Wind Turbine Noise and Health

A Presentation to the Wind Energy Text Amendment Working Group

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2012 Mass DEP/DH Panel Key Health Findings

Noise: The panel concluded that:

- There is limited epidemiologic evidence for an association between exposure to wind turbines and annoyance. There is insufficient epidemiologic evidence to determine whether there is an association between noise from wind turbines and annoyance independent from the effects of seeing a wind turbine and vice versa.

- There is a possibility that noise from some wind turbines can cause sleep disruption. Studies of other sources of noise have found sleep disruption adversely affects mood, cognitive functioning, and overall sense of health and well-being.

- There is insufficient evidence that the noise from wind turbines directly (i.e., independent from an effect on annoyance or sleep) causes other health problems or disease.

2012 Mass DEP/DH Panel Key Health Findings

- Claims that infrasound from wind turbines directly impacts the vestibular system have not been demonstrated scientifically.
- The weight of the evidence suggests no association between noise from wind turbines and measures of psychological distress or mental health problems.
- None of the limited epidemiological evidence reviewed suggests an association between noise from wind turbines and pain and stiffness, diabetes, high blood pressure, tinnitus, hearing impairment, cardiovascular disease, and headache/migraine.
- There is no evidence for a set of health effects from exposure to wind turbines that could be characterized as a "Wind Turbine Syndrome."

2012 Mass DEP/DH Panel
Key Health Findings

Shadow Flicker: The panel concluded that:

- Evidence suggests that shadow flicker does not pose a risk for eliciting seizures.
- There is limited evidence of an association between annoyance from prolonged shadow flicker (exceeding 30 minutes per day) and potential transitory cognitive and physical health effects.

Ice Throw**:** The panel concluded that:

- Falling ice is physically harmful and measures should be taken to ensure the public will not encounter such ice.

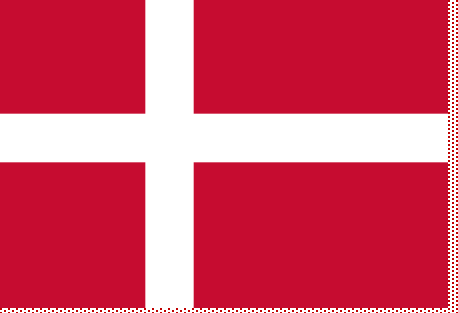
2012 Mass DEP/DH Panel Recommendations

- Noise limits be included as part of a statewide policy for new wind turbines installations. Also recommends an ongoing program of monitoring and evaluating the sound produced by wind turbines.
- Shadow flicker should not occur more than 30 minutes per day and not more than 30 hours per year at the point of concern.
- Activities in the vicinity of a wind turbine should be restricted during & immediately after icing events. Ice control measures for blades should be considered/demonstrated to work.
- Public participation should be encouraged for projects: directly involve residents in close proximity to projects. Engage the public through education and other incentives.

2012 Mass DEP/DH Panel Recommendations

- Noise limits be included as part of a statewide policy for new wind turbines installations; consider other situations; consider trade-offs between environmental and health impacts of different energy sources, and goals for energy independence, potential extent of impacts, etc.

Land Use	Sound Pressure Levels (dBs) Nighttime levels
Industrial	70
Commercial	50
Villages, mixed usage	45
Sparsely populated areas, 8m/s wind	44
Sparsely populated areas, 6m/s wind	42
Residential areas, 8m/s wind	39
Residential areas, 6m/s wind	37



2015 Schmidt & Klokker
Health Effects Related to Wind Turbine Noise Exposure: A Systematic Review

- Evidence of a dose response relationship between Wind Turbine Noise and annoyance
- Evidence of a dose response relationship between Wind Turbine Noise and self-reported sleep disturbance
- No evidence for association with tinnitus, hearing loss, vertigo, or headache
- Tolerable level around 35 dBA Leq

Understanding the Evidence: Wind Turbine Noise

The Expert Panel on Wind Turbine Noise and Human Health

Council of Canadian Academies
Conseil des académies canadiennes

Science Advice in the Public Interest

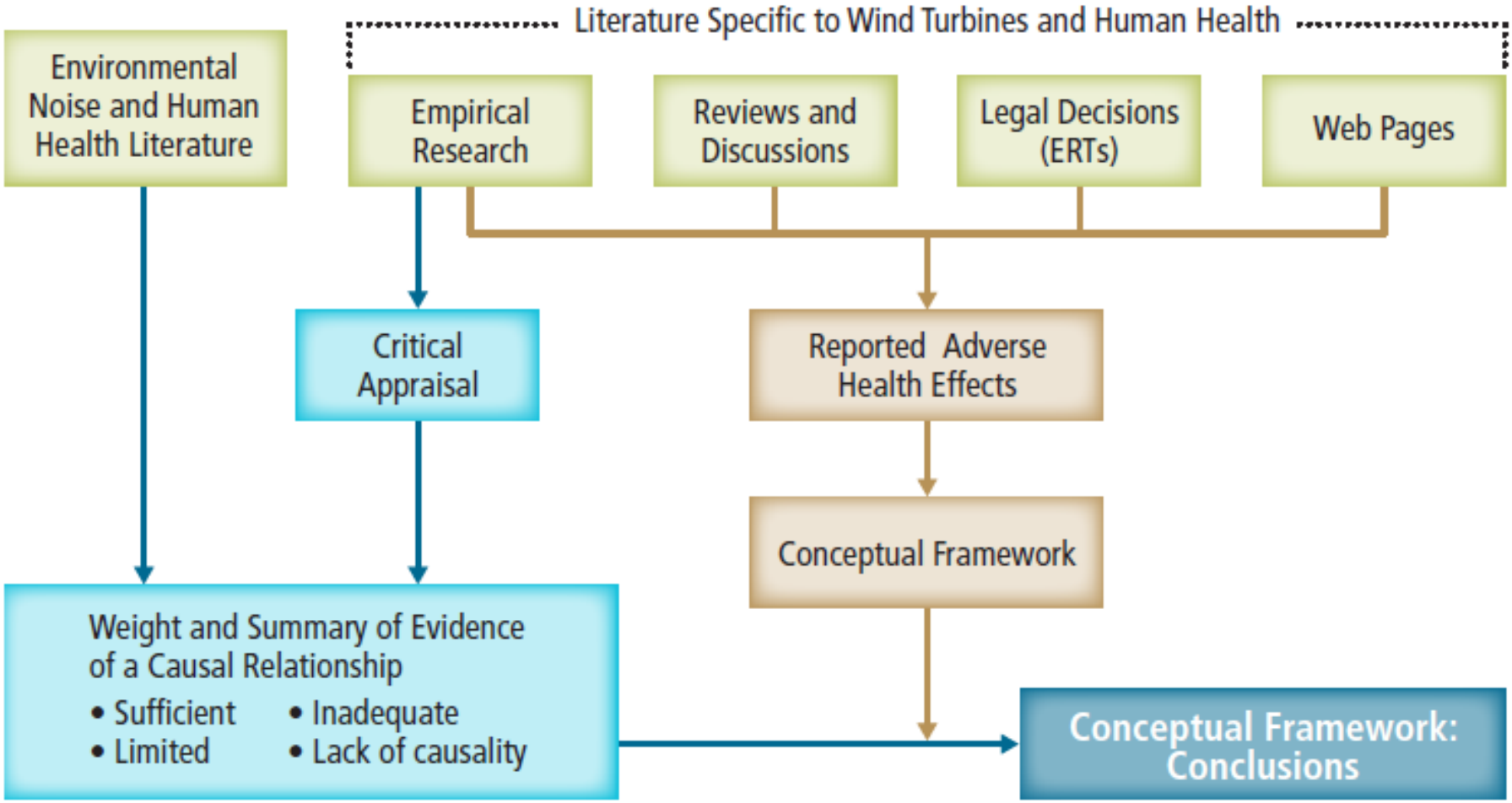


Figure 5.1

Evidence Assessment Process

Note: brown lines = potential health outcomes and mechanisms; blue lines = causal associations between wind turbine noise and health effect

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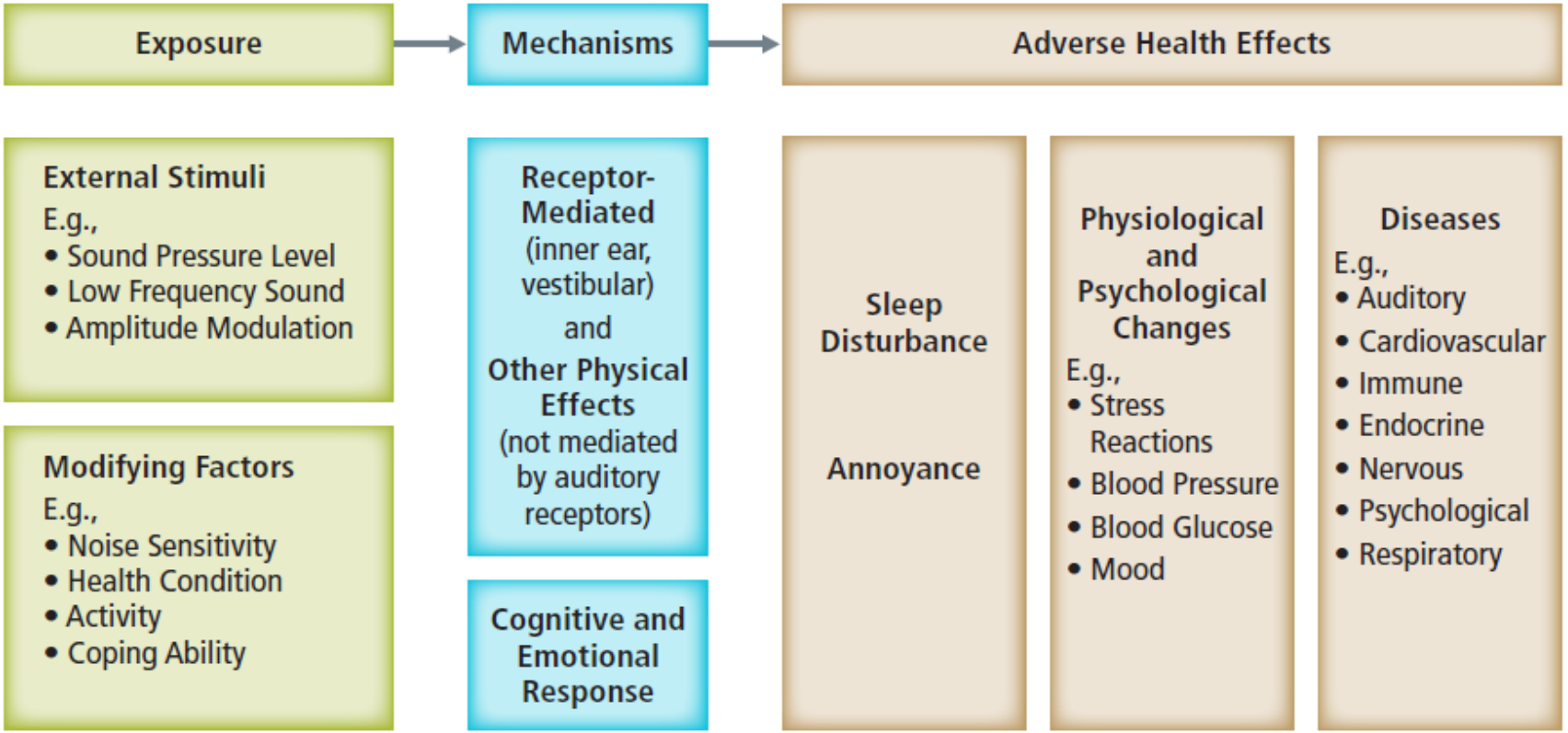

Figure 5.2

Proposed Elements of Potential Relationships Between Wind Turbine Noise and Adverse Health Effects

This framework includes proposed physical mechanisms, some of which are mediated by effects on auditory and vestibular receptors, as well as proposed effects mediated by a person's cognitive and emotional response to sound.

Council of Canadian Academies, 2015. Understanding the Evidence: Wind Turbine Noise. Ottawa(ON): The Expert Panel On Wind Turbine Noise and Human Health, Council of Canadian Academies.

Definition of Terms

6.1 ANNOYANCE

- Noise annoyance can be defined as “a feeling of displeasure evoked by a noise” and “any feeling of resentment, displeasure, discomfort and irritation occurring when a noise intrudes into someone’s thoughts and moods or interferes with activity” (Passchier-Vermeer & Passchier, 2006).

Council of Canadian Academies, 2015. Understanding the Evidence: Wind Turbine Noise. Ottawa(ON): The Expert Panel On Wind Turbine Noise and Human Health, Council of Canadian Academies.

Definition of Terms

5.6.2 Assessing Causality

Epidemiological studies cannot determine the cause of an outcome in a given individual, or even the mechanism responsible, but they can establish an association between a given exposure and the frequency of an outcome in a population … Causation can be inferred, usually based on several factors, such as the strength and consistency of the association, mechanistic plausibility, as well as the temporal sequence and biological gradient — or dose-response relationship — of the exposure and the outcome (Bradford Hill, 1965; Howick *et al.*, 2009)….

A critical appraisal guided the Panel in assessing and assigning weight to the evidence linking wind turbine noise to health effects. The Bradford Hill guidelines were used to guide Panel deliberations and to structure the summaries of evidence (Chapter 6), keeping in mind that they are not intended to be strict guidelines, and should be applied to a body of evidence rather than to individual studies. The final determination of causality was ultimately based on the Panel's judgment of the findings.

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Definition of Terms (cont.)

The Panel further adopted standard language to summarize the findings of causal relationships, following a framework similar to that used by the International Agency for Research on Cancer (IARC, 2006). The overall strength of evidence for a causal relationship falls into one of four categories:

- **Sufficient evidence of a causal relationship:** A *relationship was observed* between exposure to sound from wind turbines and a specific health effect in studies in which *chance, bias, and confounding factors <u>can</u> be ruled out with reasonable confidence*.

- **Limited evidence of a causal relationship:** *An association was found* between exposure to sound from wind turbines and a health effect for which *causal* interpretation is considered by the Panel to be *plausible*, but for which *chance, bias, and confounding factors <u>cannot</u> be ruled out with reasonable confidence*.

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Definition of Terms (cont.)

- **Inadequate evidence of a causal relationship:** The available studies are of *insufficient quality, or lack the consistency or statistical power* to permit a conclusion about the presence or absence of a causal relationship.

- **Evidence suggesting lack of causality:** *Several adequate studies* covering the full range of exposure are available that are mutually *consistent in not showing a positive association* between exposure and effect at any observed level of exposure.

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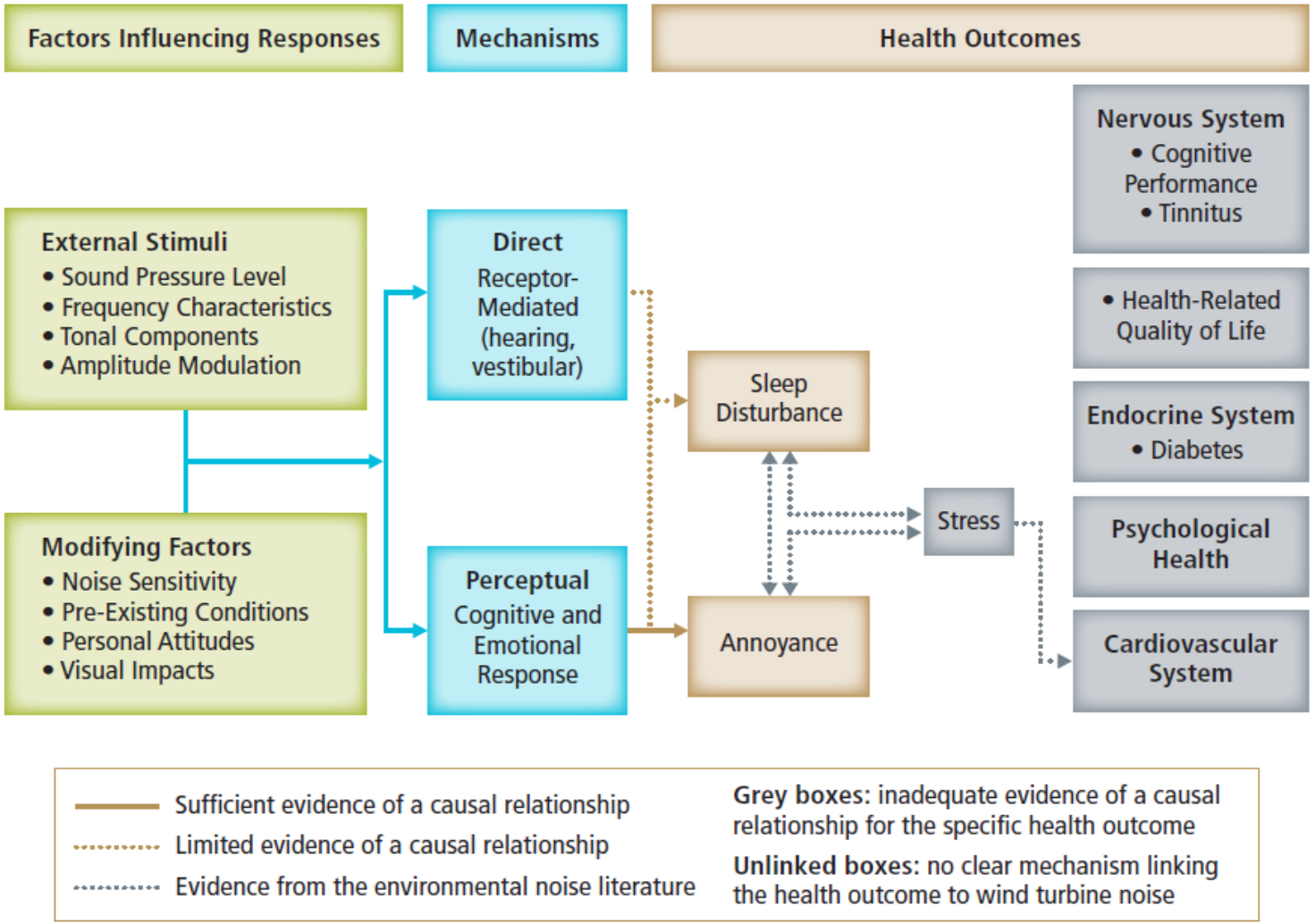

Figure 2

Summary of Evidence for Causal Pathways Between Exposure to Wind Turbine Noise and Adverse Health Effects

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Table 5.1

Proposed, but Unconfirmed, Adverse Health Effects Attributed to Wind Turbine Noise in at Least Three Documents Reviewed

Condition or Symptom	Peer-Reviewed Study	Peer-Reviewed Review	Conference Proceedings	Grey Literature	Legal Decision	Web Page
Number of Sources Reviewed	20	5	6	13	5	36
Annoyance	•	•	•	•	•	•
Sleep disturbance	•	•	•	•	•	•
Stress, tension	•	•	•	•	•	•
"Health-related quality of life"	•	•	•	•	•	•
"Vibroacoustic disease"		•	•			•
Cardiovascular System						
Cardiovascular disease			•	•		•
High blood pressure (hypertension)		•		•	•	•
Irregular heartbeat (cardiac dysrhythmia, tachycardia)	•	•	•	•	•	•
Endocrine System						
Diabetes		•	•	•	•	•
Immune System						
Impaired immunity				•		•
Musculoskeletal System						
Back pain	•				•	
Joint pain	•					•
Muscle pain (myalgia)	•				•	•
Shaking (palsy)	•			•	•	

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Condition or Symptom	Peer-Reviewed Study	Peer-Reviewed Review	Conference Proceedings	Grey Literature	Legal Decision	Web Page
Nervous System (General)						
Cognitive or task performance	•	•	•	•	•	•
Disturbances of skin sensation	•			•	•	
Fatigue	•	•	•	•	•	•
Headache	•	•	•	•	•	•
Nausea	•	•	•	•	•	•
Pressure in the chest	•					•
Sensation of internal vibration	•			•	•	•
Vertigo, dizziness	•	•	•	•	•	•
Vision problems			•	•	•	•
Nervous System (Auditory)						
Communication interference			•		•	•
Ear pressure or pain	•	•	•	•	•	•
Hearing loss			•	•		•
Tinnitus	•	•	•	•	•	•
Psychological Health						
Anxiety	•	•		•	•	•
Depression	•	•	•	•	•	•
Irritability		•	•	•	•	•
Psychological distress	•	•	•	•		•
Respiratory System						
Nosebleed				•	•	•

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Table 7.1

Overview of Findings with Regard to Adverse Health Effects Addressed in Empirical Population-Based Research on Exposure to Wind Turbine Noise

Condition or Symptom	Level of Evidence (IARC)	Possible Pathways	Knowledge Gaps
Annoyance	Sufficient	Direct – exposure to wind turbine noise can lead to annoyance; however, the effect may be modified by factors such as visual impact and attitudes.	• Role of visual impact and attitudes on perception of wind turbines. • Prevalence of annoyance in exposed populations, gravity of effect, and thresholds under different conditions. • Role of specific sound characteristics (amplitude modulation, low frequency noise).
Sleep Disturbance	Limited	Direct and indirect (via annoyance or stress response or both) pathways are possible; however, wind turbine noise is likely only one among many factors affecting sleep quality.	• Nature of the mechanism (direct, indirect, or both) and the relative prevalence and magnitude of the effect for each. • Impacts of specific sound characteristics (including low-frequency sound) of wind turbine noise on sleep. • Long-term effects of wind turbine noise on sleep disturbance.

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Condition or Symptom	Level of Evidence (IARC)	Possible Pathways	Knowledge Gaps
Stress	Inadequate	Direct and indirect (via annoyance or sleep disturbance or both) pathways are possible; however, no evidence for a direct association was found. Wind turbine noise could be one among many factors contributing to stress response.	• Nature of the mechanism (direct, indirect, or both) and relative prevalence and magnitude of the effect. • Unclear whether mechanism or stress response is comparable with other sources of environmental noise. • Impact of specific sound characteristics on stress. • Long-term effects of wind turbine noise on stress.
Cardiovascular System and Diseases (including hypertension, cardiac dysrhythmia, tachycardia)	Inadequate	Analogous research suggests that direct and indirect (via annoyance and stress or sleep disturbance or both) pathways are possible; however, no evidence for an association with wind turbine noise was found.	• Adequate epidemiological evidence. • Effects of long-term exposure. • Nature of the mechanism.
Diabetes	Inadequate	An indirect pathway (via stress, sleep disruption, or combinations) is plausible; however, the evidence linking these to noise from wind turbines was not consistent.	• Adequate epidemiological evidence. • Effects of long-term exposure. • Nature of the mechanism and comparability to the effect of other types of environmental noise.
Hearing Impairment	Evidence of no causal relationship	Sufficient evidence was found in research on other types of noise to conclude that permanent noise exposure below 75 dB(A) does not lead to hearing loss, even after lifelong exposure.	
Tinnitus	Inadequate	Research on tinnitus suggests that an indirect pathway via stress is possible.	• General uncertainty over the causes of tinnitus and links to other conditions such as impaired hearing.

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Condition or Symptom	Level of Evidence (IARC)	Possible Pathways	Knowledge Gaps
Cognitive or Task Performance	Inadequate	Research on other types of noise suggests that noise exposure can affect cognitive performance; however, the character of the impact (positive or negative) and its strength vary with many factors, including sound characteristics and the type of task used to test cognitive performance.	• Understanding of how noise exposure affects different types of cognitive or task performance, including clear case definitions and measurement of cognitive performance.
Psychological Health (anxiety, depression, psychological distress)	Inadequate	Noise exposure could be a contributing factor to the development or aggravation of psychological disorders.	• General understanding of possible links between noise exposure and psychological disorders.
Health-Related Quality of Life	Inadequate	No mechanism identified or postulated. Exposure to wind turbine noise affects several categories that are used to measure quality of life, many of which overlap with the health impacts reviewed here.	• Research focusing on the relative impacts of wind turbine noise compared to other factors that affect quality of life.

The conditions and symptoms listed here are those attributed to wind turbine noise from various sources (see Table 5.1), for which the Panel found empirical research specific to wind turbine noise.

Box 7.1
Health Canada's Wind Turbine Noise and Health Study

In 2012, Health Canada started a large-scale cross-sectional epidemiological study involving approximately 2,000 dwellings. The aim of this study was to measure potential health outcomes in areas exposed to sound from wind turbines. This study was developed by Health Canada in collaboration with Statistics Canada to provide an evidence base and inform policies and practices in Canada regarding the development of wind energy projects. Among the outcomes measured by the Health Canada study were:

- Sleep disturbance, measured with a sleep watch that gauges sleep onset, sleep time, and efficiency. Self-reported sleep quality was also assessed with a questionnaire.
- Stress, measured by cortisol concentration in hair samples, blood pressure, and heart rate, as well as by a questionnaire (perceived stress).
- Self-reporting annoyance (indoor and outdoor), measured by self-reporting.
- Quality of life, measured using a questionnaire.

Health Canada's preliminary findings were made publicly available in November 2014. The Panel reviewed those findings but, as they were preliminary, it could not integrate this research into the evidence considered in Chapter 6. However, the Panel observed that the findings from this study were mainly concordant with its own findings. The main results are presented below.

Of the dwellings selected, 1,238 households (78.9%) agreed to participate in the study. Both self-reported conditions and physiological measurements were described in the preliminary results. Regarding self-reported conditions, the study did not find associations between wind turbine noise exposure and self-reported sleep, self-reported illnesses (such as dizziness, tinnitus, and headaches), and chronic diseases (such as heart disease, high blood pressure, and diabetes). The study also did not find any association between noise exposure and self-reported perceived stress and quality of life. However, it found an association between increasing levels of wind turbine noise and annoyance towards wind turbine characteristics (noise, shadow flicker, blinking lights, vibrations, and visual impacts). Health Canada also captured physiological measures related to stress and sleep quality and found that the measures (e.g., hair cortisol levels, blood pressure, sleep watch) were consistent with self-reported results (no association between cortisol concentration, blood pressure, sleep efficiency, and exposure to wind turbine noise was found).

(Health Canada, 2014a, 2014b)

Canadian Academies Conclusions

- Wind turbine noise is associated with annoyance
- Annoyance has many factors, not all of which are level of dBA related
- Annoyance can lead to sleep disturbance
- Sleep disturbance can lead to annoyance
- Both Annoyance and Sleep Disturbance are associated with higher stress levels, which are associated with some health outcomes

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Canadian Academies Conclusions

- The Panel stresses that, given the nature of the sound produced by wind turbines and the limited quality of available evidence (small sample sizes, small number of studies available, lack of comprehensive exposure measurement), the health impacts of wind turbine noise cannot be comprehensively assessed at this time. Furthermore, in noting the challenges of undertaking research on health impacts caused by multiple factors (large cohort studies, longitudinal studies, double-blind experiments), the Panel emphasizes that providing high-quality evidence would require a major research effort.

Council of Canadian Academies, 2015. Understanding the Evidence: Wind Turbine Noise. Ottawa(ON): The Expert Panel On Wind Turbine Noise and Human Health, Council of Canadian Academies.

Health Canada Study 2015

- ***5.3 Annoyance and Health***
- WTN annoyance was found to be statistically related to several self-reported health effects including, but not limited to, blood pressure, migraines, tinnitus, dizziness, scores on the PSQI, and perceived stress.
- WTN annoyance was found to be statistically related to measured hair cortisol, systolic and diastolic blood pressure.
- The above associations for self-reported and measured health endpoints were not dependent on the particular levels of noise, or particular distances from the turbines, and were also observed in many cases for road traffic noise annoyance.

Note: *Annoyance* was defined as a long-term response (approximately 12 months) of being "very or extremely annoyed" as determined by means of surveys.

Health Canada Study 2015

- ***5.3 Annoyance and Health***
- Although Health Canada has no way of knowing whether these conditions may have either pre-dated, and/or are possibly exacerbated by, exposure to wind turbines, the findings support a potential link between long term high annoyance and health.
- Findings suggest that health and well-being effects may be partially related to activities that influence community annoyance, over and above exposure to wind turbines.

Health Canada Study 2015

The following were not found to be associated with WTN exposure:

- self-reported sleep (e.g., general disturbance, use of sleep medication, diagnosed sleep disorders);
- self-reported illnesses (e.g., dizziness, tinnitus, prevalence of frequent migraines and headaches) and chronic health conditions (e.g., heart disease, high blood pressure and diabetes); and
- self-reported perceived stress and quality of life.

While some individuals reported some of the health conditions above, the prevalence was not found to change in relation to WTN levels.

The following was found to be statistically associated with increasing levels of WTN:

- annoyance towards several wind turbine features (i.e. noise, shadow flicker, blinking lights, vibrations, and visual impacts).

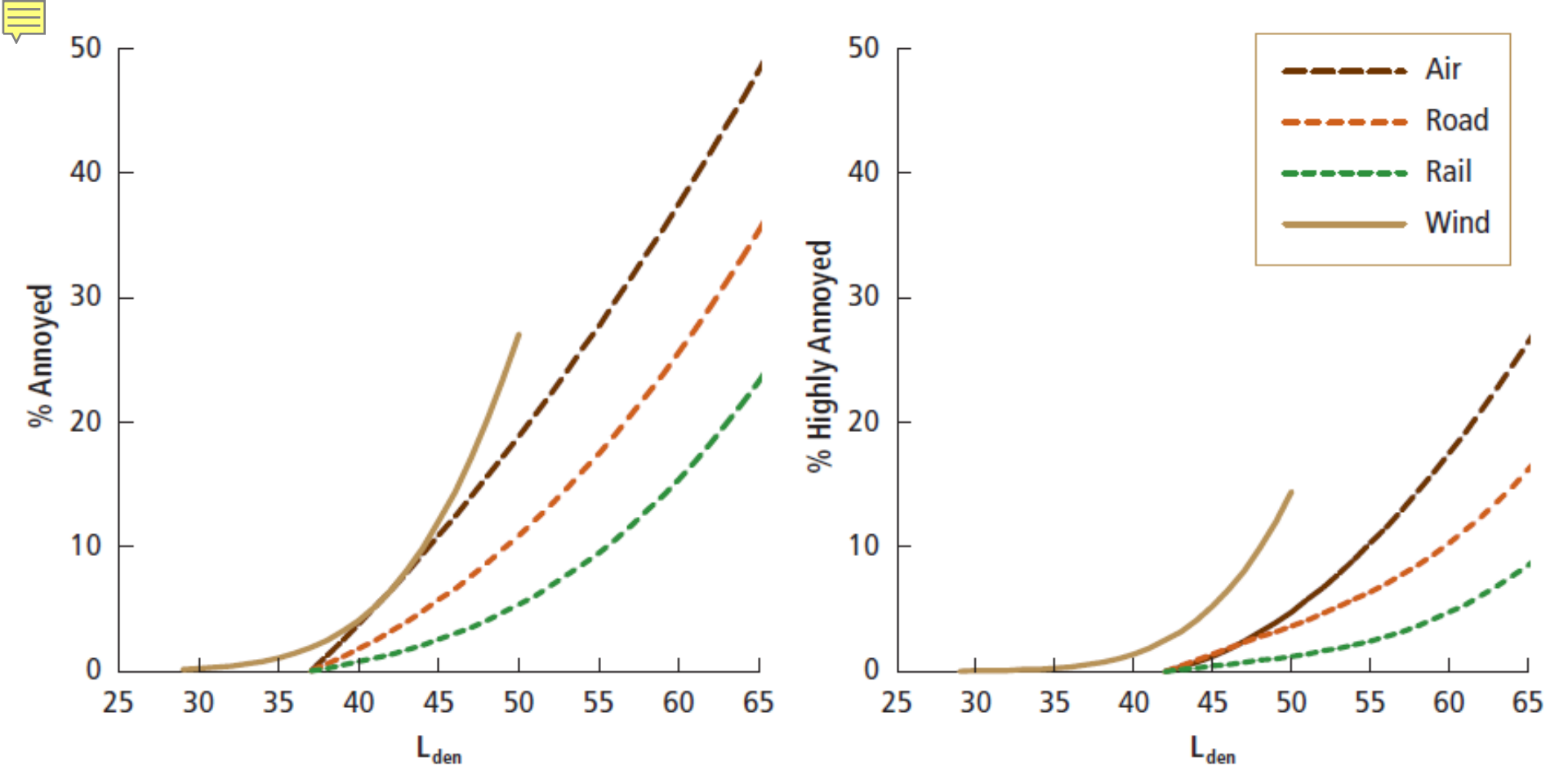

Figure 6.1

Comparison of Annoyance Due to Wind Turbine Noise and Transportation Noise

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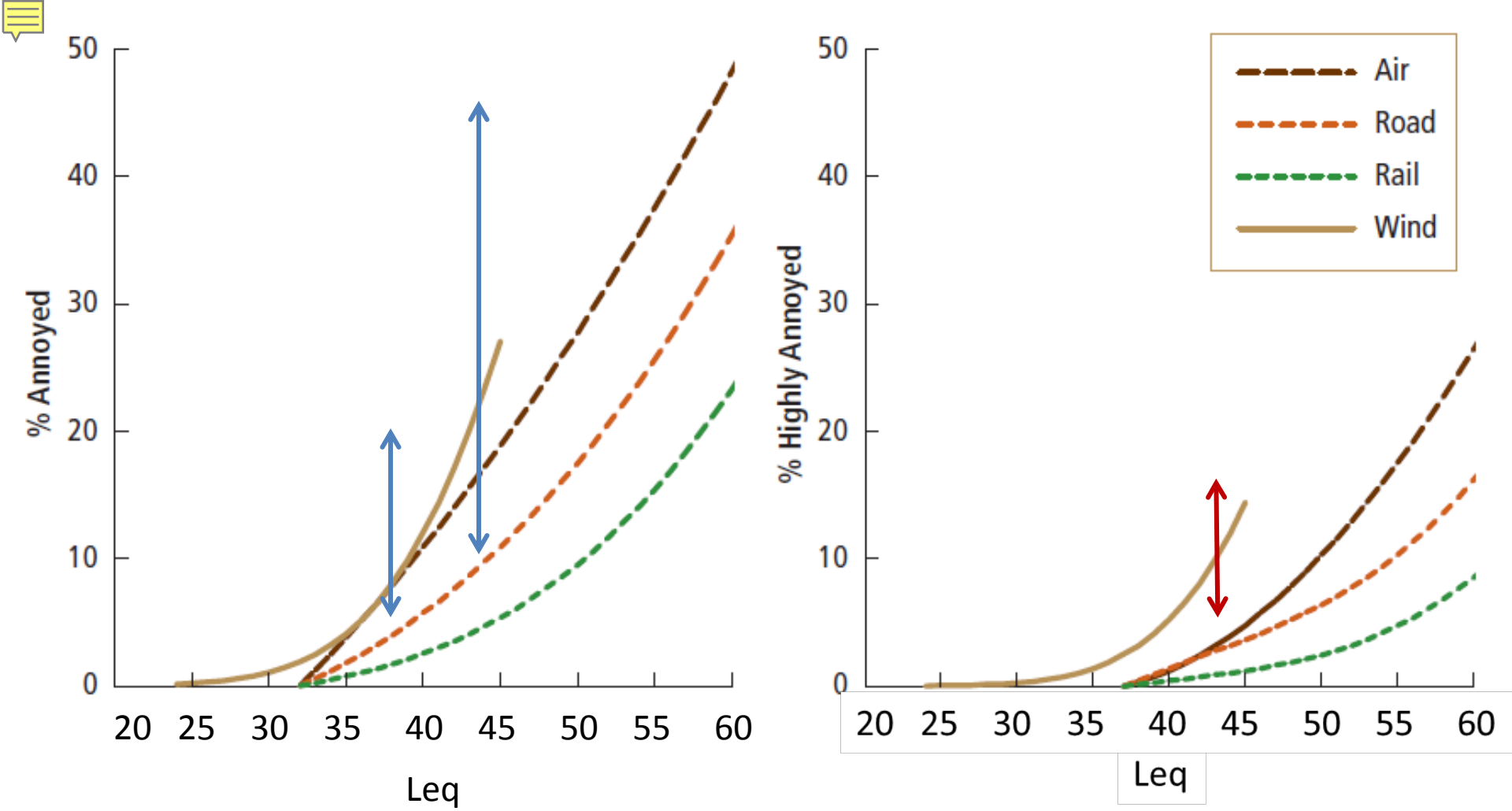

LLCHD estimates of Annoyance with Leq in dB(A)
based on Canadian Academies study Figure 6.1
using a 5dB conversion factor for Lden to Leq
- Range estimates ⇕ from Pedersen (2011)
- Range estimate ⇕ from Health Canada (2015) of very or extremely annoyed

LLCHD Conclusions

- The percent of annoyed people
  - Varies significantly
  - **Is** associated with sound measured in dBA
- A noise level of 35 dBA Leq appears to be acceptable for >90% of people near wind turbines
- A noise level of 35 to 40 dBA Leq appears to be acceptable for >80% of people near wind turbines
- A metric of 40 dBA L10 may identify noise problems associated with amplitude modulation, which is a primary factor in annoyance