaluates the risks to public health and safety posed by wind turbine installations, grounded in the special professional obligation of engineers to safeguard public welfare. The assessment also addresses specific concerns raised by residents living near such facilities. Risk is defined, following established methodology, as the combined answer to three questions: what can go wrong, what is the likelihood of it occurring, and what are the consequences.

Potential failure scenarios were identified through two complementary approaches. The first examined 13 acute incidents (blade failures, fires, tower collapses and hub failures) that occurred among 2712 wind turbines operating in Ontario, Canada. The second investigated chronic noise conditions characterised by tonal-like features and cyclical amplitude variation that residents associate with annoyance and sleep disturbance.

The calculated frequency of acute events is approximately 0.5×10^{-3} failures per turbine-year. Monitoring campaigns confirmed that special noise characteristics meeting psychoacoustic criteria for tonality and saliency occur chronically and correlate with resident complaints. Existing regulatory setbacks and warning measures were shown to be inadequate as protective barriers, allowing the possibility of fatal or serious injury outside the designated exclusion zones, as well as persistent noise-related impacts on health and well-being.

The conclusions propose more robust deterministic setbacks based on observed impact distances, the inclusion of fire-suppression systems, and the adoption of improved acoustic criteria that capture tonal-like and cyclical noise features. Implementation of these measures would strengthen public safety protection and reduce noise-induced annoyance that affects health.



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1. INTRODUCTION

1.1 The Preamble – “risk”

The book Risk Assessment, Theory, Methods, and Applications (Rausand & Haugen, 2020, p. 15) introduces the subject of risk analysis by quoting Stan

Kaplan. Kaplan observed that, in the absence of a universally accepted definition of the word “risk,” every author should explicitly state how the term will be used. This paper adopts the definition proposed by Rausand and Haugen (2020, p. 17), according to which “risk” is the combined answer to three fundamental questions:

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- What can go wrong? (identifying the accident scenarios that may cause harm)
- What is the likelihood of that happening? (Which can be answered either qualitatively, or quantitatively as probabilities or frequencies, but needs to consider all the accident scenarios identified, and essential modifiers that can impact the likelihood.)
- What are the consequences? (This needs consideration of protective barriers in the event something goes wrong.)

Often the determination of “risk” is given by the simplified word equation, Risk = Frequency x Consequences.

Engineers carry a special professional obligation with respect to risk. As an illustration, the Professional Engineers Act of the Canadian Province of Ontario (Ontario, Professional Engineers Act, 2025) establishes that the primary legal duty of Professional Engineers is to protect public safety. The Act explicitly states that this responsibility takes precedence over duties owed to clients or employers. The present paper examines how the risks to public health and safety that may arise from wind turbine installations interact with this fundamental engineering obligation.

After evaluating whether the three tests of risk are satisfied, the paper concludes by recommending a practical path forward that would enable engineers to fulfil their legal responsibility to safeguard public health and safety.

2. GATHERING THE DATA – THE EXPERIMENTAL PROCEDURE

2.1 What Can Go Wrong – Acute Accidents

Wind turbine scenarios that could do harm were identified by two methods, tracking acute accident scenarios, and investigation of chronic noise scenarios. Acute accidents are described in section 2.1 and chronic noise scenarios are described in section 2.4.

Acute scenarios were identified by tracking accidents in the Province of Ontario, Canada. Scenarios were limited to those when turbine components greater than 1 metre in size fell from wind turbines with a nominal tip height of 100 metres or higher. The components had to fall at a location that was not protected by an effective barrier that would prevent hitting a citizen. 2712 turbines meeting this size criteria have operated in Ontario, from 8 different manufacturers. Known accidents of this nature are shown in Table 1. Typical accidents are shown in Figures 1 and 2. Falling ice events and falling blade flow straighteners were not specifically tracked.

Table 1. Ontario wind turbine accidents

Date	Where / What Failure / Turbine	Age at Fail
2007-04	Port Burwell / blade / GE 1.5	0.9 years
2008-01	Prince Wind / blade / GE 1.5	2.1 years
2013-04	Kingsbridge 1 / fire / Vestas V80	7 years
2015-08	Goshen / blade / GE 1.62	0.5 years
2017-04	Bornish / blade / GE 1.62	3 years
2018-01	Raleigh / tower / GE 1.62	7 years
2018-05	Huron Wnd / blade / Vestas V80	15.4 years
2019-04	Sumac / blade / Senvion MM92	1.3 years
2021-06	Skyway / blade / Vestas V100	6.9 years
2021-08	Bow Lake / collapse / GE 1.62	6 years
2024-06	Kingsbridge 1 / fire / Vestas V80	18.2 years
2024-06	Gestner / fire / Gamesa 2 MW	11.4 years
2025-03	Port Burwell / hub / GE 1.5	18.8 years



Figure 1. Wind turbine fire (Kingsbridge 1 2024-06)



Figure 2. Tower collapse (Bow Lake 2021-08)

2.2 What is the likelihood of acute scenarios happening?

The tabulated wind turbine acute accident scenarios, and the total Ontario turbine-years of operation when each accident occurred, was used to identify a failure rate. The progression of failure rates (both mean and Chi Square) and the total turbine years in service at each failure, was plotted in Figure 3. The figure shows a fairly constant failure rate of 0.5×10^{-3} failures per turbine years in service after the first few failures had occurred.

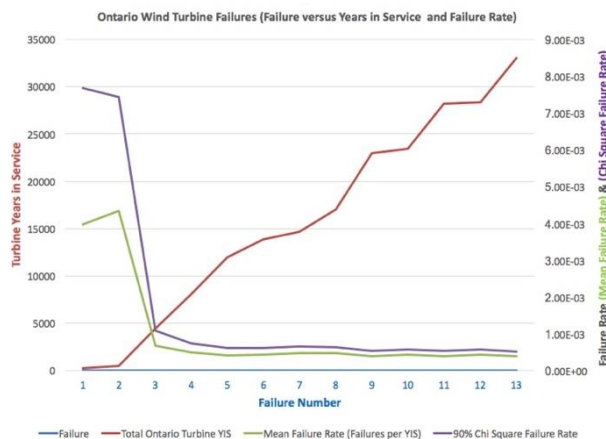


Figure 3. Ontario wind turbine failure rate

2.3 What is the consequence of acute scenarios happening?

In a comparable situation of assessing public safety risk, Canadian nuclear regulators require that a deterministic safety analysis (Canadian Nuclear Safety Commission, REGDOC 2.4.1, 2025) be conducted for every facility licence. The analysis must demonstrate that defence in depth exists to protect the public, in the event of failure of equipment, internal or external event, or operator error. The deterministic safety analysis is used in the assessment of event consequences to show that effective barriers exist. Additionally, for licensing new facilities, or for existing facilities when the licensing basis includes it, there is a requirement for a probabilistic safety assessment. (Canadian Nuclear Safety Commission, REGDOC 2.4.2, 2025) The intent of the probabilistic safety assessment is to identify that no particular feature or initiating event makes a disproportionately large or significantly uncertain contribution to risk. The combined goal of the deterministic safety analysis and probabilistic safety assessment is protection for both the most impacted individual and the population impacted by a failure.

Assessment of public safety risk for a wind turbine installation should similarly show protection for both the most impacted individual and the overall population impacted. Deterministic safety analysis would show that for each known wind turbine failure identified in Table 1, an effective barrier would have to exist. For example, for a blade failure, it would be necessary to demonstrate that a barrier such as an exclusion zone would protect any member of the public from being impacted. The consequence of the failure would then be low or negligible. A probabilistic safety assessment for wind turbine accidents identified in Table 1 would show the impact of features such as lack of fire suppression.

For wind turbine installations, the public safety impact on individuals is greater than impact on overall population. The public, or neighbours to wind turbines in

Ontario, Canada, are “protected” by a regulatory exclusion zone equal to the turbine rotor radius (blade length) plus 10 metres. (Ontario, Technical Guide to Renewable Energy Approvals). For the 2018-05 Huron Wind blade failure identified in Table 1, a 1.2 metre wire fence, located 52 metres from the turbine that failed bears a sign. The sign reads, “No Entry, High Voltage Hazard, Falling Ice Hazard (during cold weather), Trespassers will be prosecuted.” The day following the blade failure, the author visited the site, and photographed blade segments, including:

- 1.2 m x 3.6 m blade segment 150 m from tower
- 1.0 m x 3.6 m blade segment 170 m from tower
- 1.2 m x 3.0 m blade segment 210 m from tower
- 1.2 m x 3.0 m blade segment 280 m from tower
- 1.0 m x 0.15 m blade segment 560 m from tower

Other Ontario wind turbine failures have identified similar challenges to the “protective” exclusion zone. The 2021-08 Bow Lake tower collapse in Figure 2 shows the 50-ton turbine nacelle on the ground at a distance greater than blade length plus 10 metres from the tower. Wind facility staff reported to the municipality after a 2013-04 Kingsbridge 1 turbine fire consumed the nacelle, that burning debris landed 200 metres from the tower. A blade length plus 10 metre exclusion zone is demonstrably inadequate to protect the public for turbine collapse, blade failure, or turbine fire.

Ice falling from wind turbines, although not included in the table of acute failures, as hardly exceptional for Canadian installations, poses an additional challenge. Along Ontario provincial highway 21, a fence post with a 20 cm x 25 cm sign reads, “Caution, During Potential Icing Conditions Stay Back 305 metres from Turbines.” This would seem a reasonable suggestion, and is consistent with common recommendations for the turbine size. However, the sign poses several problems. First, the lettering is too small to be read from passing vehicles. Second, it is located at the boundary of the “right-of-way” of the provincial highway. The nearest wind turbine is set back 121 metres (the hub height plus blade length) from the highway “right-of-way.” Provincial monitoring shows an average daily count of 7050 motor vehicles pass by that location. (Ontario, Ministry of Transport) These vehicles cannot travel down the provincial highway and comply to stay 305 metres from the nearest wind turbine, located 121 metres from the right-of-way.

When considering consequences of accidents that are known to occur, with a frequency of some 0.5×10^{-6} failures per turbine year in Ontario, one might expect that the regulated “protective” barrier would be effective. Similarly, one would expect that when a turbine operator posts a caution sign as a “protective” barrier, that it would be possible to comply. Clearly, neither expectation can be achieved.

Recognizing that neither expectation of “protective” barrier can be assured to make the consequence of known accident scenarios to be low or negligible, it is necessary to proceed further to investigate the consequence of each accident. We will approach the investigation from the accident boundary conditions. We consider first tower collapse, demonstrated to have placed a 50-ton nacelle on the ground at a distance from the tower greater than blade length plus 10 metres. Even without medical expertise, it is apparent that the consequence at the point of impact, a location outside the protective zone, would be fatal to any human. We consider next the opposite boundary condition, ice fall from stationary wind turbine blades. Photographs and reports show ice greater than 30 cm x 30 cm x 2 cm, falling from stationary wind turbine blades, landing at a distance of greater than blade length plus 10 metres from the tower. Lateral shift of where the ice lands, away from the tower occurs even with gentle breezes. Calculation shows this ice segment falling from the height of turbine blades is equivalent to dropping an 18-kg concrete block from an 8 storey window. Again, even without an expert assessment, the consequence can be predicted to be fatal to a human. Heated turbine blades can result in even larger ice segments falling. (Froese, 2017)

We have considered bounding cases of the wind turbine tower collapse, or ice shed from stationary blades. Both demonstrated that a member of the public could suffer fatal consequences when located outside of the exclusion zones in locations purported to provide protection. It is logical that fatal consequences could occur from intermediary accidents, such as 1.2 m x 3.0 m blade segments landing 280 m from the turbine tower.

2.4 Gathering data for chronic noise issues

A presentation to the Grey Bruce Medical Officer of Health, and the Municipality of Kincardine (2012) by Crawford, documented “Health Impacts in Two Local Wind Projects” for 20 families. (Crawford, 2012, as cited in Palmer, 2017) The problems included sleep deprivation, blood pressure control, and management of diabetes control. A freedom of information request filed to the Ontario regulator showed 5832 complaints about wind turbine noise, vibration, and sound pressure filed from 2006-2018. 595 complaints were filed in 2018 alone, indicating that the frequency of complaints was not diminishing appreciably. (Wind Concerns Ontario, 2021) In addition over 100 citizens reported adverse impacts to the author of this paper. This subsection identifies the data gathering to try to understand the reported issues.

The first study looked at noise inside versus outside homes. Some reports initially appeared hard to comprehend. One resident reported that when noise inside their homes was untenable, they found some relief by sleeping in a tent, outside their home. This seemed

incredible, as it was expected that the home structure would attenuate the sound. A second resident, reported that when unable to sleep due to noise, they found some relief by reversing sleeping position, with their head at the bed foot position. Again, this report was puzzling. Data was gathered by setting up monitoring equipment within the second resident’s home, monitoring at different locations within the home and bedrooms, with windows open and closed. The results were reported at the 168th meeting of the Acoustical Society of America and were subsequently documented in the Journal, Global Environment, Health and Safety (Palmer, 2017) The investigation and data gathered showed that the phenomenon known as “room conditions” resulted in significantly different acoustic readings across a room. In this case the room was near cubic, with dimensions 3m x 3m x 2.75m. The centre of a room, near the foot of the bed, was lower in sound level than at the head of the bed in the room corner. Room shape, particularly if approaching cubic, impacts reverberation, and the variation across the room.

The second study was conducted at another wind power development, where residents reported they were troubled by tonal conditions from the wind turbines. An extended monitoring campaign was conducted in this wind power development, as initially reported at the 2017 International Wind Turbine Noise Conference, then further discussed at the 2019 International Wind Turbine Noise Conference, and at the 2024 joint conference of the 186th Meeting of the Acoustical Society of America and the Canadian Acoustical Association. This work was documented in the Proceedings of Meetings on Acoustics of the ASA. (Palmer, 2024). Summarizing the conclusions, it was found that “tonal-like” conditions existed, consistent with ECMA Standards 74/418 for tonality, where the energy in the critical “bark” (or band) surrounding the peak tonal level exceeded either the higher or lower band by about 4 dB. This finding of tonality is consistent with Zwicker and Fastl (Zwicker & Fastl, 2006, Chapter 6) who found that humans hear sounds in a critical band together. However, the standards (IEC Standard 61400-11, 2012; ISO/PAS Standard 20065, 2022) used to monitor for wind turbine tonality focus on the tone and narrow bands on either side of the tone. Those standards then consider other energy in the critical band as masking, and as a result fail to find most cases from wind turbines as tonal. Others note (Huang & Elhilali, 2017; Elhilali, 2021) saliency, a “bottom-up” stimulus-driven characteristic that captures attention, form an effective criterion for predicting unpleasantness.

The third study gathered additional data over a period of approximately 12 months within another wind power development to assess acoustic conditions identified by residents as annoying. This monitoring campaign began by studying the acoustic characteristic of the sound at times identified by the residents as annoying. A monitoring system sensitivity of 1 to 5000 Hz showed annoyance was consistent with sound profiles matching

(LZ10-LZ90) ≥ 6 dBZ, while (LA10-LA90) ≤ 3 BA. To verify if this might be an effective criterion for annoyance, cases of wind turbine shutdown and restart over a short time period were studied. The criterion was met when wind turbines were operating, but not met when they were shutdown, even with little change in wind speed. Then, simultaneous monitoring was carried out at the residence near the wind turbines, and at a second location of the same environmental profile, but without nearby wind turbines. Terrain, proximity to roads, and wind conditions, were the same at both sites. The turbines at the impacted site were visible in the distance at the second location. This further verified the annoyance consistent with the criterion near the wind turbines, but not distant from them, even though wind was the same at both sites. During the monitoring period, the site near the wind turbines experienced conditions matching the annoyance criterion on 7 of 10 days, ranging from 2 to 12 hours per day. This is a chronic condition. This work was also documented in the Proceedings of Meetings on Acoustics of the ASA. (Palmer, 2024).

3. RESULTS

This work represents an update and further expansion of the 2018 study that examined public safety risks associated with wind turbine installations (Palmer, 2018). Despite the progressive deployment of newer turbine models and improved technology, the overall failure rate has not declined and remains relatively constant at approximately 0.5×10^{-3} failures per wind turbine year of operation (equivalent to roughly one significant failure per year across the Ontario fleet). In the same manner, the frequency of noise-related complaints submitted by nearby residents has shown no meaningful reduction over time, suggesting that the underlying issues continue to affect communities.

The findings were systematically evaluated against the three fundamental risk questions articulated by Rausand and Haugen (2020, p. 17):

- Risk question #1, have known accidents or impact on health occurred?
 - Accidents capable of endangering public safety have occurred, as documented in Table 1.
 - Noise conditions that produce annoyance and related health effects continue to be reported, as confirmed by the ongoing stream of formal complaints.
- Risk question #2, is the frequency of accidents or noise annoyance known?
 - The quantified accident frequency of 0.5×10^{-3} failures per turbine-year is clearly shown in Figure 3.
 - Chronic noise annoyance meeting the verified acoustic criterion was

recorded near operating turbines on 7 out of 10 days during the monitoring period.

- Risk question #3, what are the consequences, or, is protection provided by known barriers?
 - Fatal or serious injuries remain possible outside the designated protective barriers as a result of known accidents or ice shedding from turbine blades.
 - Existing acoustic standards do not adequately address the annoyance experienced by residents. Tonal-like characteristics are largely missed by the measurement methods currently in use, and the cyclical amplitude variations (saliency) identified by the applied criterion are not covered by present regulatory frameworks.

4. DISCUSSION

When considering the consequences of the failures that have occurred, a useful comparison can be drawn with other energy-generating industries that set explicit safety goals aimed at protecting both the most impacted individual and the wider affected population. While it is true that wind turbines generally produce limited effects at the population level, they nevertheless exert a clear and measurable impact on individuals living nearby. For these residents, the enjoyment and amenity of their property are significantly diminished, often leading to persistent irritability and reduced quality of life. The situation experienced by someone who resides permanently in the affected area is fundamentally different from that of a person who merely visits the same location on an occasional basis.

It is inappropriate for a wind turbine developer to encroach upon the safety envelope of a neighbouring property. The individuals most severely affected are frequently those who deliberately relocated to a quiet rural setting precisely because it offered a sanctuary from previous stress or urban pressures. Expropriation — the legal power of a government to transfer private property into public ownership, even when justified by a perceived public benefit — normally includes some form of negotiated compensation for the loss incurred.

Although this paper does not itself present detailed clinical evidence of specific health outcomes linked to wind turbine noise, the studies referenced clearly demonstrate that certain acoustic characteristics of turbine sound are consistent with the annoyance repeatedly reported by residents. This ongoing loss of pleasure and amenity in one's own home effectively constitutes a form of de facto expropriation. More comprehensive reviews of the associated health impacts

have been provided by researchers with medical expertise (Krogh et al., 2024).

5. CONCLUSION

To fulfil the engineering legal obligation to protect public safety, meaningful and concrete changes are required in order to adequately safeguard the most impacted individuals who live at the boundary of wind turbine installations. The evidence presented in this paper demonstrates that current regulatory setbacks and protective measures are insufficient to prevent serious harm. Deterministic safety assessment clearly indicates that appropriate protective boundaries must be established around turbines on the basis of the actual observed impact distances of known failure events, rather than on theoretical or minimal distances currently prescribed.

In the specific case of blade failure, fragments capable of causing fatal consequences have been documented at distances of up to 280 metres from the turbine tower, while smaller fragments likely to cause significant injury have travelled as far as 560 metres. These real-world observations strongly suggest that a minimum setback of at least 280 metres should be adopted for turbines approximately 120 metres in tip height. Correspondingly larger setbacks would be necessary for the taller machines that are increasingly being installed. Without such adjustments, members of the public remain exposed to the possibility of fatal or life-changing injury outside the zones that are presently declared “safe.”

In addition, probabilistic analysis of the recorded accidents highlights a further critical gap: the absence of effective fire-suppression systems. Turbine fires have repeatedly occurred, and in several instances burning debris has been carried well beyond the existing

exclusion zones. The installation of reliable fire-suppression equipment capable of allowing personnel to exit a burning turbine safely, and of limiting the spread of burning material, is therefore an essential safety measure that should be required.

Equally important is the protection of public health from the specific acoustic conditions that are known to generate chronic annoyance and irritability — a recognised health impact under ICD-10 code R45.4. Two clear technical requirements must be met. First, “tonal-like” conditions that satisfy the ECMA 74/418 criteria — in which the energy within the critical bark band exceeds the adjacent upper or lower bands by more than 4 dB — must be avoided through improved design, operation or mitigation. Second, significant cyclical amplitude variation, objectively identified by the criterion $(LZ10-LZ90) \geq 6$ dBZ while $(LA10-LA90) \leq 3$ dBA, must also be prevented, as this characteristic has been shown to correlate strongly with resident complaints and sleep disturbance.

Taken together, the adoption of evidence-based setbacks, mandatory fire-suppression systems, and more sensitive acoustic criteria would enable engineers to meet their paramount legal duty to protect public health and safety, while substantially reducing the adverse impacts currently experienced by neighbouring communities.

Acknowledgement: The image in Fig. 1 of the wind turbine fire is from a CTV News broadcast by CTV reporter Scott Miller. The image in Fig. 2 of the turbine collapse is from SaultOnLine.com. Both were used with permission.

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