Understanding the Evidence: Wind Turbine Noise

Appendix

Council of Canadian Academies
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Science Advice in the Public Interest

Appendices

Appendix A: Study Designs

The study designs presented in Table A1 are arranged in a general way by descending order of the strength of evidence they provide regarding causation (Atkins *et al.*, 2004; Howick *et al.*, 2009). Designs at the top of the list are more likely to reduce bias and the influence of potential confounding factors, whereas designs near the bottom may not be representative of population-level responses. Nevertheless, each design has strengths and weaknesses and contributes in a different way to an overall body of evidence.

Table A.1

Study Designs in Epidemiology

	Type of Study	Description	Strengths and Limitations
Experiments Exposure randomized, confounding factors and bias more easily controlled.	Experiment	An orderly procedure carried out to verify, refute, or establish the validity of a hypothesis.	Provides insight into cause-and-effect by demonstrating what outcome occurs when a particular factor is manipulated. Limited by ethical constraints when dealing with human subjects.
	Randomized Controlled Trial (RCT)	Scientific experiment in which subjects are randomly allocated to receive treatment/exposure.	Cross-sectional studies and cohort studies can be designed to mimic RCTs by randomly selecting subjects from very large exposed and unexposed populations, if large data sets are available.
	Experiments with Animal Models	Use of animal models to test effects of interventions or exposures.	Allows flexibility and control, at lower cost than research on humans. Limited by anatomical comparability, comparability of context, small sample size, and ethical constraints.
Observational Studies Exposure not randomly assigned, greater potential for confounding factors or bias.	Cohort Study	Type of longitudinal study that selects subjects based on exposure status. Subjects should be at risk of developing an outcome at the beginning of the study but not yet affected by the outcome.	Can estimate relative risk – the probability of disease for an exposed individual over the probability for an unexposed person. Similar requirements for statistical significance as for case-control studies, unless base incidence rate is very low.
	Case-Control Study	Comparison of historical or retrospective exposures between a group that is positive and a group that is negative for a disease or other health outcome.	Establishing temporal order between exposure and outcome can be difficult in retrospect. Better suited to study diseases or outcomes with low incidence than exposures with low incidence.
	Cross-Sectional	Observational study that collects data from a	Mostly descriptive, provides evidence of

	Type of Study	Description	Strengths and Limitations
	Study	population, or a representative subset, at one specific point in time.	prevalence within a population as well as statistical associations between outcome and suspected causes.
	Case Report, Case Series	Qualitative study of a single patient (case report), or small group of patients (case series) with a similar diagnosis, or a comparison of a patient's experience during exposed and unexposed periods.	Mostly descriptive of individual cases and cannot be used to make inferences about a population of exposed individuals. May lead to formulation of a new hypothesis.

The study designs presented in this table are arranged roughly in descending order of quality or of the strength of evidence they provide regarding causation. Designs at the top of the list are more likely to reduce bias and the influence of potential confounding factors, whereas designs near the bottom may not be representative of population-level responses. Nevertheless, each design has strengths and weaknesses and contributes in a different way to an overall body of evidence.

The strength of evidence provided by laboratory experiments is limited by smaller sample sizes, ethical considerations, and practical and technical limits to the simulation of sound exposure and environmental factors. Experiments nonetheless provide important complementary evidence, such as tests of the effect of specific sound characteristics, or controlled measurements of exposure–response relationships.

Some evidence considered in this report comes from experiments using animals, such as bullfrogs, mice, guinea pigs, or chinchillas. Animal models are used to study mechanisms when experiments in humans are not feasible or ethical. Experiments using animal models allow multiple exposures and controlled experimental conditions; furthermore, some experiments use animals with certain biological similarities to humans (Colby *et al.*, 2009). However, in the context of noise exposure, animal studies cannot easily be generalized to humans, and results should be interpreted with caution. The Panel considered animal studies for this report only when other evidence was unavailable or scarce, as is the case for physical and physiological effects of infrasound on the inner ear.

Causal relationships can often be established even when highly controlled and randomized experiments are lacking or not feasible (Howick *et al.*, 2009). High-quality observational studies that account for and control for plausible confounders can provide convincing and high-quality evidence.

Cross-sectional data are limited as evidence for temporality: proof that the exposure preceded the effect. In general, temporality was not called into question in the primary research examined. Health outcomes can either occur at the moment of the noise exposure or over longer timeframes (chronic effects following a *latency period*). Epidemiological studies based on self-reported survey data may not provide a firm confirmation of temporality. In some cases, subjects may report pre-existing health conditions that came to be perceived as a consequence of wind turbine noise after the onset of exposure; however, the masked design of the questionnaires used in most surveys we refer to reduces respondent bias or responses in which subjects deliberately attribute such conditions to wind turbine noise. Experiments may control for temporality by conducting tests for pre-existing conditions, such as hearing tests or questionnaires on general health and well-being.

Appendix B: Overview of Primary Evidence

Table B.1

Search Terms Used to Retrieve Primary Evidence on Wind Turbine Sound and Health

Database	Search term
SCOPUS	TITLE-ABS-KEY(("wind turbine*" OR "wind farm*") AND (sound or noise) AND (health OR disease OR ill OR illness OR annoy* OR sleep OR stress OR "quality of life" OR "vibroacoustic" OR cardiovascular OR hypertension OR dysrhythmia OR diabet* OR immunity OR "back pain" OR "joint pain" OR "muscle pain" OR palsy OR psycholog* OR fatigue OR headache OR nausea OR "pressure in the chest" OR vision OR "communication" OR tinnitus OR hear* OR pain OR anxiety OR anxious OR depress* OR "vestibular disturbance" OR vertigo OR irritab* OR cancer) AND NOT (“structur*” or “health monitor*”))
PubMed	("wind turbine" OR "wind farm" OR "wind turbines" OR "wind farms") AND (health OR disease OR ill OR illness OR annoy* OR sleep OR stress OR "quality of life" OR "vibroacoustic" OR cardiovascular OR hypertension OR dysrhythmia OR diabet* OR immunity OR "back pain" OR "joint pain" OR "muscle pain" OR palsy OR psycholog* OR fatigue OR headache OR nausea OR "pressure in the chest" OR vision OR "communication" OR tinnitus OR hear* OR pain OR anxiety OR anxious OR depress* OR "vestibular disturbance" OR vertigo OR irritab* OR cancer)

Table B.2

Overview of Primary Evidence on Health Effects of Wind Turbine Noise

Title	Data Set*	Sample Size	Study Type	Primary Objective/ Research Question	Exposure	Case Definitions	Main Findings	*Publication Type*
Psycho-acoustic characters of relevance for annoyance of wind turbine noise **(Persson Waye & Öhrström, 2002)**		25	Laboratory experiment	Investigate role of psycho-acoustic characteristics of wind turbine noise for annoyance.	Recorded samples of 5 most common wind turbine designs at distances of 100 metres at wind speed of 7-10m/s were used to generate samples of 20s continuous loop playback for exposure times of 3 to 10 minutes. Each sample represented 1 type of wind turbine. Paper provides equivalent 1/12 octave-band sound pressure levels. Exposure in sound insulated room.	Psycho-acoustic parameters calculated with different models based on measured sound data. Subjective annoyance was evaluated on a 10 cm visual analogue scale ranging from 0 "not at all" to 10 "very much." Relative annoyance was rated on 5-point scale ("least" to "most annoying"). Perception of annoyance of 14 psycho-acoustic descriptors rated on 5-point scale (do not notice – very annoying).	Rating of annoyance and awareness was different for the 5 different types of wind turbines. This could not be explained by any of the psycho-acoustic parameters.	*Peer-reviewed journal article*
Perception and annoyance due to wind turbine noise — A dose–response relationship **(Pedersen & Persson Waye, 2004)**	SWE-00	351	Cross-sectional	"Evaluate the prevalence of annoyance due to wind turbine noise and study dose–response relationships."	Calculated sum of contributions by surrounding wind turbines to A-weighted SPL, assuming downwind conditions and wind speed of 8m/s at 10 m height, based on sound propagation model of Swedish Environmental Agency (verified by field measurements).	Verbal description of annoying sound properties (14 adjectives). Chronic illnesses (diabetes, tinnitus, cardiovascular diseases, hearing impairment). Well-being (headache, undue tiredness, pain, stiffness in the neck or shoulders, feeling tense, stressed, irritable). Sleep habits and any kind of sleep disturbance.	7% of subjects were annoyed indoors (n=25, 95% CI 5%–10%); 45% of those annoyed outdoors were also annoyed indoors (n=24, 95%CI 32%–59%); statistical significance, correlation between indoor annoyance and sound category (rs=0.348, n=340, p<0.001). 16% of residents exposed to wind turbine noise >35dB(A) stated that their sleep was disturbed by wind turbine noise (n=20, 95%CI 11%–20%). The percentage of residents annoyed increases with sound exposure and does so in accordance with an exposure–response relationship. Annoyance from wind turbine noise is higher and increases more rapidly than annoyance from aircraft, road traffic, and railway noise.	*Peer-reviewed journal article*

Living in the vicinity of wind turbines — A grounded theory study **(Pedersen *et al.*, 2007)**	SWE-00	351 (survey) + 15 interviews	Cross-sectional	Develop a deeper understanding of wind turbine perception.	Estimated A-weighted SPL (see Pederson and Persson Waye, 2004).	Territoriality and feelings of intrusion (empirically based derivation of hypotheses on perception of wind turbines as "outside my territory" and "intrusion into privacy").	Wind turbine noise was perceived as an "intruder" by some residents. This may help explain differences in reaction to wind turbine noise among different individuals.	*Peer-reviewed journal article*
Wind turbine noise, annoyance and self-reported health and well-being in different living environments **(Pedersen & Persson Waye, 2007)**	SWE-05	754	Cross-sectional	"Evaluate prevalence and perception of annoyance from wind turbine noise and study relations between noise perception and annoyance with focus on difference in living environments."	Estimated A-weighted SPL (see Pederson and Persson Waye, 2004).	Perception of wind turbine noise was rated on a 5-point verbal rating scale (VRS). Annoyance was rated on a 5-point VRS. Health, sleep (disturbed sleep, undue tiredness), coping (11 items, including active steps to avoid negative impacts and discussing and seeking information).	Odds ratio (OR) for *perception* of wind turbine noise: 1.3 (95% CI 1.25–1.4) for each dB increase (almost linear increase between sound categories: 71% of respondents at 37.5–40dB(A) [n=71], 90% at >40dB(A) [n=20]). No association with terrain, but OR for noticing sound was 1.8 (95% CI 1.27–2.64) for rural areas. OR for *annoyance* from wind turbine noise: 1.1 (95% CI 1.01–1.25) for each dB increase (6% annoyed at 37.6–40dB(A) [n=71], 15% at >40dB(A) [n=20]). OR for annoyance in rural areas: 3.8 (95% CI 1.8–7.83). No association of wind turbine noise and health items. Sleep disturbance related to annoyance. Some coping strategies correlated with annoyance.	*Peer-reviewed journal article*
The impact of visual factors on noise annoyance among people living in the vicinity of wind turbines **(Pedersen & Larsman, 2008)**	SWE-00 SWE-05	1095	Cross-sectional	To better understand influence of visual factors on annoyance	Auditory exposure: estimated A-weighted SPL (see Pedersen and Persson Waye, 2004). Visual exposure: vertical visual angle (angle of line between dwelling and nearest wind turbine hub).	Noise annoyance based on: annoyance from wind turbine noise (5-point VRS); annoyance from rotor blade noise (5-point VRS). Visual attitude: impact on landscape, beautiful-ugly, natural-unnatural (all 5-point VRS).General attitude*:* opinion on wind turbines, efficient-inefficient, necessary-unnecessary (all 5-point VRS).	Annoyance correlated with A-weighted sound pressure level (SPL) (r=0.37, n=1095, P<0.001). Increasing 1dB(A) exposure led to a theoretical increase in 0.12 categories on the 5-point VRS (b=0.12, 95% CI 0.1–0.14, RS=0.13). Vertical visual angle (VVA) was correlated with annoyance (r=0.36; p<0.001); an increase in 1° in VVA corresponded to an increase of 0.2 on the 5-point VRS for annoyance (RS= 0.12 b=0.21, 95% CI 0.18–0.24) after controlling for possible correlation: b= 0.1, 95% CI 0.11–0.15). Correlation of	*Peer-reviewed journal article*

							noise annoyance with wind turbine noise significantly stronger when wind turbine visible (Δ=0.06; p<0.001). No significant difference for flat/rocky hilly terrain. No difference for rural/built-up areas. Visual attitude had positive effect noise annoyance in f4 hypothesized models while general attitude did not.	
Wind turbines — Low level noise sources interfering with restoration? **(Pedersen & Persson Waye, 2008)**	SWE-00 SWE-05	1095	Cross-sectional	Analysis of study data with emphasis on perception of wind turbine noise, annoyance and consequences on restoration	Estimated A-weighted SPL (see: Pederson and Persson Waye, 2004)	Annoyance from wind turbine noise (5-point VRS) Annoyance from wind turbine noise sound characteristics (5-point VRS). Sensitivity score***:*** composed of sensitivity to odour, noise, air pollution, littering (alpha = 0.852; factor loadings > 0.7; 69% of variation). Stress score: strain/stress, feeling irritable, undue tiredness. Restoration***:*** included in questions on expectations towards living environment (possibility for recovery and regaining strength – 5-point VRS).	Perception of wind turbine noise was correlated with A-weighted SPL (rs=0.401; n=1079; p<0.001). Most highly correlated sound characteristics (n=519; p< 0.001): Swishing (RS=0.664), whistling (RS=0.508), resounding (RS=0.418). Proportion of respondents annoyed by wind turbine noise increased above 37dB(A). Judgement on restoration negatively correlated with annoyance (RS= 0.128; n=745; p<0.001). Annoyance not correlated with hearing impairment, diabetes, cardiovascular diseases. Fairly/very annoyed respondents had higher stress scores than others (t = 2.38; df = 1038; P< 0.05).	*Peer-reviewed journal article*

Response to noise from modern wind farms in the Netherlands **(Pedersen *et al.*, 2009)**	NL-07	725	Cross-sectional	Identify/describe exposure–response relationship for annoyance; understand contributing factors.	Calculated sum of contributions by surrounding turbines to A-weighted SPL, assuming downwind conditions and wind speed of 8m/s at 10 m height, based on sound propagation model legally required for impact assessments in the Netherlands.	Annoyance from wind turbine noise indoor/outdoor (5-point VRS). Sensitivity (5-point VRS). Attitudes measured as combination of general attitude toward wind turbines and attitude toward visual impact as well as 8 polarized items.	Annoyance increased with SPL outdoor (rs=0.5, n=708, p<0.001) and indoor (rs=0.36, n=699, p<0.001). Proportion of those annoyed outdoors/indoors increased from 7%/4% at 30–35dB(A) to 18%/16% at 40–45dB(A) and then decreased to 12%/7% at >45dB(A). Wind turbine noise more annoying than noise from aircraft, industry, road traffic, railways based on A-weighted SPL converted to L_{den}.	*Peer-reviewed journal article*
Wind turbine syndrome: A report on a natural experiment **(Pierpont, 2009)**		37 self-identified subjects from 10 families	Case series	Document a complexity of symptoms experienced by adults and children while living near wind turbines, examine individual susceptibility, and investigate possible pathophysiologic mechanisms.	Distance used as a proxy (from 875m to 1000m).	Sleep disturbance, headache, tinnitus, dizziness, nausea, anxiety, concentration problems evaluated through a questionnaire. No formal definitions given.	Wind turbine noise appeared to be associated with a set of symptoms in the cases examined, which the author summarized as “wind turbine syndrome.”	*Book*
Can road traffic mask sound from wind turbines? Response to wind turbine sound at different levels of road traffic sound **(Pedersen *et al.*, 2010)**	NL-07	725	Cross-sectional	Explore masking of wind turbine noise through road traffic.	Calculated sum of contributions by surrounding turbines to A-weighted SPL, assuming downwind conditions and wind speed of 8m/s at 10 m height, calculated in accordance with ISO-9613. Difference between wind turbine noise and road traffic noise was expressed as difference in time averaged sound levels (L_{den}).	Annoyance**:** self-reported annoyance using a questionnaire on environmental factors, including questions on wind turbine and road traffic sound.	Annoyance was inter-correlated with traffic and wind turbine noise exposure. Visibility and attitude towards wind turbines were significantly correlated with noise annoyance from wind turbines.	*Peer-reviewed journal article*
A comparison between exposure–response relationships for wind turbine annoyance and annoyance due to other noise sources **(Janssen *et al.*, 2011)**	SWE-00, SWE-05, NL-07	1820	Cross-sectional	Compare exposure–response relationship for annoyance from wind turbine noise with that of other types of environmental noise.	See exposure measures for SWE-00, SWE-05, and NL-07. Exposure measures were converted to time averaged exposure levels (L_{den}) for comparison with studies on other types of noise.	See case definitions for SWE-00, SWE-05, and NL-07.	Annoyance due to wind turbine noise occurs at lower exposure levels than for noise from air, rail, and road traffic. Subjects start being annoyed at 30dB(A) L_{den} vs ~37dB(A) L_{den} for air traffic noise and almost 40dB(A) L_{den} for rail noise; the exposure–response curve increased more steeply than for other types of noise. Economic benefits reduced level of annoyance while visibility of wind turbine increased it.	*Peer-reviewed journal article*

Annoyance caused by amplitude modulation of wind turbine noise **(Lee *et al.*, 2011)**		30	Laboratory experiment	Examine the relations between annoyance and amplitude modulation of wind turbine noise.	Sound recordings from a single wind turbine at 62m, 98m, 150m and 200m taken upwind and perpendicular to wind direction. 2 samples selected that represent amplitude modulation in 2 different sound spectra. 50 stimuli representing different SPL and modulation depth. Stimuli with different levels of amplitude modulation created by reducing modulation depth of original samples. 30 stimuli administered in random order in 2 sets per subject.	Self-reported annoyance on an 11-point numerical scale.	Both sound level and amplitude modulation of wind turbine noise are significantly associated with annoyance under laboratory conditions.	*Peer-reviewed journal article*
Evaluating the impact of wind turbine noise on health-related quality of life **(Shepherd *et al.*, 2011)**		39 (exposed) 158 (control)	Cross-sectional	Identify impacts of wind turbine noise exposure on health-related quality of life (HRQOL).	Exposed/control groups selected based on distance (located <2km/>8km distance from nearest wind turbine). Exposed group was exposed to wind turbine noise of 20-50dB(A) based on measurements taken by operators (self-citation).	HRQOL measured by a shortened version of the WHOQOL-100 assessment. This questionnaire measures physical, psychological, and social elements.	Lower overall HRQOL scores in exposed group, significantly lower in physical and environmental HRQOL; high incidence of annoyance in exposed group; lower sleep satisfaction ratings in exposed group; noise sensitivity is a strong predictor of annoyance and correlated with facets of HRQOL.	*Peer-reviewed journal article*
Health aspects associated with wind turbine noise — Results from three field studies **(Pedersen, 2011)**	SWE-00, SWE-05, NL-07	1755	Cross-sectional	Meta-analysis of 3 studies to identify prevalence of multiple health effects.	See exposure measures for SWE-00, SWE-05, and NL-07.	See case definitions for SWE-00, SWE-05, and NL-07	The increase of annoyance with increasing sound levels was consistent through all studies. Sleep interruption was correlated with sound levels in 2 out of 3 studies. No other measured variables (related to health or well-being) were associated with sound levels.	*Peer-reviewed journal article*
Infrasound and low frequency noise from wind turbines: Exposure and health effects **(Bolin *et al.*, 2011)**	SWE-00, SWE-05, NL-07	n/a	Cross-sectional	Review studies for evidence of impacts from low-frequency sound.	See exposure measures for SWE-00, SWE-05, and NL-07. (In these studies no exposure measures were defined and no exposure data were collected for infrasound or low-frequency sound).	See case definitions for annoyance, sleep disturbance, and other health effects used in SWE-00, SWE-05, and NL-07.	The study did not find any evidence that infrasound from wind turbines contributes to perceived annoyance or other health effects.	*Peer-reviewed journal article*
WindVOiCe, a self-reporting survey: Adverse health effects,		109 (self-identified participants)	Case series	"Provide vigilance monitoring for those wishing to report their perceived adverse health effects	Self-reported distance used as proxy for exposure divided into 4 categories: 350m-499m, 500m-	Self-reported symptoms of: sleep disturbance, migraines, depression, palpitations,	102 out of 109 self-selected survey participants reported altered health quality of life.	*Peer-reviewed journal*

industrial wind turbines, and the need for vigilance monitoring **(Krogh *et al*., 2011)**				associated with industrial wind turbines."	699m, 700m-899m, and 900m-2000m.	excessive tiredness, stress, anxiety, tinnitus, hearing problems, quality of life measured with a "yes"/"no" questionnaire.	Frequency of participants (and reported health impacts) increased with less distance from wind turbines. Perceived distress (wind turbine-related or other) appeared to be major reason for participation. Response pattern could indicate a relationship between exposure (based on distance) and frequency and strength of health impacts (sleep disturbance, excessive tiredness, and headaches).	*article*
Effects of industrial wind turbine noise on sleep and health **(Nissenbaum *et al*., 2012)**		79	Cross-sectional	Investigate impacts on sleep and health	Distance used as proxy for exposure: exposed group 375m-1400m from closest wind turbine; control group 3.3km-6.6km from closest wind turbine.	Sleep quality: measured with the Pittsburgh Sleep Quality Index. Daytime sleepiness: measured with the Epworth sleepiness score. General health: measured with the SF36v2 questionnaire.	Participants in the "exposed group" had worse sleep quality (PSQI > 5 with P=0.0745) and daytime sleepiness (ESS > 10 with P+0.1313) and worse mental component scores than those in the control group.	*Peer-reviewed journal article*
Impact of wind turbine sound on annoyance, self-reported sleep disturbance and psychological distress **(Bakker *et al*., 2012)**	NL-07	725	Cross-sectional	Understand the relationship between exposure to wind turbine noise and the prevalence of annoyance, sleep disturbance, and psychological distress.	Calculated sum of contributions by surrounding turbines and road traffic (if present) to A-weighted SPL, assuming downwind conditions and wind speed of 8m/s at 10 m height, based on sound propagation model legally required for impact assessments in the Netherlands (ISO9613.2). 5 exposure categories of 5dB(A) each (<30dB(A) to >45dB(A)).	Annoyance**:** 2 questions (indoor/outdoor) on 5-point VRS; 11-point Likert scale ranging from "not annoyed at all" to "extremely annoyed." Sleep disturbance: 5-point VRS raging from "almost never disturbed" to "almost daily" with "at least once a month" considered to be sleep disturbance. Psychological distress: based on 12-item General Health Questionnaire designed to detect psychiatric disorders (4-point VRS).	Annoyance: 23% of respondents annoyed outdoors, 14% annoyed indoors. Increased exposure led to increased rate of respondents annoyed. Rate annoyed was 4 times lower among those who benefitted economically than among those who did not (3% vs 12% with Zmwu= -2.55, P<0.05); however, both groups had the same rate of respondents noting wind turbine noise and being slightly annoyed. Sleep disturbance: increased exposure led to increased disturbance among all respondents, with 48% being disturbed at least once a month at SPL >45dB(A), OR 2.98 (95% CI 1.347–6.597). Disturbance was attributed to wind turbine noise by 6% of respondents in quiet area and 4% in noisy area.	*Peer-reviewed journal article*

							Psychological distress: a positive correlation was found in quiet areas (r=0.208) and all area types (r=0.160, p<0.01).	
Individual reactions to a multisensory immersive virtual environment: the impact of a wind farm on individuals **(Ruotolo *et al.*, 2012)**		93	Laboratory experiment	Assess the visual and noise annoyance as well as cognitive tasks performance under the exposure of wind turbine noise.	4 virtual reality scenarios based on visual and auditory stimuli using recordings at 20m, 100m, 250m, and 600m distance from wind turbines.	Cognitive tasks: measured through short-term verbal memory, semantic memory, and executive control tests. Noise annoyance: self-reported using a 10-point Likert-type scale.	"Performance in executive control and semantic memory deteriorated with increasing proximity to wind farms" (visual and auditory). There is a reciprocal influence between visual and auditory stimuli on annoyance.	*Peer-reviewed journal article*
Influence of distances between places of residence and wind farms on the quality of life in nearby areas **(Mroczek *et al.*, 2012)**		1277	Cross-sectional	Identify the effect of wind farms on health-related quality of life.	Distance used as proxy for exposure in 4 categories: <700m, 700m-1000m, 1000m-1500m, and >1500m.	Quality of life was assessed with the Norwegian version of the SF-36 General Health Questionnaire (using 8 subscales of health: physical functioning, role-functioning physical, bodily pain, general health, vitality, social functioning, role-functioning emotional, mental health) and a Visual Analogue Scale.	No evidence that a place of residence near a wind turbine lowers quality of life. Quality of life was highest among those living closest to wind turbines and worst among those living farthest away. (Authors caution, however, that some factors are not controlled for.)	*Peer-reviewed journal article*
Reduction of wind turbine noise annoyance: an operational approach **(Bockstael *et al.*, 2012)**		8 families	Case study	Understand impact of operational regime and meteorological conditions on annoyance.	Noise measurements taken at residence that was closest to 1 of 3 wind turbines. Contribution of closest wind turbine to measured SPL depending on annular blade velocity was between 30dB(A) and 45dB(A).	Self-reported annoyance evaluated with an adapted version of the International Organization for Standardization (ISO) standard annoyance question. The annoyance was self-reported with a web-based application by the participants over 3 months.	Risk of annoyance increases with increasing angular blade velocity, wind direction, and with decreasing humidity (in addition to wind speed). Wind-turbine specific emissions can be linked to operational characteristics. Operational measures (reduced rotation speed, adjustments in nacelle wind angle) can reduce risk of annoyance.	*Peer-reviewed journal article*
The influence of background sounds on loudness and annoyance of wind turbine noise **(Bolin *et al.*, 2012)**		32	Laboratory experiment	Test the influence of background sound on perceived loudness and annoyance.	Exposure from 26dB(A) to 59dB(A) for sessions without background sound, and from 35dB(A) to 56dB(A) for sessions with background sound.	Loudness and annoyance were assessed by free number magnitude estimation.	If the level of background sound is higher than the level of wind turbine noise, both perceived loudness and annoyance decrease.	*Peer-reviewed journal article*
Wind turbine acoustic investigation: Infrasound and low-frequency noise — A case study **(Ambrose *et al.*, 2012)**		Acoustician(s) undertaking measurements (number not found)	Case study	Provide measurements of infrasound exposure.	Paper provides detailed measurement protocols of indoor/outdoor measurements at 1 site, including measurements of infrasound (see paper for details).	None provided. Self-reported health issues.	Authors found an association between wind turbine sound and various health effects experienced by researchers during the study, such as nausea, dizziness, irritability, headache, loss of appetite, inability to concentrate,	*Peer-reviewed journal article*

							anxiety, sleep. No statistics or data about number of people affected were provided.	
A longitudinal study of the impact of wind turbine proximity on health related quality of life ***(Follow-up to Shepherd et al., 2011)*** **(McBride *et al.*, 2013)**		Exposed group: 56 houses; control group: 250 houses	Cross-sectional	To investigate whether health-related quality of life had changed in 2 years since first study at the same site was conducted.	Measurements from previous study (Shepherd *et al.* 2011) ranging from 20dB(A) to 54db(A) (L_{95} (10min)).	Health-related quality of life measured by a shortened version of the WHOQOL-100 assessment, which measures physical, psychological and social elements.	When compared with the control group, the residents in the exposed group scored more poorly in the physical WHOQOL domain and rated themselves as having poorer health in 2012 than in 2010.	*Conference paper*
Annoyance, detection and recognition of wind turbine noise **(Van Renterghem *et al.*, 2013)**		50	Laboratory experiment	Study annoyance, recognition, and detection of wind turbine noise using a 2-stage listening experiment. Particular focus on possibility of masking wind turbine noise with road traffic noise.	Recorded samples of wind turbine noise (30m downwind at 8-10m/s) and highway and road traffic noise were used to generate stimuli that could be combined to simulate different scenarios of combined 7.5 minutes sound samples with L_{Aeq} of 40dB(A). Exposure during quiet leisure activity was followed by a concentrated listening test to detect wind turbine noise that was masked with other sound.	Annoyance: measured on a scale ranging from 0 ("Not at all annoyed") to 10 ("Extremely annoyed").	Wind turbine noise did not increase average annoyance among participants who were unaware of wind turbine noise. Road traffic noise with wind turbine noise was perceived to be more annoying than wind turbine noise only. Authors concluded that noticing sound could be an important factor in wind turbine annoyance.	*Peer-reviewed journal article*
Association between industrial wind turbine noise and sleep quality in a comparison sample of rural Ontarians **(Lane, 2013)**		23	Cross-sectional	Investigate whether exposure to wind turbine sound is associated with parameters of sleep quality.	Exposed vs. control group. Mean measured indoor sound exposure (L_{Aeq}) was 31.82dB(A) (30.7dB(A)-34dB(A)) for exposed group. Data for unexposed group incomplete (30.5dB(A)-41dB(A)).	Sleep quality measured with daily sleep diary and actigraphy.	Actigraphy sleep parameters were found to be poorer (e.g., lower average sleep efficiency, longer sleep onset latency, longer week after sleep onset) among the exposed group, but the results were not statistically significant.	*M.Sc. Thesis*

Dose–response relationships for wind turbine noise in Japan **(Yano *et al.*, 2013)**	JAP-10	747	Cross-sectional	Develop a representative exposure–response relationship for annoyance, from wind turbine noise and consider influence of moderating factors.	Average night-time exposure ($L_{Aeq,n}$) as function of distance based on outdoor measurements at participating households. 5 categories (<30 dB(A), 31dB(A)-35dB(A), 36dB(A)-40dB(A), 41dB(A)-45dB(A), >45dB(A)).	Annoyance evaluated with the International Commission on the Biological Effects of Noise (ICBEN) 5-point verbal scale ranging from "extremely" (annoyed) to "not at all."	Dose–response relationship between annoyance and wind turbine noise was similar to that observed in the Swedish and Dutch surveys (SWE-00, SWE-05, NL-07). Annoyance was lower close to the sea due to the masking effect of the sea wave sound. Self-reported sensitivity to noise, interest in environmental problems, and landscape disturbance were associated with annoyance.	*Conference paper*
Exploring underlying mechanisms for human response to wind turbine noise **(Bockstael *et al.*, 2013)**		50	Laboratory experiment	Test the "underlying mechanisms for human response to wind turbine noise by studying the effects in terms of source detection, recognition, and annoyance, with and without road traffic noise."	Recorded samples of wind turbine noise (at 30m downwind) and road traffic noise (15m) were used to generate stimuli of road traffic noise only, wind turbine noise only and mixed sound with wind turbine noise at -10dB and 0dB signal-to-noise ratio. Participants exposed during 7.5 minutes during light leisure activity (reading). Second stage involved detection test using 30s fragments of stimuli via headphones.	Participants were asked to report the sounds they heard and rate noise annoyance on a 10-point scale.	Presence of wind turbine noise in sample mix did not noticeably alter reported annoyance compared with traffic noise when participants were unaware of wind turbine noise source. Participants who detected wind turbine noise in the unfocused listening test also reported higher annoyance.	*Conference paper*
Psychoacoustic aspects of noise from wind turbines **(Fastl & Menzel, 2013)**		13	Laboratory experiment	Test the annoyance from recorded wind turbine sound and recorded video of wind turbines.	The subjects were exposed to recorded sound from wind turbines ranging from 38dB(A) to 50dB(A). Visual stimuli: 5 short videos showing wind turbines at different distances and angles.	Self-reported annoyance. (Participants said a number out loud that corresponded to their subjective feeling of annoyance without using a pre-defined scale.)	Annoyance rating increased with the sound pressure level. The video presented had a limited influence on the rating.	*Conference paper*

Social survey on community response to wind turbine noise in Japan **(Kuwano *et al.*, 2013)**	JAP-10	747 (exposed group), 332 control (group)	Cross-sectional	Test the impact of wind turbine noise on exposed population through a social survey (satisfaction with living environment, annoyance, sleep).	Sound measurements not reported, but appear to be same data as Yano et al., 2013.	No case definitions are given for the health outcomes studied. Satisfaction with the environment tested for convenience of shopping, convenience of transportation, amount of greenery, clean air, quietness, and public facilities.	Satisfaction with living environment: the only difference reported between the exposed and control group was about quietness. Approximately 10% were dissatisfied with the quietness of their environments, whereas about 3% from the control group were dissatisfied. No statistics are provided. Annoyance: 16% of respondents from the exposed group reported wind turbine noise as the most annoying among 6 other types of sound. Rates in control group not reported. Sleep: about 15% percent of exposed respondents and 10% of unexposed respondents reported sleep issues.	*Conference paper*
Study on the amplitude modulation of wind turbine noise: Part 2 auditory experiments **(Yokoyama *et al.*, 2013)**		10	Laboratory experiment	Test the effect of amplitude modulation on perceived noisiness.	4 15-second stimuli of recorded sound from wind turbines with amplitude modulation. $L_{Aeq(15s)}$ 35.4dB(A) to 46.6dB(A) (representing 908 to 252 m of distance from wind turbines at recording). Amplitude modulation depth 3.5dB to 5.32dB. Matching with artificially generated sounds to index AM depth.	Assessment of "noisiness" by the subject using 3 categories (fluctuation not felt, slightly felt, clearly felt). Sound was also described by the subject using an onomatopoeic word. Adjustment of "noisiness" of test sound using controller.	Fluctuation sensation from amplitude modulation was perceived by subjects when AM depth was greater 1.7dB, corresponding to an index ΔL higher than 2.0dB.	*Conference paper*
The effects of low frequency noise on mental performance and annoyance **(Alimohammadi *et al.*, 2013)**		90 (students)	Laboratory experiment	Investigate impact of low frequency noise on mental performance, taking into account personality traits.	Exposure to generated low-frequency sound of 50dB(A) and 70dB(A) (broadband – no frequencies specified) while taking mental performance tests.	Annoyance: measured on 12-scale self-reported questionnaire. Mental performance: mental performance measured with the Stroop and Cognitrone tests.	For low frequency noise between 50dB(A) and 70dB(A), the authors did not find a significant difference in mental performance with a quieter environment. Authors did not find association between low frequency noise and noise annoyance. Personality type did influence annoyance from higher frequency sound, but did not have a noticeable effect on response to low-frequency sound.	*Peer-reviewed journal article*

The effects of vision-related aspects on noise perception of wind turbines in quiet areas **(Maffei *et al.*, 2013)**		46 (18-33 years)	Laboratory experiment	Investigate influence of different visual stimuli on perception and annoyance.	30 seconds stimuli extracted from recorded sound samples at 150m, 250m, and 500m distance. 5 samples per distance category. Subjects exposed to sounds in 3D virtual reality environment simulating 13 different scenarios of: sound sample number, distance, and colour of wind turbines.	Annoyance and stress were self-reported and measured on a 100-point Likert scale.	Annoyance was influenced by the distance and the number of wind turbines. Stress ratings were influenced by distance from wind turbines. Turbine colour had large effect on visual and a moderate effect on sound evaluations.	*Peer-reviewed journal article*
Wind turbine amplitude modulation: Research to improve understanding as to its cause and effects Work Package B(2): Development of an AM dose–response relationship **(von Hünerbein *et al.*, 2013)**		11 participants divided into 4 groups	Laboratory experiment	Determine the threshold of onset of annoyance and develop a metric that describes the relationship between mean annoyance score and amplitude modulation depth. (i.e., the correction factor that expresses the increase of perceived loudness for amplitude modulated sound).	Exposure consisted of masking noise and wind turbine noise that was synthesized using a model calibrated with real world recordings. Participants were exposed to stimuli representing different SPL combinations of wind turbines and masking sound in random order.	Participants rated annoyance of sound stimuli on a 10-point scale from not at all annoying to very annoying.	Increase in modulation depths led to higher levels of annoyance (consistently and monotonically). Average adjustments to expressed perceived loudness were 1.7dB(A) for a 40dB(A) test sound and 3.5dB(A) for a 30dB(A) test sound. The average adjustment over all frequencies tested was 2.3dB(A).	*Research report*
Can expectations produce symptoms from infrasound associated with wind turbines? **(Crichton *et al.*, 2014b)**		54 (students)	Laboratory experiment	Investigate role of negative expectations on perception of health effects under exposure to infrasound.	2 groups with positive and negative expectations about infrasound (see Crichton *et al.*, 2014a) were divided into subgroups that were exposed to 10 minutes of infrasound (40dB(A) at 5Hz) and no ("sham") sound.	Rated 12 symptoms identified as typical from exposure to infrasound (e.g., headache and dizziness) in relation to 12 symptoms that are not usually associated with infrasound. The rating was evaluated on a 7-point Likert scale ranging from 0 (not at all) to 6 (extreme).	The group that expected physiological effects from infrasound reported significantly higher symptoms scores both during infrasound and sham infrasound exposure than the control group.	*Peer-reviewed journal article*
Characterising noise and annoyance in homes near a wind farm **(Zajamsek *et al.*, 2014)**		2 houses	Case study	Relationship between indoor sound pressure level, local weather conditions, wind farm output power, and resident rated annoyance at 2 homes.	Continuous non-weighted 1/3-octave band noise levels recorded every 2 minutes. Measurements ranged from 40dB(A)-70dB(A) SPL for 1-100Hz spectrum; 15dB(A)-40dB(A) SPL for frequencies >1000 Hz.	Self-reported sound annoyance ranked as follows: not annoyed, slightly annoyed, moderately annoyed, very annoyed.	Annoyance was related to noise level and local wind speed in the closest home (2.5km). In the home located 8km from the wind turbine, this association was not observed. In that case, time of day seemed to play a more important role.	*Peer-reviewed journal article*

Evaluation of annoyance from the wind turbine noise: A pilot study **(Pawlaczyk-Łuszczyńska *et al.*, 2014)**	POL-13	156	Cross-sectional	Evaluation of annoyance from the wind turbine noise.	A-weighted SPL calculated as the sum of contributions of wind turbines in a specific area.	Questionnaire based on SWE-00. In particular this study evaluated annoyance, physical health, well-being and mental health status. Self-reported conditions were reported on a 5-point scale. Contributing factors were also assessed.	Noise at calculated sound pressure of 30dB(A)–48dB(A) was perceived as annoying by 33.3% of the subjects outdoors (20.5% indoors). OR of being annoyed increased with increasing sound pressures. Attitude to wind turbines, sensitivity to landscape littering were found to have an impact on the perceived annoyance.	*Peer-reviewed journal article*
Evaluation of community response to wind turbine-related noise in western New York State **(Magari *et al.*, 2014)**		63	Cross-sectional	Investigate whether there is a correlation between annoyance and satisfaction with living environment and short-term measurements at the dwelling.	Short duration sound level monitoring (SPL) in and outside the home at the time of the survey.	Self-reported annoyance, satisfaction with living environment, self-reported health effects. No medical records were reviewed.	62 individuals interviewed from 52 homes. An individual's concern about health effects was statistically significantly correlated with his or her general opinion on wind turbines, opinions on the altered landscapes, sensitivity to noise in general, and general annoyance with wind turbines both indoors and outdoors. There were no statistically significant correlations between the indoor and outdoor noise measurements and an individual's level of concern about experiencing health.	*Peer-reviewed journal article*
The power of positive and negative expectations to influence reported symptoms and mood during exposure to wind farm sound **(Crichton *et al.*, 2014a)**		60 (students)	Laboratory experiment	Investigate role of positive expectations on perception of health effects under exposure to infrasound.	7-minute sample of wind turbine noise including infrasound components (sound characteristics not specified). One group received messages about positive, one about negative impacts of infrasound.	Subjects rated their experience of 24 physical symptoms and 12 positive mood items. The rating was evaluated on a 7-point Likert scale ranging from 0 (not at all) to 6 (extreme).	Participants with negative expectations reported a significant increase in symptoms and deterioration in mood while positive-expectation subjects reported a significant decrease in symptoms and increase in mood.	*Peer-reviewed journal article*

*Only datasets cited in the report have been given a codename. Codename is given after the country of the study and the year the study was undertaken. Such convention has also been used in other reports such as (Merlin et al., 2013).

The highest-quality evidence was provided by a series of cross-sectional studies conducted in Sweden and the Netherlands (Datasets SWE-00, first published in Pedersen & Persson Waye, 2004; SWE-05, first published in Pedersen & Persson Waye, 2007; and NL-07, first published in Pedersen *et al.*, 2009). These studies provided data for 11 publications on health impacts, as well as on the role of acoustic characteristics of wind turbine noise and contributing factors. The studies used surveys to gather self-reported data on health effects and to compare these with sound exposure levels estimated on the basis of real sound measurements using International Organization for Standardization (ISO)-approved models of sound propagation. These surveys were presented as general surveys about noise, with no indication of any focus on wind turbines, to reduce self-selection bias.

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